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Performance Comparison of Contemporary Stencil Coatings and Under Wipe Solvents on 0.4mm BGA Packages

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ABSTRACT

As package I/O's get smaller and denser, characterizing the effects of different stencil underside wiping strategies grow in importance. An experiment was devised using the SMTA Miniaturization test vehicle to gain insight into the effects of different underwipe chemistries. The tests examined the effects of wiping on different sized packages, different wipe frequencies, and different wipe chemistries.

The experiment used wipe frequencies of 2, 4, 6, 8 and 10 prints per wipe. Data collected by the SPI machine was analyzed in two ways: the overall performance within the wipe frequency group, and the pre-wipe and post-wipe print performance at each wipe interval. Two different chemistries and dry (vacuum) wipe were evaluated, along with an uncoated stencil and one with commercially available adhesion-resistant coating.

The results indicated the following conclusions:

- The process that was studied was very well controlled; far better than many that have used the same test PCB
- At the 0.5 BGA level and below, adhesion-resistant coating is very impactful to achieving high quality print results
- Wet wipe is better than dry; with one chemistry proving better on shorter wipe intervals, and one proving more appropriate for longer wipe intervals.

The findings lead to a hypothesis that the formulation and drying time of the underwipe chemistry is a considerable factor in solvent selection, which can be based on stencil aperture density, print area length in the Y-axis and production throughput rates.

Key words: stencil under wipe, stencil cleaning,

INTRODUCTION

The practice of periodically wiping excess solder paste off the side of the stencil that contacts the PCB during the printing process can take many different forms and frequencies. The objective of wiping is to remove unwanted solder paste from the contact side of the stencil.

How does solder paste find its way to the contact side of the stencil? By nature, solder paste sticks to both the PCB pad and the stencil. It does not fully release from the aperture upon separation, depending on the Area Ration (AR) of the aperture. Very often, Transfer Efficiency (TE), or the amount of solder paste removed from the aperture, is less than 100%. The remaining paste often forms "strings" that snap back to the stencil's contact side (Figure 1).

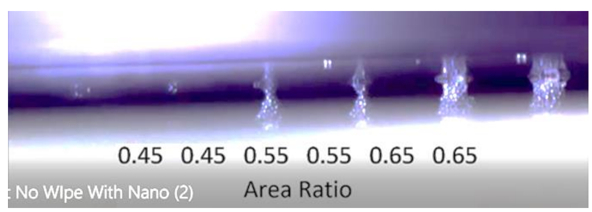


Figure 1. Solder paste release from stencil, side view

How does errant paste on the contact side of the stencil affect print quality? The solder paste left on the bottom side of the stencil prevents it from gasketing against the PCB and is often the root cause of excessive solder deposits, solder bridges and solder balls. Therefore, it is important to remove the excess paste *before* it negatively affects the process.

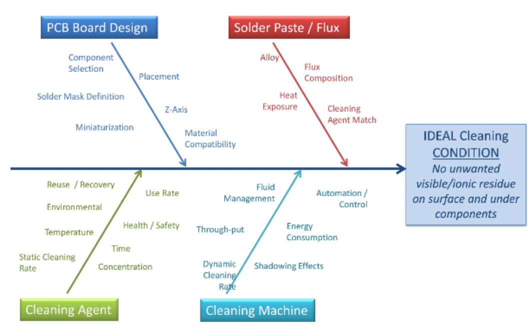


Figure 2: Factors that affect stencil cleanliness

The underwipe process itself has a number of variables, including printer hardware capabilities, wiper media type (paper or fabric), solvent type (if any), number of passes per wipe cycle (prints per wipe, or PPW). These process parameters are typically adjusted based on systemic variables such as PCB layout, solder paste type, machine capability, board support, stencil coating and finest pitch components, as seen in the fishbone diagram of Figure 2.

PREVIOUS WORK

The role of underwiping on solder paste print quality was diligently studied in the mid 2010's. Research investigated the effects of print parameters, stencil types, stencil coatings, underwipe chemistries and wipe sequences.[1-5]

Findings included:

- Wet wipe was better than dry wipe[1]
- IPA could seize up certain solder paste formulations in the stencil[1]
- Release speed had a considerable influence (faster is better)[2]
- Solder paste "strings" upon release[3]
- Coated stencils limit the stringing and improve release[4]
- Ending with a Vac pass is better than ending with a Dry pass[1]
- Wet wipes keep the process consistent and limit the "bounce" seen with dry wipes[5]

Videos showing the effectiveness of Wet-Vac-Vac over Wet-Vac-Dry can be seen at:
https://www.youtube.com/watch?v=kpK_INTP1Rg&list=PLaoVr4cm7GBNkY2z6qN-K1zQwTevWZKV5

EXPERIMENT

Procedure

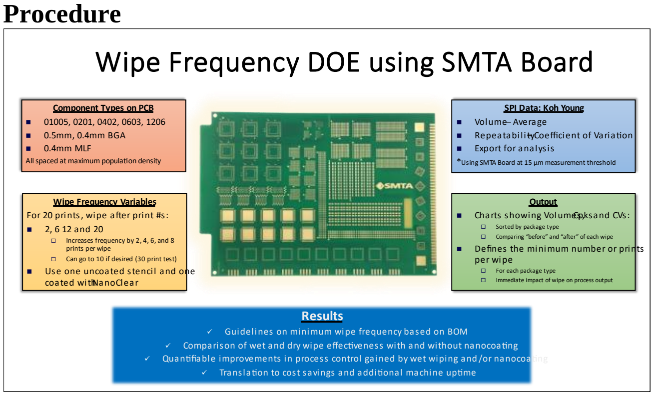


Figure 3. Underwipe experimental design overview

Leveraging knowledge gained in the aforementioned studies, an experiment was designed to test components in numerous package sizes and different wipe frequencies. Figure 3 illustrates the experimental design.

The experiment was executed on production equipment that included:

- EKRA Serio 4000 printer
- Clean, new squeegee blades
- Solid board support plate
- Poly/cellulose wiper textile
- Two laser-cut stencils, one coated and one uncoated
- Two different underwipe chemistries
- Mycronic Pi Solder Paste Inspection
- Type 4 Tin-lead solder paste (popular, 20+ year old formulation)

After kneading 4 strokes to ensure the solder paste was in its working viscosity range, the stencil was cleaned with a Wet-Vac-Vac (WVV) wipe sequence twice to ensure cleanliness at the start. 2 boards were printed, for 2 PPW, then the stencil was cleaned with a single WVV. This was repeated at wipe intervals of 4, 6, 8 and 10 prints. 2 replicates were run for each combination of stencils and chemistries.

The experiment was later repeated without cleaning chemistry. It utilized the same exact setup but the wipe sequence was Vac-Vac-Vac (VVV) without any chemistry.

The order of execution is detailed in Appendix A.

Test Vehicle

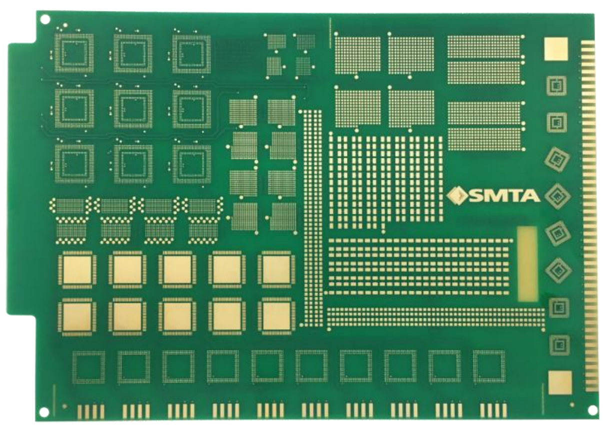


Figure 4. The SMTA miniaturization test vehicle

The test vehicle used was the SMTA test board, shown in Figure 4. It contains footprints for many different sized SMT components. The component sizes of interest in this study are analyzed in the order of decreasing aperture sizes as shown in Table 1.

Table 1. Device and aperture sizes tested

Typical Stencil Aperture Sizes and Area Ratios

Component Size		Type	Stencil Aperture Size		Area Ratio
Imperial	Metric		mil	µm	4 mil (100µm) Foil
0201	0603M	Chip	10.8 x 13.5	275 x 350	0.79
20 mil pitch	0.5mm pitch	BGA	10 x 10*	250 x 250*	0.63
01005	0402M	Chip	8 x 8	200 x 200	0.50
16 mil pitch	0.4mm pitch	BGA	7.5 x 7.5*	190 x 190*	0.47

Increasing Difficulty

Data Analysis

Transfer Efficiencies (TEs) were exported and consolidated in Excel. Again, TEs express the amount of solder released from the stencil and deposited on the pad as a percentage of the theoretical aperture volume for each deposit.

TE statistics are calculated using pivot tables. The average TEs and Coefficients of Variation (CVs) are calculated for each component size. The CV is one standard deviation divided by the average. It relates the spread of the data to the mean of it and is widely used in characterizing stencil printing processes.

Ideally, the CV is less than 10% of the mean, which is indicated in the output charts by green data points. CVs of 10-15% are considered acceptable and indicated by yellow data points; CVs greater than 15% are considered unacceptable and indicated by red data points.

The rationale behind the CV guidelines is based on a normal distribution of data and typical SPI tolerances of 50 – 150% the TE goal, as illustrated in Figure 5.

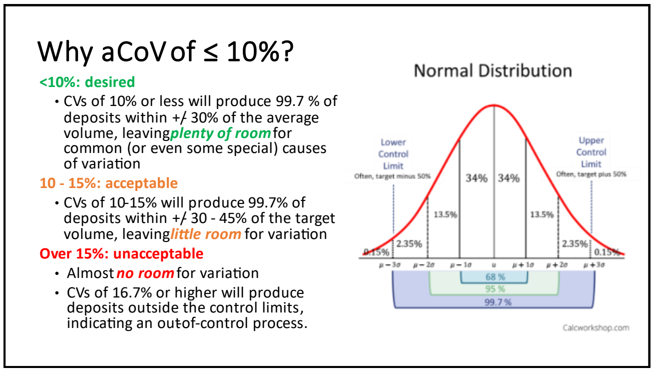


Figure 5: The normal distribution and Coefficient of Variation

ANALYTICAL METHODS AND RESULTS

Overall Print Quality

Print volumes were extremely consistent, indicating a very well-controlled print process.

- 0201 and 05BGA components all showed > 100% Transfer Efficiency (TE) with nearly all CVs under 10% and only a few in the 10-15% range, on both coated and uncoated stencils (Tables 2 and 3)

Table 2: TE and CV for 0201 components

0201 AR = 0.79				
Chemistry	Uncoated Stencil		Coated Stencil	
A	TE	CV	TE	CV
2PPW	102	6%	114	10%
4PPW	102	7%	109	5%
6PPW	106	7%	109	6%
8PPW	106	6%	110	6%
10PPW	105	5%	109	6%
FinalPPW	106	7%	113	4%
B				
2PPW	105	6%	113	7%
4PPW	106	7%	110	5%
6PPW	107	9%	112	6%
8PPW	108	7%	112	5%
10PPW	108	7%	111	5%
FinalPPW	108	8%	111	5%

Table 3: TE and CV for 0.5mm pitch BGA components

05BGA AR = 0.63				
Chemistry	Uncoated Stencil		Coated Stencil	
A	TE	CV	TE	CV
2PPW	112	7%	122	13%
4PPW	110	12%	116	5%
6PPW	113	8%	117	5%
8PPW	112	7%	118	7%
10PPW	112	6%	117	6%
FinalPPW	116	8%	123	4%
B				
2PPW	112	5%	119	5%
4PPW	113	5%	120	5%
6PPW	116	7%	121	6%
8PPW	118	6%	120	4%
10PPW	116	6%	119	5%
FinalPPW	115	5%	120	3%

- 01005 components showed an obvious trend: The coated stencils produced CVs of at most 11%, whereas the uncoated stencils produced CVs of approximately 30-60% (Table 4).

Table 4. TE and CV for 01005 components

01005 AR = 0.50				
Chemistry	Uncoated Stencil		Coated Stencil	
A	TE	CV	TE	CV
2PPW	75	45%	108	11%
4PPW	70	59%	105	8%
6PPW	86	41%	105	8%
8PPW	87	28%	106	9%
10PPW	82	36%	103	11%
FinalPPW	70	57%	111	7%
B				
2PPW	81	43%	109	8%
4PPW	75	55%	107	6%
6PPW	80	54%	109	7%
8PPW	84	47%	108	8%
10PPW	82	54%	107	7%
FinalPPW	96	34%	109	5%

This finding illustrates the influence of coating stencils for miniaturized devices. At the AR of 0.63, the coating's impact was not apparent. Using wet wipes, the process was capable even without stencil coating. But at the 0.50 area ratio, it was far from capable without the coating, even with wet wipes and at short wipe intervals.

- The process window for the uncoated stencil closed somewhere between the 0.63 and 0.50 AR, but did not noticeably narrow for the coated stencil until the 0.47 AR (Table 5).

As anticipated, the uncoated stencil performed more poorly on the 0.47 AR than the 0.50 AR, in both TE and CV. The coated stencil, however, showed >100% TE and the CVs were in the 9-19% range, indicating the edge of the process window, and making it the most informative data set to further explore.

Based on the normal curve model shown in Fig 5**,** the CVs on uncoated stencils indicate complete incapability for them and would add statistical noise to the analysis. Therefore, the effects of uncoated stencils are eliminated from the analysis.

Table 5. TE and CV for 0.4mm BGA components

04BGA AR = 0.47				
Chemistry	Uncoated Stencil		Coated Stencil	
A	TE	CV	TE	CV
2PPW	70	57%	111	14%
4PPW	72	59%	107	9%
6PPW	94	31%	106	13%
8PPW	88	33%	106	14%
10PPW	83	43%	102	19%
FinalPPW	51	83%	112	12%
B				
2PPW	66	70%	111	12%
4PPW	71	63%	109	11%
6PPW	79	61%	111	9%
8PPW	79	59%	110	9%
10PPW	82	60%	109	10%
FinalPPW	96	39%	111	10%

It should again be noted that the edge of the print process window was identified at the 04BGA pitch (0.4mm). indicating a very well set up process. Many print processes reach the edge of their window at the 05BGA pitch (0.5mm).

The Leading Edge Effect

The PCB layout for the 04BGAs is shown in Figure 6.

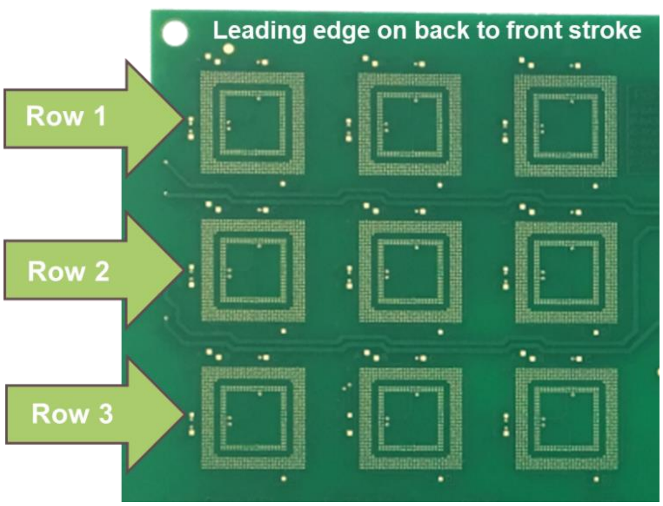


Figure 6. Close up of the layout of 04BGA on SMTA board

Row 1 consistently shows the greatest amount of variation. In solder paste printing, this is often referred to as the "Leading Edge Effect." It is typically observed when the first few apertures in the direction of the squeegee stroke do not get complete fill, and it is more common as apertures size decreases.

Row 3 consistently shows the least amount of variation. It is located in the middle part of the print stroke, where the solder paste has reached its lowest printing viscosity.

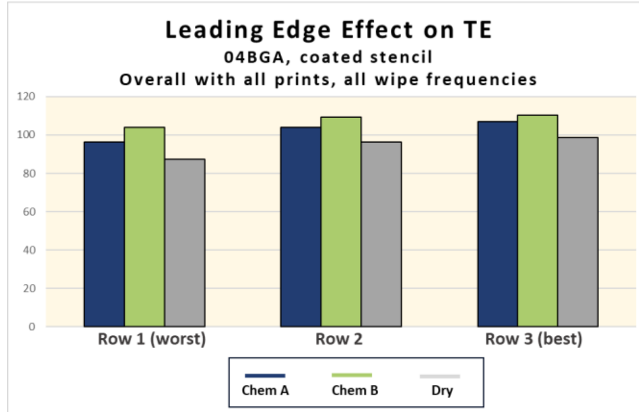


Figure 7. TE for top (Row 1), middle (Row 2) and bottom (Row 3) rows of 04BGAs

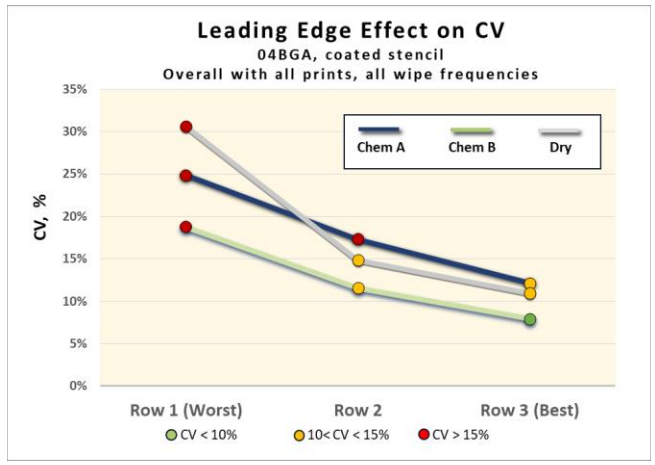


Figure 8. CV for top (Row 1), middle (Row 2) and bottom (Row 3) rows of 04BGAs

Figures 7 and 8 show the differences in print quality among the three rows. TEs in Row 1 are slightly lower than Rows 2 or 3 which appear to be relatively equal. The CVs on Row 1, however, are considerably higher than those of Rows 2 or 3. In fact, the CVs on Row 1 are so high that the process is not considered capable (<15%) . Rows 2 and 3 provide better indicators on the effectiveness of under wiping.

Further quantification of the Leading Edge Effect is outside the scope of this study, but may become the subject of others. Data from the leading edge is excluded from further analysis.

Having identified the finest pitch partially capable and eliminated the noise introduced by the uncoated stencil and the leading edge effect, the effects of the wipe on process capability can be more precisely gauged.

Overall Transfer and Variation for Each Wipe Type

Each print stroke produces 3,720 data points. There are 620 apertures per component, and 6 components in the 2 rows analyzed. Each experiment had 2 replicates; therefore, the sample size for each stroke is 7440.

The first analysis method examines the overall TE and CV at different wipe intervals *for all prints* in that particular interval, eg. 2 prints at 2 prints per wipe (PPW), 4 prints at 4 PPW, etc. The Final PPW is actually the 31st print and is performed after the 30th print, or 10 PPW interval.

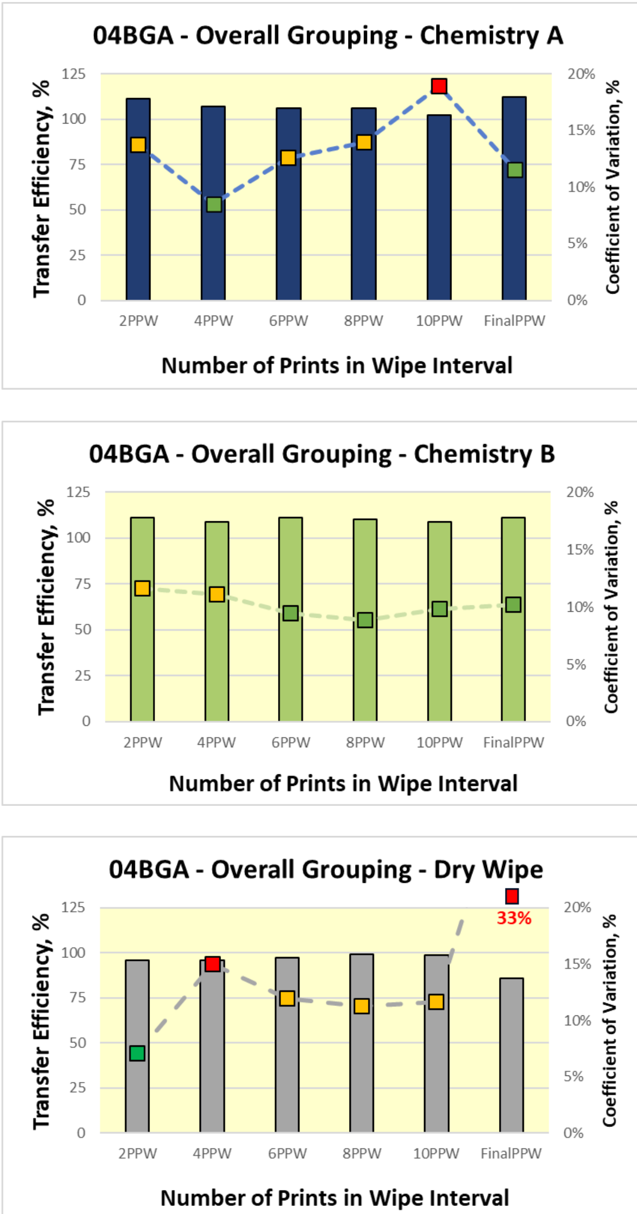
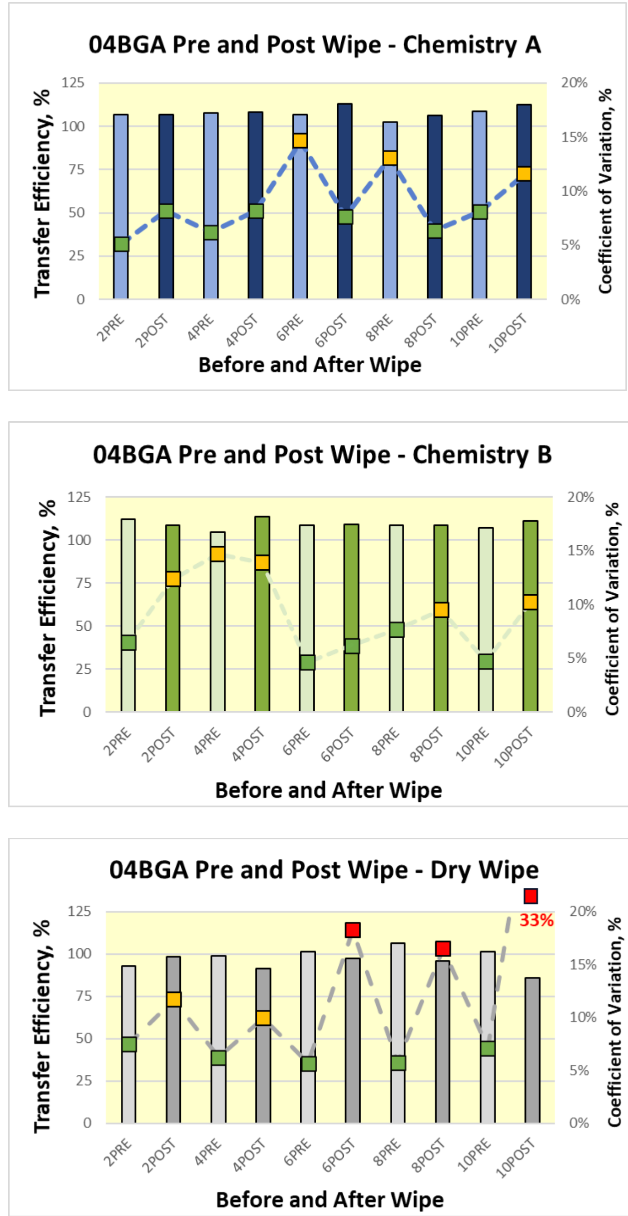


Figure 9-11. TE and CV at different wipe intervals

Results of the first analysis method can be viewed in Figures 9-11. Examining the data for groups as a whole, several inferences can be drawn:

- Chemistry B provides the most stable process, with TEs consistently above 100% and CVs less than 15%.
- Chemistry A also exhibits TEs above 100% but does not maintain CVs below 15% at the 10 PPW interval.
- Dry wipe almost reaches to 100% TE but does not achieve it. Two CV points are greater than 15%, particularly the final PPW.

To better understand the impact of underwipe chemistry, the data was also analyzed by the print quality before and after each wipe. Results of this second analysis method provide more information on the immediate effects of underwipe as opposed to the overall effects.



Figures 12-14. TE and CV before and after wipe

Figures 12 through 14 take a closer look at what happens to the print process output when an under wipe is applied.

- Chemistry A appears to be very stable for pre-and post-wipe prints up to 4 PPW intervals. However, at 6 PPW and higher intervals, it appears to be less effective than Chemistry B.
- Chemistry B appears to trend in the opposite direction of Chemistry A. While its pre- and post-wipe prints are all of acceptable quality, the longer wipe intervals show better performance than the shorter ones.
- The dry wipe shows a repeatable pattern in CV: it is better before the wipe than after. Also, with the

exception of the 2 PPW interval, it shows a pattern of higher TE before the wipe and lower TE after it.

DISCUSSION & CONCLUSIONS

The print quality on these tests was remarkable compared to other production processes. This leads to conclusions that:

- Best practices are deployed throughout the process
- Results from this study are not necessarily predictive of other production processes that are not as tightly controlled
- Results from this study are comparable to those performed in laboratory environment rather than production environments
- With the proper process controls and best practices in place, production environments can perform at the same quality level as laboratories

The biggest contributor to print quality was coating the stencil with a surface-modifying coating. Stencil surface modifiers have been used for over a decade with well-documented improvements in print quality, especially at area ratios less than 0.60. It should be a given that apertures with 0.47 ARs do not get processed without a stencil coating.

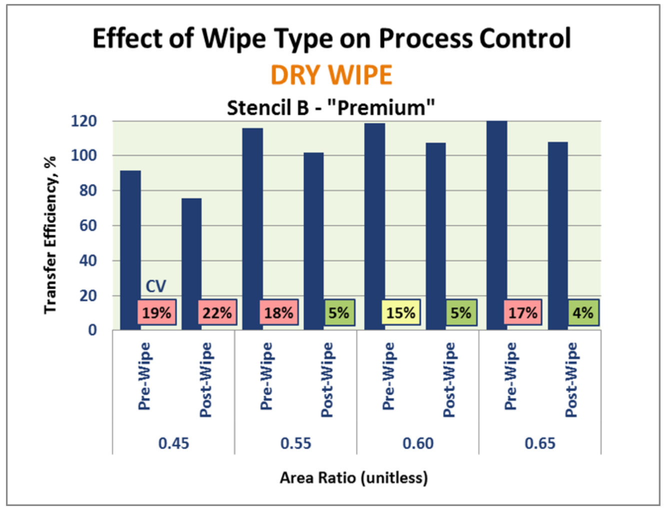
The second largest contributor was the position of the components relative to the print stroke. Apertures on the leading edge of the print stroke consistently displayed lower TE and higher CV than similar apertures later in the print stroke. Process engineers generally do not have influence over PBC layout, and some printer manufacturers offer machine options to overcome the leading edge effect, including changing squeegee speed or angle as the squeegee position approaches the print area.

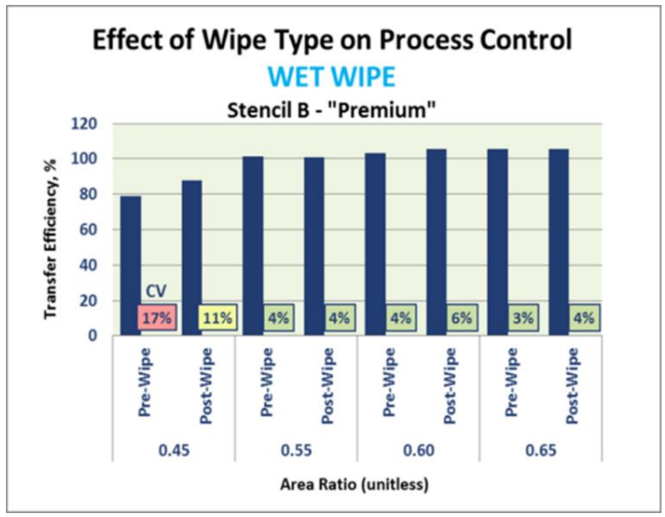
On apertures nearer the middle of the board, the variation due to the leading edge is minimized. Focusing on the apertures that are on the edge of the process window gains the most insight into the third largest contributor: underwipe type. It further allows exploration within the wet type of wipe.

Wet wipe outperformed dry wipe, in a manner similar to in previous studies (results shown in Figure 15-16). It provided a consistent process in terms of TE throughout the different wipe intervals.

The data in figures show the results of a previous study[5] using chemistry B and a different solder paste. The trend is again obvious: the process "bounces" with a dry wipe. The process is consistent with a wet wipe. Similar results were recorded in the same study with an uncoated stencil.

Both studies agree: Wet wipes remove more print variation than dry wipes. Dry wipes tend to show a cyclical pattern of out-of-control and in-control before and after the wipe, whereas wet wipes tend to keep the process steadier.





Figures 15 and 16. TE and CV with dry and wet wipe on coated stencil from 2016 study.[5]

Of the two wet chemistries, different characteristics were observed:

- A performed better than B on shorter wipe intervals
- B performed better than A on longer wipe intervals

This difference in performance – seen in both types of analysis – indicate that Chemistry A may dry faster than Chemistry B, but not clean this paste quite as effectively. Conversely, Chemistry B may dry more slowly than Chemistry A, but can clean this solder paste more effectively.

The perceived difference in cleaning and drying capability leads to the conclusion that in processes where frequent wipes are required, i.e. high aperture density and low ARs, Chemistry A would be a better choice for the process. By contrast, Chemistry B would be a better choice for lower density, coarser pitch, or wider boards that would benefit from the slower drying liquid and the longer wipe intervals.

Regardless of chemistry choice, wet wiping clearly improves print performance over dry wipes. The dry wipes show increasing TE prior to wipe, decreasing TE after wipe, and

CVs dramatically increasing after the wipe. This is presumably because there is nothing to dilute the sticky paste flux, and dry wiping smears it on the bottom of the stencil (even coated stencils), as demonstrated in previous studies.

Non-conforming solder paste prints cost assemblers in a multitude of ways:

- The lowest cost of a poor print is that of labor: cleaning the bare PCB, drying it and rerunning it
- The next level of incurred cost is the touch-up or repair labor at the end of the assembly line
- The cost of repair grows even more if it is found at test, which carries very high overhead expenses
- The worst cost impact is when the joint fails in service and the PCB must be replaced

SMT manufacturing is both a cost-conscious and quality-conscious business. Considerations include assembly performance class, projected lifetime, upfront investments, material costs, production costs, repair costs and brand equity. Each assembly operation is unique and has different factors influencing its manufacturing strategy. Systemic defect prevention can often be more economical than specific, after-the-fact remedies.

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APPENDIX A – DOE Execution Step-by-Step Directions

Stencil Under Wipe Testing Run Sheets

Chemistry A

1) Clean and purge printer's tanks and lines
2) Make sure there's enough wiper material on the roll to complete the run
3) Clean and inspect stencil and blades

Start Time: ____________				Stencil : Coated or Bare (circle one)	
Print Speed: ____________		Print Pressure: ____________		Separation Speed and Delay: ______________________	
Top Side					
Print	Print Number	Board/Barcode Number	SPI index Number	SPI Time Stamp	Observations/Comments
	KNEAD TO ACHEIVE WORKING STATE				Min 4 kneads.Underwipe 2-3X Start print with back->front
	1	101			
	2	102			
	UNDER WIPE				
	3	103			
	4	104			
	5	105			
	6	106			
	UNDER WIPE				
	7	107			
	8	108			
	9	109			
	10	110			
	11	111			
	12	112			
	UNDER WIPE				
	13	113			
	14	114			
	15	115			
	16	116			
	17	117			
	18	118			
	19	119			
	20	120			
	UNDER WIPE				
	21	121			
	22	122			
	23	123			
	24	124			
	25	125			
	26	126			
	27	127			
	28	128			
	29	129			
	30	130			
	UNDER WIPE				
	31	131			