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SOLDER PASTE QUALIFICATION TESTING FOR EMS PRODUCTION

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ABSTRACT

In the world of solder pastes, one size does not fit all, which is why so many different formulations exist. The myriad of options can be overwhelming, and matching the right product to the operation can be confusing, time consuming and costly.

When a small EMS provider determined it was time to update the SMT process chemistry, they needed to develop a test program that they could execute efficiently while keeping production running and costs under control. The result is a consolidated test plan that gauges key solder paste properties and requires less than one shift of line time per product evaluated.

This paper reviews the test plan, data collection and analysis processes, and presents the results. It discusses some of the issues encountered during test development and their resolutions or workarounds. Finally, it interprets the findings as they apply to the operation, the product types and customer needs.

INTRODUCTION

A review of existing SMT practices revealed an opportunity to improve quality and throughput by updating the solder paste chemistry used on the assembly lines. The incumbent did not exhibit best-in-class performance in printing or wetting. The sub-par print and reflow performance was impacting quality and throughput, creating bottlenecks at print/SPI, at AOI and at rework areas.

A quick substitution of another paste formulation from the same manufacturer demonstrated an instant print quality improvement – enough to justify the time and expense of a solder paste qualification.

REVIEW OF SOLDER PASTE PROPERTIES

Solder pastes have over 20 properties or tendencies that can influence SMT assembly quality. Appendix A lists them, along with their impact on the SMT process, how to test for them and the associated test criteria.

It is unrealistic to try to test individual paste properties in serial format; for efficiency purposes they must be nested in a designed test.

Furthermore, it is also unrealistic to expect top performance in every category. Trade-offs are always made in solder paste formulations; an ingredient that helps one tendency can harm another. An excellent example is the current solder paste's tradeoff of very good post-reflow properties - like pin testability and corrosion resistance – by compromising in-process properties, like print and reflow.

It is critical to understand the compromises and how they affect the process and the end product in order to make a well-informed decision on process chemistry. To that end, four candidate solder pastes were tested as identically as possible – on the same assembly line, with the same lot of PCBs, using the same stencil, run by the same operators/engineer, and all judged by the same criteria. All four of these solder paste candidates were among the industry's current top-performing SAC305 no-clean products.

TEST METHODS

Test Vehicle

The original plan used a new test vehicle designed for evaluating solder pastes in miniaturized applications.[1] Side A, aka "top side" or "populated side" is shown in Figure 1. Side B, aka the "bottom side," "reflow side" or "unpopulated side" is shown in Figure 2.

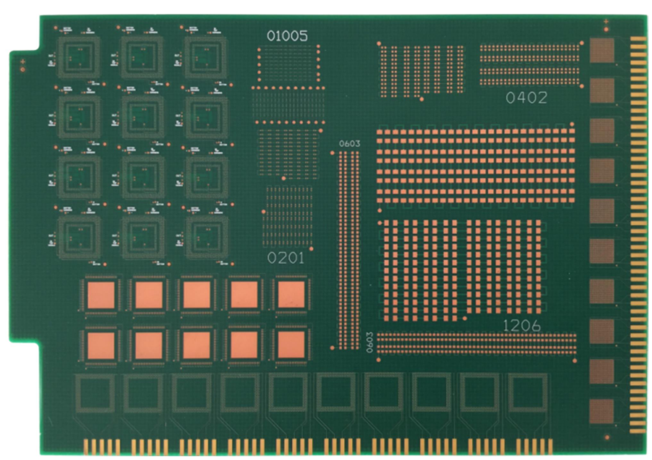


Figure 1. Side A of test vehicle

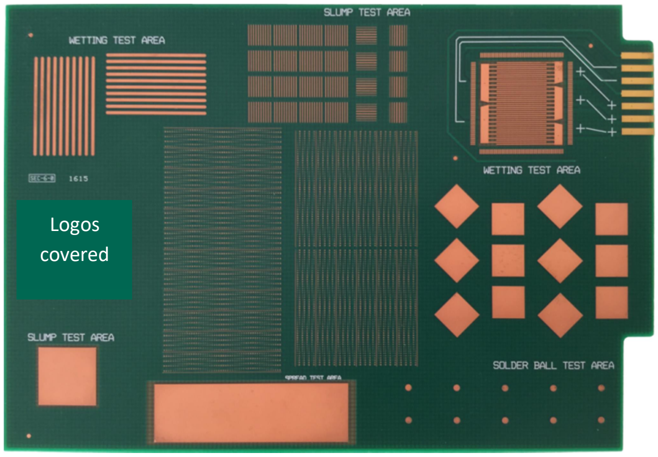


Figure 2. Side B of test vehicle

The test board, at its beta stage of design during this evaluation, incorporates print and component-based tests for components as small as 01005s and 0.3mm WLPs on the populated side. The unpopulated side contains test patterns for wetting, spread, slump, solder ball/coalescence, cleanability/SIR and an extensive array of fine features referred to as Print-To-Fail (PTF) test pattern.

Upon receipt at the testing facility, some deficiencies were noted on the PCB fabrications. Many of the smaller pads were overetched – some to the point of disappearance – and the stretch in the board made alignment of the stencil apertures and pads extremely difficult. Although all solder pastes would be evaluated under the same conditions, the PCB would not give an accurate indication of paste performance, especially the critical Print-To-Fail (PTF) patterns on which so many print tests are based.

To capture the critical PTF data, an off-the-shelf test vehicle[2] containing similar patterns was substituted for Side B of the planned test board. The board is shown in Figure 3. It is a popular test board throughout the industry and is stocked by a dummy component supplier.

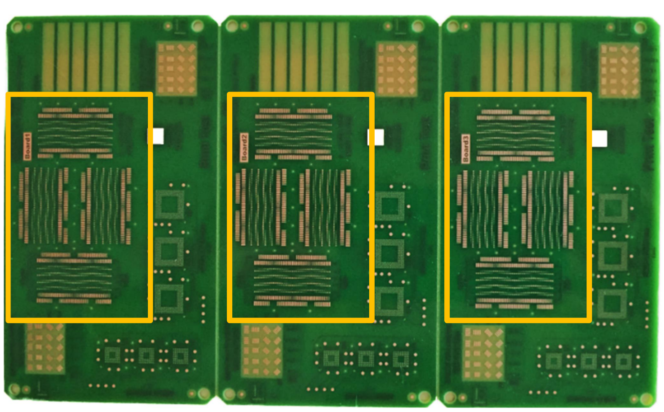


Figure 3. Substitute test vehicle with PTF patterns outlined

Assembly Equipment
The assembly line was configured as follows:

- Print: MPM Momentum HiE
- SPI: Koh Young 8030
- Place: Panasonic NPM-W
- Reflow: Vitronics 820 XPM3 oven
- AOI: Koh Young Zenith AOI

All equipment is relatively new, well maintained and in excellent condition.

Test Sequence
Because two different PCBs were used for print and reflow analysis, the original test plan was adapted to accommodate the different boards.

Part 1: Developmental board for reflow tests

- Paste was kneaded as per technical support directions
- 3 new PCBs were printed
- All PCBs were processed through SPI
- The first PCB was unpopulated and reflowed without components to look for signs of spattering, wetting, spread or fusion issues
- The second PCB was populated and reflowed immediately to simulate a typical production run
- The third PCB was populated, held for four hours at ambient environmental conditions, and then reflowed to check for propensity to solder ball through moisture absorption and other environmental sensitivities similar to those listed for PCB #1.
- Both populated PCBs were processed though AOI
- The five MLFs on each PCB were X-rayed for voiding analysis

Part 2: Substitute board for print tests

- Paste was kneaded as per technical support directions
- Stencil under side was cleaned with extended cycle to ensure cleanliness
- 9 new PCBs were printed
- Standard Solvent-Vacuum-Vacuum wipe applied
- 10^{th} board was printed
- 11^{th} board used for cold slump
- 12^{th} board used for hot slump
- Approximately 20 more (previously printed and cleaned PCBs) were printed to work the paste before the abandon test
- 4 hour abandon
- Standard Solvent-Vacuum-Vacuum wipe[3,4] applied
- Print boards 101, 102…110 to gage response to abandon and number of prints to get the paste back into its good working range of viscosity

For the multiple categories tested, a score card was developed, and each category was weighted in accordance with its importance to the operation and performance expectations of the process engineers.

RESULTS

Solder Paste Printability Analysis

There are two simple statistical methods for quantifying print transfer rates and their consistency. Using a Solder Paste Inspection (SPI) system that employs Moiré interferometry, each individual deposit is measured and its volume, height and area (among other data) are recorded.

Both analysis methods use the same basic statistics – the average and standard deviation – to describe the quality of the solder paste prints. One method normalizes the spread of the data, or standard deviation, by expressing is as a percentage of the average. This is known as the Coefficient of Variation (CV) and is often indicated as an annotation or color coded data point when the average solder paste transfer rates are plotted. As a general rule, 80% transfer efficiency (TE) with less than 10% CV is desired. Up to 15% CV may be acceptable on challenging prints, but greater than 15% indicates an out-of control process and is considered unacceptable.

The second metric uses the same averages and standard deviations as the first, but includes target values and specification limits in the calculations to form a composite index of process capability known as Cpk. Because the index is affected by both the spread of the data and its proximity to the target value, any drift in average TE, either above or below 100%, will negatively affect the Cpk value. Values of 2.0 or higher are desired, as 2.0 indicates a very robust 6σ process. Cpk values of 1.67 or more are often considered acceptable (5σ+), as many processes inherently struggle to meet the 2.0 mark.

In this print test analysis, TE and CV are used first:

1) As a baseline check to compare with similar data to ensure good system performance
2) To determine the edge of the process window where paste performance is well differentiated among the candidates

Cpk data is then used to:

1) Characterize each paste's capability relative to each other in terms of fine feature print capability
2) Examine the print data board-by-board

Print data from the PTF patterns was analyzed using the typical approach for this test PCB design:

- The best case print scenario is square, solder mask-defined pads using square stencil apertures
- The worst case print scenario is round, copper-defined pads using round stencil apertures
- Note that the two cases in between best and worst, i.e. square copper-defined and round, mask-defined have historically always fallen between on this test vehicle and are no longer typically analyzed because they offer less insight into print behavior.

Solder Mask Defined (SMD) pads provide better gasketing against the stencil than copper-defined (or NSMD) mask) pads and therefore better, more repeatable print quality. Square apertures transfer solder paste better than circular ones because of the unequal adhesion forces along walls and in corners. Therefore, out of the four test combinations of circle/square and SMD/NSMD, the two that are typically reviewed first are the best and worst cases, or square/mask defined and circle/copper defined.

The first 10 prints, on new, unused PCBs, were analyzed. Results are shown in Figures 4 and 5, where the different solder pastes are represented by different line colors, and the CV is indicated by the color of the data point. Again, the typical benchmark to indicate a controlled process is a minimum of 80% transfer and less than 10% CV (green). Up to 15% CV may be acceptable depending on the feature (yellow), but over 15% is unacceptable (red). The sample size for each data point shown is 480.

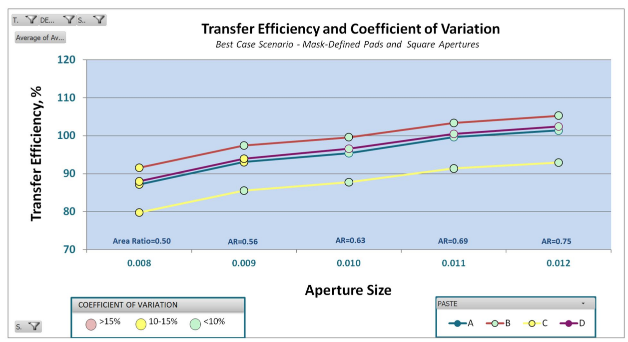


Figure 4. Transfer efficiency and Variation on PTF patterns using **best** case scenario

In the best case scenario (Fig.4), Paste B showed the best transfer, and acceptable variation down to the 0.56 area ratio. Paste C showed the lowest transfer, although still better than the 80% benchmark, and acceptable variation down to the 0.56 area ratio (AR). Pastes A and D printed similarly to each other, transferring less paste than B but more than C; however, unlike B and C, their variation was unacceptable at the 0.56 AR. Each paste maintained its rank in transfer efficiency throughout the range or ARs.

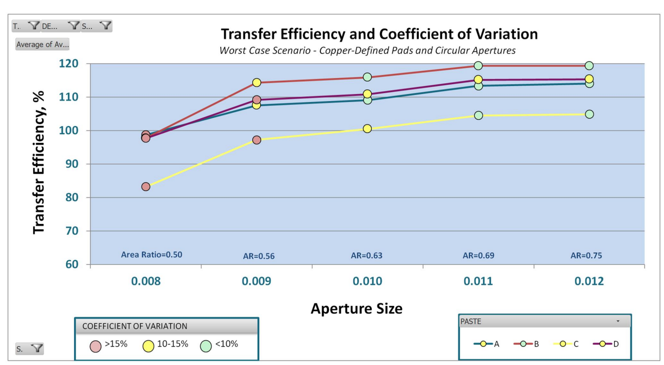


Figure 5. Transfer efficiency and Variation on PTF patterns using **worst** case scenario

In the worst case print scenario of circular, copper defined pads (Fig 5), Paste B again demonstrated the best transfer and held acceptable variation down to the 0.56 AR. Also again, Paste C showed the lowest transfer, and it's CV rose above 10% at the 0.63 AR. Again, maintaining their ranks, pastes A and D demonstrated TEs in between pastes B and D, but while paste A's variation remained good, D's was unacceptable up to an AR of 0.56 and marginal throughout the rest of the ARs.

Paste D appeared to show good release, but completely unacceptable variation. Further investigation showed the source of variation was two boards, print numbers 4 and 6, which got little or no solder paste. The engineer running the tests informed us that the solder paste was sticking to the squeegee blades, and videoed it curtaining off the blades incorrectly. The data was then analyzed for a 10-print sequence starting with print #7, to see if it stabilized, but it showed more problems on prints #9, 11 and 13. This product did not demonstrate print performance representative of the class of materials in which is it considered. It may have been somehow compromised somewhere in the supply chain.

This test vehicle has been used extensively, and with the exception of Paste D, the data collected during the 4Front trials is similar to that collected using other solder pastes, printers, and SPI systems. Typically, the mask defined squares should print well down to the 9 mil in a 4mil foil or an AR of 0.56. Because there is greater challenge in the round, copper defined pads, they typically begin experiencing print issues in the 10 mil aperture size, or 0.63 AR range. As a basic reality check, this data tracks with the findings of many other studies, with the exception of paste D.

This first cut of data indicates the edge of the process window, or the best area for further investigation to differentiate print performance. It is indicated by the yellow data points in the TE graphs. For the best case scenario of mask-defined squares, that's 8mil (AR=0.50) features. For the worst case scenario of copper-defined circles, that's in the 9-10mils (AR=0.56-0.63) range.

Cpk to Gauge Process Capability with Higher Resolution

To get better insight on fine feature printability, Cpks were calculated for each feature size and shape in the PTF patterns and a database was constructed to query them. The process capability indexes are then used to explore the lower edges of the process window as indicated by the TE/CV analysis. Figures 6 through 10 show the Cpks on a print-by-print basis for the first 10 prints.

As previously described, the Process Capability Index, or Cpk, indicates both the distribution of the data and its proximity to the target value and specification limits. For the calculations in this report, target values of 100%, with upper and lower control limits of +/- 50% were used. These are the typical default specifications on SPI equipment. The sample size for each print is 48.

Cpk values of 2.0 or higher are desired, as they indicate a six sigma process. Six sigma repeatability can be a difficult goal to meet; new processes are often developed to meet Cpk values of 1.67 or 1.5 depending on their degree of difficulty.

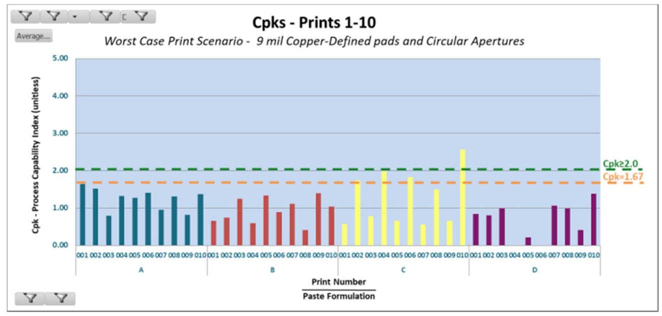


Figure 6. Cpks of worst-case features at lower edge of process window (AR=0.56)

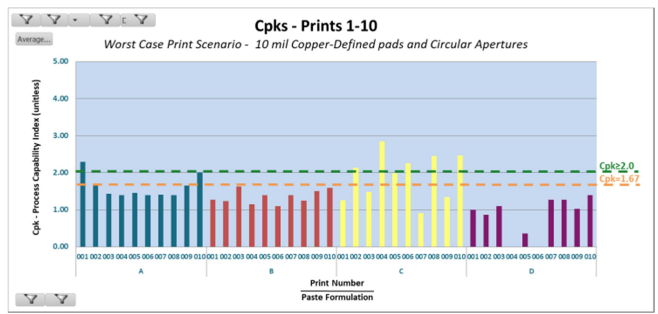


Figure 7. Cpks of worst-case features at lower edge of process window (AR=0.63)

The Cpk values tell an interesting story. Paste D shows negative Cpks on prints 4 and 6. This occurs when the mean value falls outside a specification limit; in this case, the lower limit. Paste B has lower Cpks than either paste A or C primarily because B released more than 100%, moving its average away from the 100% target. Paste A, which consistently had more variation than B (roughly 1-2%), had better Cpks because its mean volumes were closer to the target. The same applies to paste C, which had by far the lowest release, but it was also closer to the target. Overall Cpks were much higher on 10 mil (AR=0.63) than the 9 mil (AR=0.56).

Compare the values of the difficult-to-print padstack with the easier-to-print padstack. Figures 8 and 9 show the Cpks for the best case.

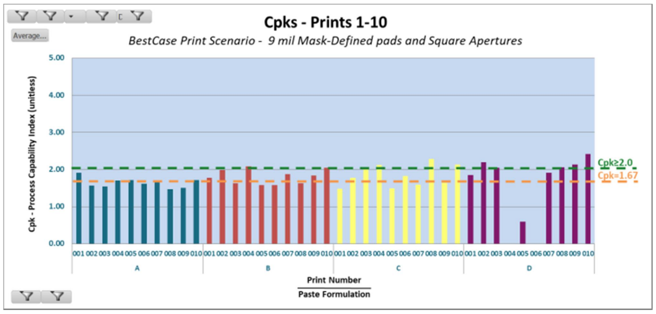


Figure 8. Cpks of same size features as Figure 6, except with best-case padstack (AR=0.56)

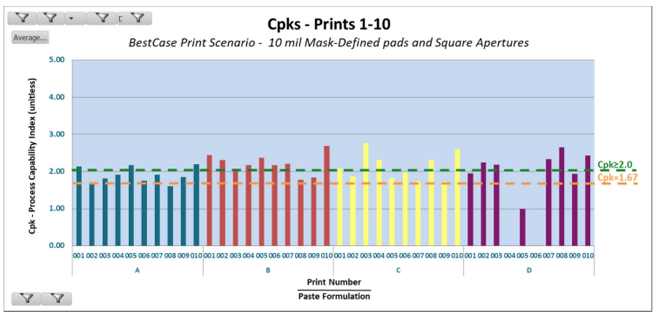


Figure 9. Cpks of best-case features at lower edge of process window (AR=0.63)

The 9 mil mask-defined, square pads and apertures printed better and more consistently than the 9 or 10 mil metal defined, circular pads. The 9 mil feature size represents a 0.4 mm BGA. A quick comparison of the responses between mask- and metal-defined pads provides DFM guidance for PCB layout. Finer features print far more robustly on mask-defined pads. Furthermore, a quick visual comparison of transfer efficiencies (Figures 4 and 5) show that mask defined pads maintain TEs closer to 100%, whereas metal-defined pads often show more than 100%TE due to gasketing issues.

Figure 10 shows the true edge of the process window for mask-defined pads and square apertures. When the effects of metal-defined gasketing issues are resolved and deposits center more closely around 100%, pastes B is clearly the most consistent. Paste A shows good capability also. In the more difficult to print feature types, Paste C shows up a repetitive up and down trend similar to that of partial squeegee sticking. Paste D could not produce 10 decent prints in a row.

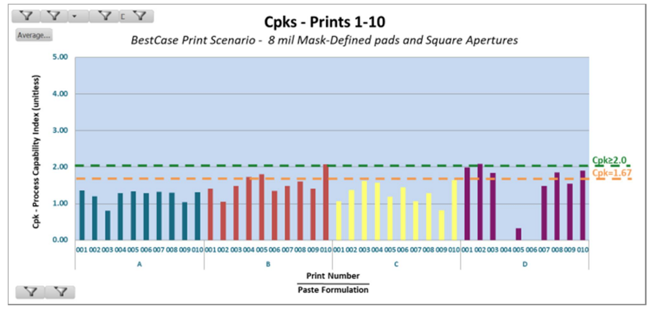


Figure 10. Cpks of best-case features at lower edge of process window (AR=0.50)

Observations

- Paste D had negative Cpks on boards 4 and 6 because their means fell below the lower specification limit of 50% aperture volume. The raw data showed a lot of null reads. This appears to be paste sticking to the squeegee after prints 3 and 5.
- Paste C also showed an interesting pattern of ups and downs with each squeegee stroke on the copper-defined 9 mil circles. This pattern could be interpreted as differences between front->back and back->front strokes; however, but the pattern is not repeated on the other data sets, so it is more likely related to paste release off the squeegee. Paste C showed far more inconsistencies on the metal-defined pads.
- On the more challenging circular pad stacks, Paste A had higher Cpks than Paste B, but Paste B had higher release and similar variation. Because both released over the target value of 100%, the higher release is farther from the center of the process window and therefore has a lower Cpk.
- Paste B consistently released more than Paste A regardless of pad and aperture design, but statistically, they were both equally consistent in the spread of the data.

From the transfer efficiency and repeatability perspective, Paste B is the best candidate and Paste D is the worst. Of the two remaining candidates, Paste A releases better than C, but C is much more consistent. They are ranked in Table 1.

Table 1. Rank order for paste TE and repeatability (the higher the better)

Paste	Rank
A	3
B	4
C	2
D	1

Tendency for Peaking or Stringing

The tendency for peaking or stringing can often be assessed by comparing the heights of rectangular deposits for QFNs. If two solder paste deposits have similar volumes but different heights, then it is easy to conclude that the one with the higher average height has higher peaks on the ends. In this case, the height differences tracked with the volume differences in the same rank, so the tendency for peaking is more difficult to assess. The only conclusion that can be drawn is from pastes A and D, which deposited similar volumes. Paste D's readings showed much higher peaks than paste A. Paste D continues to demonstrate substandard print capability.

Wipe Sensitivity

Because a wet-vac-vac stencil under wipe was run between boards 9 and 10, a jump in Cpks between boards 9 and 10 indicates a wipe sensitivity. Pastes A, C and D all showed capability jumps after the wipe for both borderline feature sizes, as seen in figures 11 and 12. Paste B did not appear to need that wipe after board 9. The ranking are shown in Table 2.

Wipe sensitivity is not as prominent in mask-defined padstacks, primarily due to the improved gasketing. Therefore, mask-defined padstacks were not analyzed for wipe sensitivity.

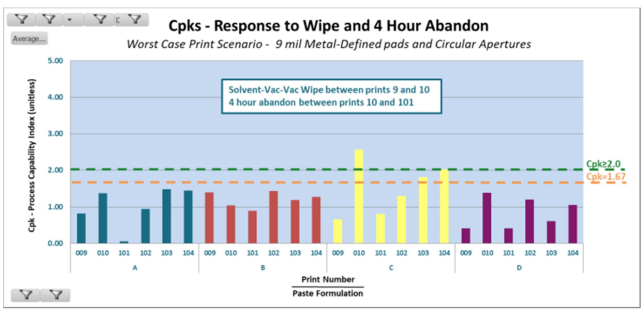


Figure 11. Cpks before and after wipe (9&10) and pause (10 and 101) for 9 mil metal-defined circles

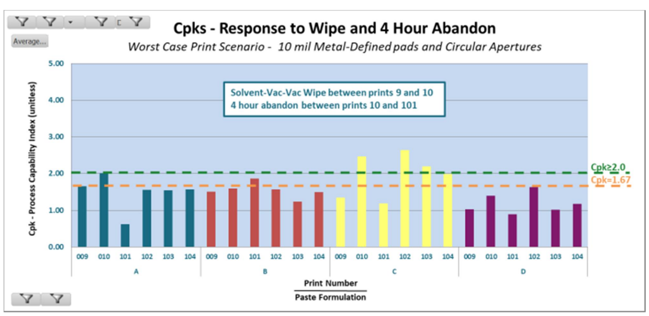


Figure 12. Cpks before and after wipe (9&10) and pause (10 and 101) for 10 mil metal-defined circles

Table 2. Rank order for paste wipe sensitivity (the higher the better)

Paste	Rank
A	2
B	4
C	1
D	3

Abandon Time

All pastes were subjected to a 4-hour abandon time. After the abandon and prior to the first print afterwards, they were solvent-vacuum-vacuum wiped. Comparing prints 10 with 101 indicates the solder pastes' responses to the long printing pause. Comparing the number of prints to regain capability indicates the relative need for kneading prior to printing or after a pause.

- Paste A lost print capability after the pause, but recovered it in 2 prints.
- Paste B showed little, if any, print capability compromise after the pause
- Paste C lost print capability but seemed to recover better than paste A
- Paste D also lost print capability and was generally the poorest performer

The final ranks are shown in Table 3.

Table 3. Rank order for paste abandon time (the higher the better)

Paste	Rank
A	3
B	4
C	2
D	1

Slump Tests

Slump test patters printed on the board were inspected visually and with SPI. The cold slump boards, which aged 20 minutes at ambient, and the hot slump boards, which aged 20 minutes at 185°C, showed no discernable differences in deposit quality, bridging, or increased areas.

The slump tests performed on site showed little differentiation and are considered inconclusive. This will not impact overall test results, as slump testing is part of solder paste development, and most modern, lead-free pastes have little or no known issues associated with slump.

REFLOW ANALYSIS

Standard reflow profiles were developed for each solder paste in conjunction with the supplier's technical support engineer. The profile for each candidate solder paste can be seen in Appendix B.

QFN Voiding

Five different ground pad designs were used in this test. They are shown in Figure 13.

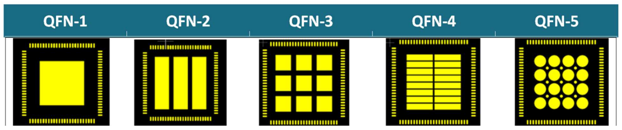


Figure 13. Different QFN ground pad solder paste patterns

Two assemblies were X-rayed for each solder paste type. During the initial phase of the investigation, the void calculation algorithm needed fine tuning, so the X-ray images were captured without the calculations and visually compared and ranked. The images and their ranks are shown in Appendix C.

Visual assessment of void formation ranked the pastes from best to worst as A, B, C, D, with A being far better than B, and C and D performing similarly.

When the void calculation algorithm was ready, one set of assemblies for each paste were analyzed. The results, and their ranks, are shown in Table 4.

Table 4. Void percent, number of voids, and average void size for each QFN ground pad design and solder paste.

Solder Paste Void Testing

X-Ray Analysis of QFN Center Pad

Paste	Pattern	Void %	# Voids	Avg Void Size
A	1	9.6	53	0.2
	2	15.7	50	0.3
	3	12.8	52	0.2
	4	8.1	52	0.2
	5	10.6	57	0.2
Average		11.36	52.8	0.22
Rank		4	4	
B	1	27.9	14	2
	2	10.3	19	0.5
	3	17.4	28	0.6
	4	15.6	34	0.5
	5	21.7	26	0.8
Average		18.58	24.2	0.88
Rank		3	2	
C	1	22.6	45	0.5
	2	18.4	51	0.4
	3	29.9	47	0.6
	4	10.3	29	0.4
	5	20.1	37	0.5
Average		20.26	41.8	0.48
Rank		2	1	
D	1	24.3	98	0.2
	2	18	65	0.3
	3	34.1	84	0.4
	4	15.3	90	not shown
	5	21.6	76	0.3
Average		22.66	82.6	0.3
Rank		1	3	

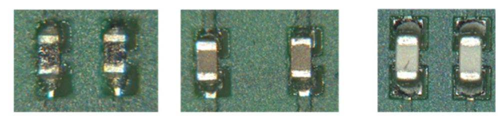
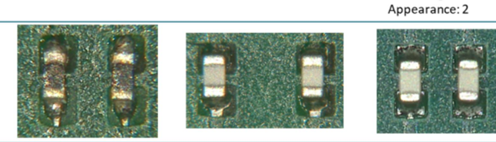
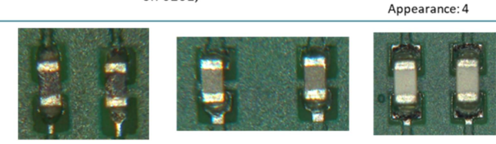
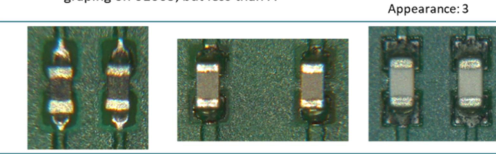
The numerical analysis of one board from each paste ranks the voiding performance (from best to worst) as Paste A, B, D and C, again with very little differentiation between C and D. These results concur with the visual analysis of the voiding behavior.

Table 4 also shows the lowest void-forming aperture designs, QFN-2 and QFN-4 by highlighting their results in yellow. The numerical analysis also concurs with the visual analysis for void-minimizing aperture design.

Coalescence or Graping

Solder joints on 01005, 0201 and 0402 (Imperial) components were photographed; representative images are shown in Table 5.

Table 5. Reflow Images

Paste	01005	0201	0402
A			
Comment/ Rank	Propensity for graping on 01005 and some 0201		Graping: 1 Wetting: 2 Appearance: 2
B			
Comment /Rank	No evidence of graping on 01005; nice cosmetics on 0201,		Graping: 4 Wetting: 4 Appearance: 4
C			
Comment /Rank	Overall very good reflow, slight propensity for graping on 01005, but less than A		Graping:3 Wetting: 3 Appearance: 3
D			
Comment /Rank	Minor evidence of graping, wetting not great, poor cosmetics on 0402, some solder beads		Graping: 2 Wetting: 1 Appearance: 1

Solder paste A showed the strongest tendency to grape, or fail to completely fuse during the reflow process. Paste B showed little to no graping, paste C showed excellent wetting but a small amount of graping. Paste D showed poor wetting and poor joint cosmetics, further indicating potential damage to the solder paste prior to the test. Referencing the scorecard shown in Appendix D, in order of overall reflow performance on small chip components, the pastes rank in order from best to worst: Paste B, A, C and D.

At this juncture, solder paste D will be excluded from further analysis, as the remaining tests are more labor-intensive, and based on print, void and joint formation results, D is no longer considered a viable candidate for this operation. Furthermore, the extensive graping of of paste A on 01005s is also considered a disqualifier.

01005 Tests

The 01005 tests run in this experiment were a baseline test for this assembler. As they operation gears up for 01005 capabilities, they had already purchased qualified placement equipment and had upgrades for SPI and AOI on order, and have since invested in new-generation optical and digital microscopy tools.

On the solder paste trial run, the SPI and AOI upgrades had not been implemented. The SPI failed all of the 01005 solder paste deposits for insufficients. The 7x8 mil apertures have area ratios of 0.47 in the 4 mil foil that was used, and the resulting small deposits barely crossed the 40µm threshold of the SPI machine, as viewed on its screen

An alternate method of gauging the solder paste print is by viewing the X-ray images of the solder joints after reflow. Larger deposits will create darker images, and smaller deposits will create lighter images. Examples of insufficients, opens and solder balls are shown in figure 14, and the images from each solder paste are shown in figure 15.

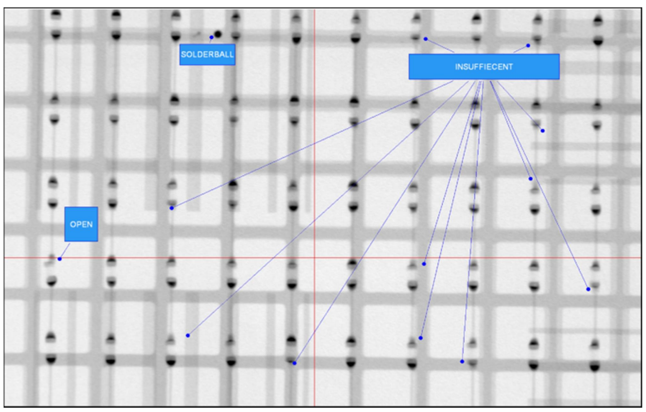


Figure 14. Types of 01005 defects visible in X-Ray analysis

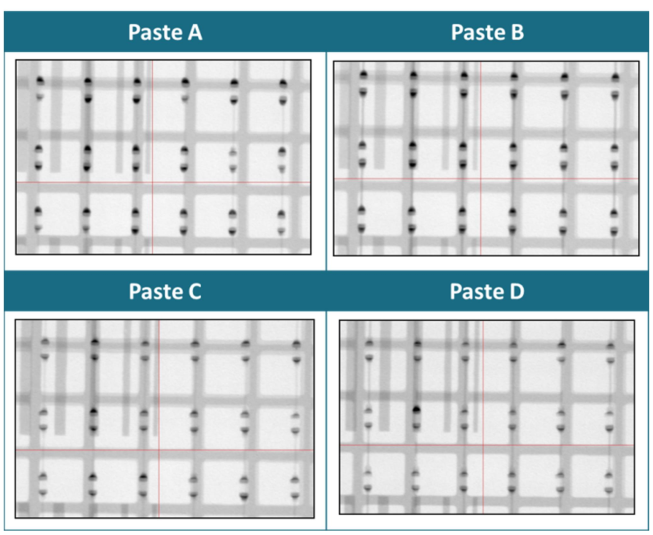


Figure 15. Results of 01005 X-ray for each solder paste.

Differences in 01005 performance were qualified relative to each other. Paste B had the most consistent deposit sizes and solder joints. Paste A had the most inconsistency.

Visual Inspection

None of the unpopulated PCBs showed any signs of spattering or other reflow issues. The samples will be reinspected using the new video microscopes.

Mid-chip solder balls on 0201s had historically been an issue for this operation. It was successfully addressed with aperture design changes. The test stencil used both the suggested aperture design and the assembler's new design. No mid-chip solder balls were found on the 0201s for any of the solder pastes tested.

Side-mount LEDs floating and skewing were also a nagging issue with the incumbent solder paste, so they were mounted on 1206 pads. No floating or skewing were noted with any of the candidate solder pastes.

Several 0402s were skewed on one board. They were mounted in close proximity to each other and appear to be a handling issue. No defects were attributed to the solder paste, but the defects and likely root cause are noted for the record.

AOI programs found no missing, skewed, tombstoned, tilted or misplaced parts on the 0201 or larger components. 01005 data was collected as a baseline for comparison after the upgrades are installed.

Testability and Residues

Initial visual examination of the residues by test engineering did not reveal any obvious problems. Originally, a flying probe test was planned to differentiate among the 4 candidates. However, after paste D was eliminated due to overall performance issues and paste A was eliminated for reflow performance a flying probe test was not deemed necessary. Data will be collected on paste B during its beta runs and compared with the incumbent products, and PM schedules may be varied based on the results.

Cleanability

Bottom Termination Components and other packages with low standoff are specified to run in No-Clean only processes, because their low clearance makes full dissolution and removal of the flux residues very challenging. Yet, CEMs are asked to do it every day. It is imperative that the cleaning chemistry and process is compatible with whatever solder paste is selected.

The operation's cleaning process was developed in conjunction with their chemistry supplier, and the correct levels of cleaning chemistry are automatically maintained in a closed-loop process. Upon discussions with the supplier regarding compatibility testing with the solder pastes, the operation was assured that all four pastes had been tested with their current solvent system. The supplier provided reports on their internal tests with all four candidate solder pastes. The solvent will not need changing, but the concentration may require minor adjustment.

Score Card

The Solder Paste Score Card shown in figure 16 itemizes the major and subcategories on which solder pasted were rated, along with the criteria that was used to rate them. In each subcategory, the performance of each is ranked on a 4-point scale, with 4 being the best and 1 being the worst. The subcategories are then totaled for an overall category score, which is then weighted based on importance to the operation.

Weighting key:
10- critical
7.5-Very Important
5-Important
2.5-Less Critical/ Important
1-not Critical

4FRONT SOLUTIONS

Solder Paste Score Card - Rank Order for Each Solder Paste Characteristic

Weight %		Category	Paste A	Paste B	Paste C	Paste D	Criteria	Comments
		Printability						
30	10	Volumes	3	4	2	1	TE and CV, Cpk	Volumes of 8-12 mil features
	10	Heights (peaking)					TE and CV, Cpk	Heights on QFN I/Os
	5	Wipe frequency requirements	2	4	1	3	Compare Cpks before and after wipe	9 prints
	2.5	Recovery from Abandon Time	3	4	2	1	Compare Cpks before and after abandon	4 hours
	2.5	Slump					Compare prints pattern before and after 20 min	Cold - room temp; Hot - 185°C
		Weighted Category Results	*47.5*	*70*	*30*	*27.5*		
		X-Ray/Voiding						
25	5	Visual - rank order	4	3	2	1	<30% (IPC), the smaller the better	Average for all gnd pad patterns for each paste, but check each design for BIC
	10	Voiding %	4	3	2	1	The fewer the better	
	10	Void Size/Count	4	2	1	3	The smaller the better; more small ones better than one big one	
		Weighted Category Results	*100*	*70*	*50*	*60*		
		Reflow/AOI on chips						
41	10	Coalescence / Graping	1	4	3	2	Presence and amount of graping on 01005	Visual
	10	Wetting	2	4	3	1	Angle and height on terminations, pad spread	Visual
	5	Appearance	2	4	3	1	Residue, reflectivity, inspectability	Visual
	10	Defects	3	4	2	1	Total quantity	AOI
	5	Solder balls (maybe)	4	4	4	4	Total quantity	
	1	False Call	0	0	0	0	Total quantity	AOI
		Weighted Category Results	*90*	*160*	*115*	*65*		
		Testability						
7.5	7.5	Residue effect on test fixture	tbd	tbd	tbd	tbd	Test Engineering to rank order based on their physical review of residues	
		Weighted Category Results						
		Cleanability						
20	10	Solvent Compatibility	4	4	4	4	1) ionograph - Pass/Fail (averages ionic contamination over entire board)	
	10	Solvent Compatibility	tbd	tbd	tbd	tbd	2) ion chromatography under QFN - Pass/Fail	looks specifically under the low standoff components
		Weighted Category Results	*40*	*40*	*40*	*40*		
		Supplier and Value Proposition						
29.5	5	Price per Gram (10,000gr. / yr base)	3	4	3	3	Cost per gram based on 10,000 gr. Break	
	5	Distribution/ Supply Chain	4	4	3	3	Local Distributor channels to maintain inventory-	
	5	Technical Support	4	4	4	3	Technical Support Resonse/ access ability/ resources	
	1	Shelf Life/ Storage	3	3	4	4		
	1	Reclaim Services	4	4	3	4	Available reclaim with cost recovery	
	10	Compaitibility w/ under stencil chemistry	4	4	4	4	Flux dissolution into current chemistry for under stencil cleaning	
	2.5	Lead version available same flux vehicle	4	4	4	4	Lead and lead-free have same flux vehicle	
		Weighted Category Results	*112*	*117*	*107*	*103*		

Total points
153

	Paste A	Paste B	Paste C	Paste D
OVERALL WEIGHTED TOTAL:	390	457	342	296
Normalized on 1-4 scale (4=best)	2.5	3.0	2.2	1.9

Best Paste for this Operation

Figure 16. Customized Solder Paste Score Card

A larger, more legible image of the scorecard can be seen in Appendix D.

Discussion and Conclusions

Review of the score card, and the strengths and weaknesses of each solder paste relative to each other, demonstrates the tradeoffs in solder paste selection.

- Paste B was the best at print and reflow, but not at voiding. It was not sensitive to wipe frequency or abandon time, giving it a very robust stencil life, excellent for low- to medium-volume manufacturing.
- Paste A was very good at print transfer and repeatability, great at voiding, but had problems at reflow, and had the Achilles heel of poor recovery after abandon time.
- Paste C printed well in that it was very consistent and had the best repeatability. Its release properties weren't as good as two other pastes, but it's voiding was respectable and its reflow was respectable. Its two weak spots were under wipe sensitivity and abandon time. Overall it is a good general purpose solder paste because while it does not excel in any particular area, it has no fatal weaknesses, either.
- Paste D appears to be compromised from the beginning. It showed extremely bad print and reflow properties, and did not fare well in voiding performance, either. This is uncharacteristic of a top tier solder paste.

COST SENSITIVITY

Cost is always a consideration in any manufacturing operation. There are multiple costs associated with a solder paste qualification process:

- Test vehicle boards and component inventory
- Line time, labor and lost revenue opportunity on SMT line
- Cost differential between incumbent and new products – will the upgrade be worth it?

To address each area of concern, cost mitigation was considered early in the planning stages. To limit the cash outlay on PCBs, off-the-shelf test vehicles were used. They are less expensive than production PCBs, and have designed experiments built into them. The reflow board was costly, but the cost has since been designed out. Both test PCB fabrications cost less than $10/board.

The BOM uses a lot of chip components, which, with the exception of the 01005s, are pennies or less per piece. The QFNs cost about $4 each, so of the 10 footprints on each PCB, only 5 were populated. Leaving the other 5 unpopulated provided an opportunity to see how the different ground pad patterns flowed, and saved money. Only two boards were populated, so the total cost per paste to gauge QFN voiding was about $40.

To minimize line time and labor costs, many tests are included on each test PCB, and the test sequence nests tests to maximize the return on the time investment.

To ensure the proper value proposition, annual volumes were provided and quotes requested prior to the tests. All suppliers' pricing were close to each other. Suppliers were also graded on their levels of technical support, local stocking, and ability to provide turnkey packages that included reclaim services and similar flux vehicles in tin-lead and SAC305 solder paste. Because only top-tier suppliers were invited to the solder paste qualification, they all met the supplier qualification criteria.

FUTURE WORK

On the assembler's side, several actions are outstanding:

- Assessment of ATE test fixture maintenance – more or less frequently
- Low standoff cleanliness testing
- Review and redocument reflow results, especially for chosen solder paste, with new imaging equipment
- Use populated boards to baseline and test AOI upgrades

On the consultant's side:

- Follow up on remaining outstanding assembler actions to finalize documentation of tests
- Continue to support SMT objectives as needed

- Continued development of single test vehicle that can be fabricated robustly and economically
    - At the time of publication, this effort is 90% complete
    - More information available at IPC/APEX 2018
- Publish costed BOM for final test vehicle
    - Complete but not yet published
    - Cost reducing options quantified in spreadsheet
- Publish test sequence for new TV that maximizes information return and minimizes line time and labor
- Continue to make information available in public domain

ACKNOWLEDGEMENTS

The authors would like to recognize and thank the many people and organizations that supported this effort:

- Four solder paste companies that participated in this qualification process and provided on-site technical support throughout the trials to help ensure sound test methods and fair, data-driven evaluations.
- Henkel corporation for providing test PCBs, stencils, and supporting the development of the expedited test process

REFERENCES

1. Test PCB known as the "Henkel board," under development at time of publication. Estimated release is Q4 2017.
2. Test PCB known as the "Jabil Board," available from Practical Components
3. Shea, C., and Bixenman, M., *Video Analysis of Solder Paste Release From Stencils –Part III,* Proceedings of SMTA International, September, 2016
4. For video comparing Wet-Vac-Vac and Wet-Vac Dry wipe effectiveness, go to https://www.youtube.com/watch?v=K5cFkUhR2uc

APPENDIX A

Solder Paste Properties That Influence the Assembly Process

Category/ Paste Property	Impact on SMT Process	How to Test	Test Criteria
Print Characteristics			
Transfer Efficiency & Print Variation	Insufficients, opens, bridges, solder balls, HIP, frequent wiping	Print solder paste and measure deposits with automated SPI Analyze: - Volumes of small deposits - Heights of rectangular deposits - Positional offsets Compare Cpks from SPI machine *or* download data and manually calculate mean and coefficient of variation	Cpks using standard +/- 50% spec limits - Volumes: higher is usually better - Heights: lower is usually better if it is greater than the stencil thickness Positional offsets should be less than 25 µm or 1 mil in either axis. Stencil offsets should have been set at beginning of run. Positional offsets can cause higher volume readings and skew the data. **Low variation is just as important as the volumes and heights.**
Wipe Frequency	Solder defects, excessive use of consumables, line downtime during wipes	Analyze print stats on 10 print test. Print 9 boards, wipe. Compare stats between prints 9 and 10.	Cpk pre-wipe vs. Cpk post-wipe
Abandon time	Poor quality first print Knead paste and clean/dry/reuse PCB	Determine typical abandon time to test. Compare print stats before and after abandon time	Cpk pre-abandon vs. Cpk on first print post-abandon # of prints to reach steady state
Print Definition	Solder Defects, frequent wiping	Compare to visual scale *Often used when SPI is not available* *Can be used in conjunction with SPI volumes to determine overall print quality.*	Visual scale

Stencil & Assembly Line Behavior			
Cold slump	Bridges, random solder balls	IPC or proprietary slump patterns Print, place in ambient environment, wait 20 minutes and read pattern	Smallest gap to bridge
Hot slump	Bridges, Insufficents on PTH, solder buildup in oven from PTH drips	IPC or proprietary slump patterns Print, place in oven at 182°C for 20 minutes and read pattern	Smallest gap to bridge
Stencil Life	Solder Defects, frequent wiping	IPC or proprietary slump patterns Cold slump after extensive print or knead strokes and/or environmental exposure	Smallest gap to bridge after extensive kneading or printing
Tack	Positional errors on components, tombstones, solder balls, missing or transient components	Hold printed PCB for a period of time before placing and reflowing	AOI or End of Line quality data # of defects
Reflow Properties			
Wetting	Insufficients, opens, tombstones, solder balls, skews, non-wets, HiP, perceived voiding	Print test patterns with different coverage on substrate and look for full wetting on 10x10mm pad Assemble PCB with known difficult-to-wet components and inspect.	Visual - Uniform wetting (Y/N), spatter (Y/N)
Spread	Insufficients, opens, solder balls	Print solder paste on exposed copper traces with gaps between paste deposits and observe the distance of the gaps that bridge closed	Largest gap to bridge
Coalescence	Solder balls, graping, poor pull back on over prints	Print deposits of varying sizes onto small round pads on substrate and reflow. Look for coalescence and rate as Preferred, Acceptable or Unacceptable as per IPC standards.	Preferred/Acceptable/Unacceptable

	Random Solder Balls	Require removal	Print, populate and reflow PCB. Inspect for random solder balls, or satellites, near overprinted pads, around the leads of fine pitch devices or in random locations on the PCB. Check gold fingers, if applicable.	Number of balls larger than the smallest gap between conductors on the assembly or assembler's specification
	Solder Beads or Mid-Chip Solder Balls	May require removal	Print, place and reflow small chip components. Inspect for solder beads visually or with X-ray.	Number of balls larger than the smallest gap between conductors on the assembly or assembler's specification
	Tombstones or Skews	Defect that requires rework	Print, place and reflow small chip components. Inspect visually or with AOI.	Defect count
	Voiding	Poor thermal heat sinking or electrical gounding on BTC, potentially weaker solder joints Expensive rework	Print, place, reflow, X-ray. Analyze for: - Average void % - Max void % Note: For any average voiding %, more, smaller voids are preferable to fewer, larger voids.	< 30 % or customer specification Lower is better (see note at left)
	Head-in-Pillow	Expensive rework, scrap or warranty returns	Print, place and reflow BGAs Inspect with X-ray	Defect count
	Joint Appearance	Inspection time and accuracy	Inspector-dependent based on wetting angle, flux residue, shine, other. Subjective.	Grade, 1-5 *or* Rank order
	Flux Residue Appearance	Inspection time and accuracy Customer perception	Inspector-dependent based on color, clarity and consistency. Subjective.	Grade, 1-5 *or* Rank order
Testability				
	Residue Brittle or Ductile (hard/shatter or soft/complant)	False Fails & Retests ($),Test Fixture downtime for cleaning	Evaluation by Test Engineering	Grade, 1-5 *or* Rank order
	Contact Resistance	False Fails & Retests ($)	Evaluation by Test Engineering	Grade, 1-5 *or* Rank order

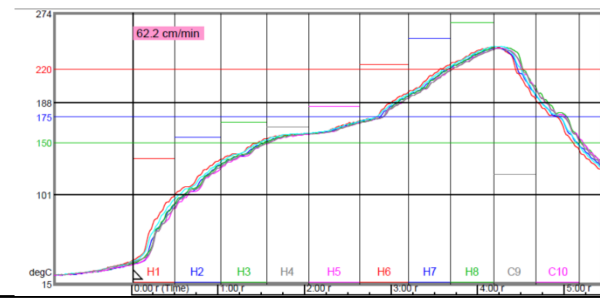
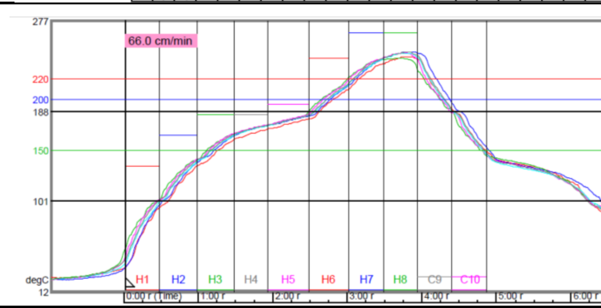
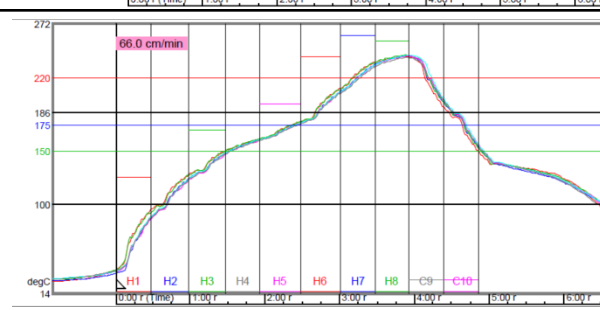
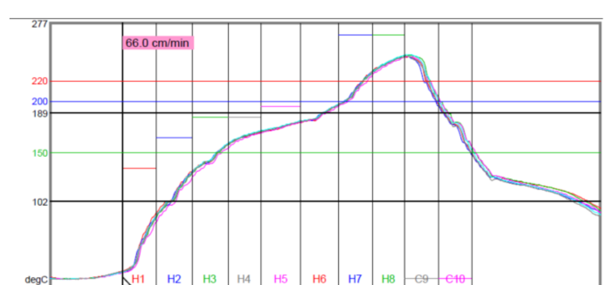
Cleanability			
Complete removal of residues	Dendritic growth, field failures, warranty returns	Ionograph - internal process tests the overall cleanliness of the wash/rinse water but not in specific areas of the PCB	1) ionograph - Pass/Fail to customer specification
Removal under low-standoff components	Dendritic growth, field failures Very important but often difficult to achieve	Ion chromatography – quantitative, focused, conclusive test on cleanliness under low standoff compoennts	2) ion chromatography under low standoff component - Pass/Fail to customer specification

Table courtesy of Henkel Electronic Materials, Inc.

Appendix B

Reflow Profiles for Each Candidate Solder Paste

Developed on-site in conjunction with each supplier’s technical support engineers

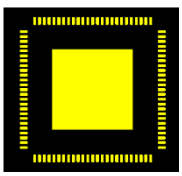
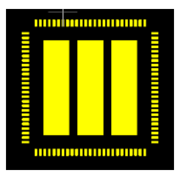
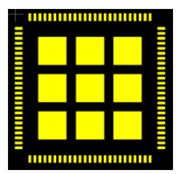
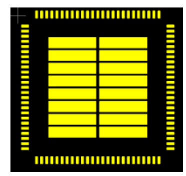
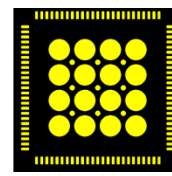
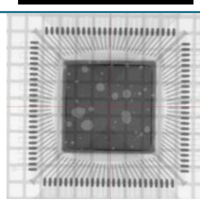
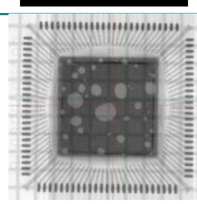
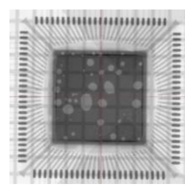
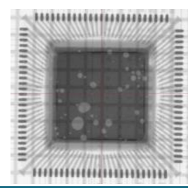
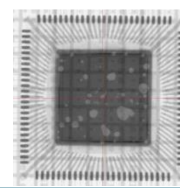
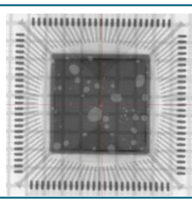
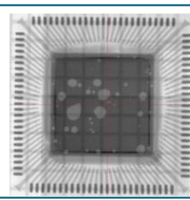
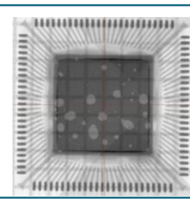
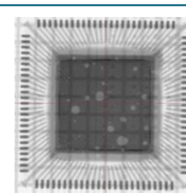
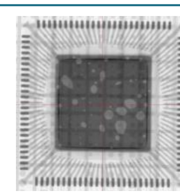
Paste A	
Paste B	
Paste C	
Paste D	

Appendix C

Voiding Analysis

QFN100 Thermal/Gnd Pad

In the absence of an X-ray voiding algorithm, images were compared visually and ranked relative to each other.

	QFN-1	QFN-2	QFN-3	QFN-4	QFN-5
Aper-ture Design					
AH002					
Rank	8	6	7	8	8
AH003					
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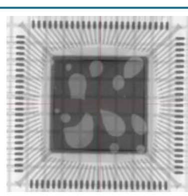
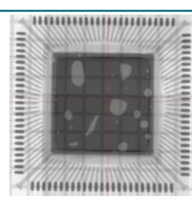
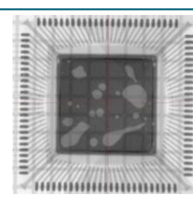
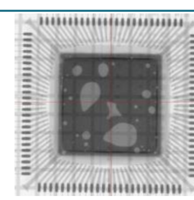
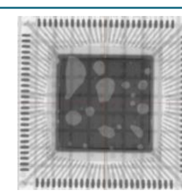
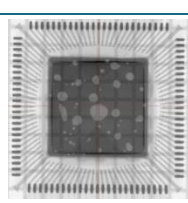
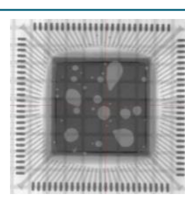
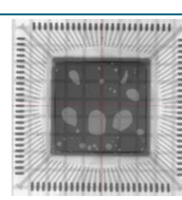
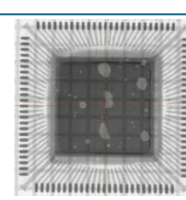
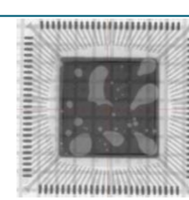
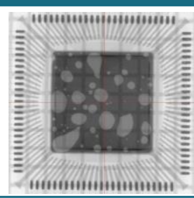
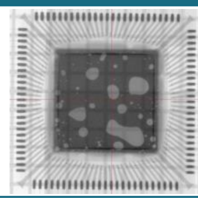
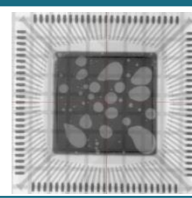
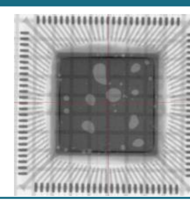
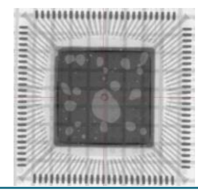
BH002					
Rank	1	8	5	3	2
BH003					
Rank	6	3	6	6	1

Voiding Analysis Cont'd

QFN100 Thermal/Gnd Pad

	QFN-1	QFN-2	QFN-3	QFN-4	QFN-5
CH002					
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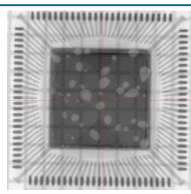
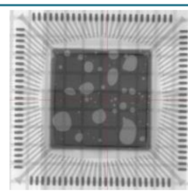
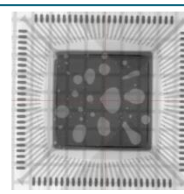
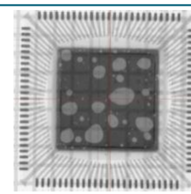
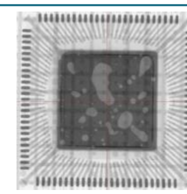
CH003					
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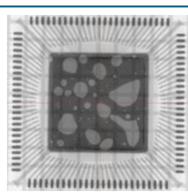
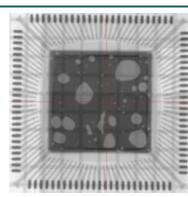
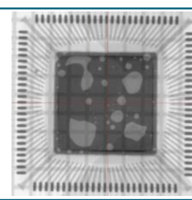
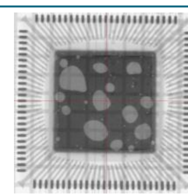
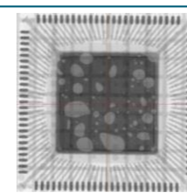
DH002					
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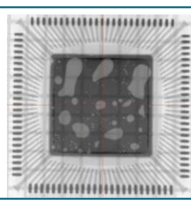
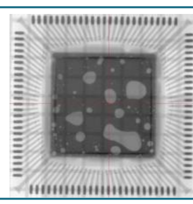
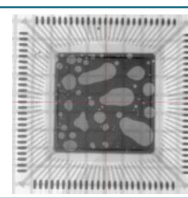
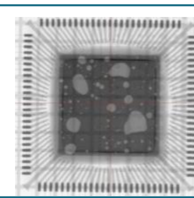
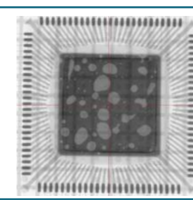
DH003					
Rank	1	5	1	4	4

Final Rank Order (best to worst):

Paste A
Paste B
Paste C
Paste D

Appendix D
Solder Paste Score Card

4FRONT SOLUTIONS

Weighting key:
10- critical
7.5-Very Important
5-Important
2.5-Less Critical/ Important
1-not Critical

Solder Paste Score Card - Rank Order for Each Solder Paste Characteristic

Weight %		Category	Paste A	Paste B	Paste C	Paste D	Criteria	Comments
30		**Printability**						
	10	Volumes	3	4	2	1	TE and CV, Cpk	Volumes of 8-12 mil features
	10	Heights (peaking)					TE and CV, Cpk	Heights on QFN I/Os
	5	Wipe frequency requirements	2	4	1	3	Compare Cpks before and after wipe	9 prints
	2.5	Recovery from Abandon Time	3	4	2	1	Compare Cpks before and after abandon	4 hours
	2.5	Slump					Compare prints pattern before and after 20 mir	Cold - room temp; Hot - 185°C
		Weighted Category Results	*47.5*	*70*	*30*	*27.5*		
25		**X-Ray/Voiding**						
	5	Visual - rank order	4	3	2	1	<30% (IPC), the smaller the better	Average for all gnd pad patterns for each paste, but check each design for BIC
	10	Voiding %	4	3	2	1	The fewer the better	
	10	Void Size/Count	4	2	1	3	The smaller the better; more small ones better than one big one	
		Weighted Category Results	*100*	*70*	*50*	*60*		
41		**Reflow/AOI on chips**						
	10	Coalescence / Graping	1	4	3	2	Presence and amount of graping on 01005	Visual
	10	Wetting	2	4	3	1	Angle and height on terminations, pad spread	Visual
	5	Appearance	2	4	3	1	Residue, reflectivity, inspectability	Visual
	10	Defects	3	4	2	1	Total quantity	AOI
	5	Solder balls (maybe)	4	4	4	4	Total quantity	
	1	False Call	0	0	0	0	Total quantity	AOI
		Weighted Category Results	*90*	*160*	*115*	*65*		
7.5		**Testability**						
	7.5	Residue effect on test fixture	tbd	tbd	tbd	tbd	Test Engineering to rank order based on their physical review of residues	
		Weighted Category Results						
20		**Cleanability**						
	10	Solvent Compatibility	4	4	4	4	1) ionograph - Pass/Fail (averages ionic contamination over entire board)	
	10	Solvent Compatibility	tbd	tbd	tbd	tbd	2) ion chromatography under QFN - Pass/Fail	looks specifically under the low standoff components
		Weighted Category Results	*40*	*40*	*40*	*40*		
29.5		**Supplier and Value Proposition**						
	5	Price per Gram (10,000gr. / yr base)	3	4	3	3	Cost per gram based on 10,000 gr. Break	
	5	Distribution/ Supply Chain	4	4	3	3	Local Distributor channels to maintain inventory-	
	5	Technical Support	4	4	4	3	Technical Support Resonse/ access ability/ resources	
	1	Shelf Life/ Storage	3	3	4	4		
	1	Reclaim Services	4	4	3	4	Available reclaim with cost recovery	
	10	Compaitibility w/ under stencil chemistr	4	4	4	4	Flux dissolution into current chemistry for under stencil cleaning	
	2.5	Lead version available same flux vehicle	4	4	4	4	Lead and lead-free have same flux vehicle	
		Weighted Category Results	*112*	*117*	*107*	*103*		

Total points
153

	Paste A	Paste B	Paste C	Paste D
OVERALL WEIGHTED TOTAL:	390	457	342	296
Normalized on 1-4 scale (4=best)	2.5	3.0	2.2	1.9

Best Paste for this Operation

Solder Paste Qualification Testing for EMS Production

Chrys Shea

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Raymond Lawrence

GMI • MFG
Advanced Electronic Manufacturing

Agenda

- Why change solder paste?
- What are the key characteristics to look for?
- How to test for them?
- Results and Discussion
- Score Card
- Cost Concerns
- Q & A

Why Change Solder Pastes?

- Newer formulations are better than older ones
- You are fighting defects on your line that paste developers already resolved in the lab
  - Printing, wetting, voiding, solder balling…

The latest generation of lead-free solder pastes are the best yet. Use one if you can.

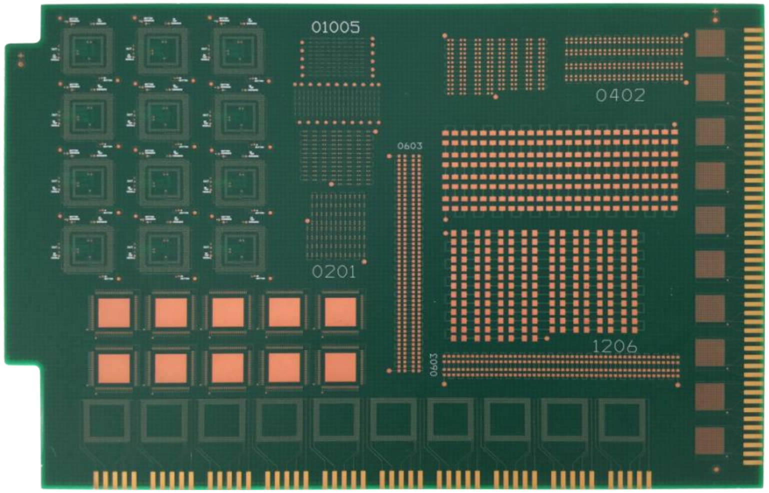
Key Properties of Solder Paste

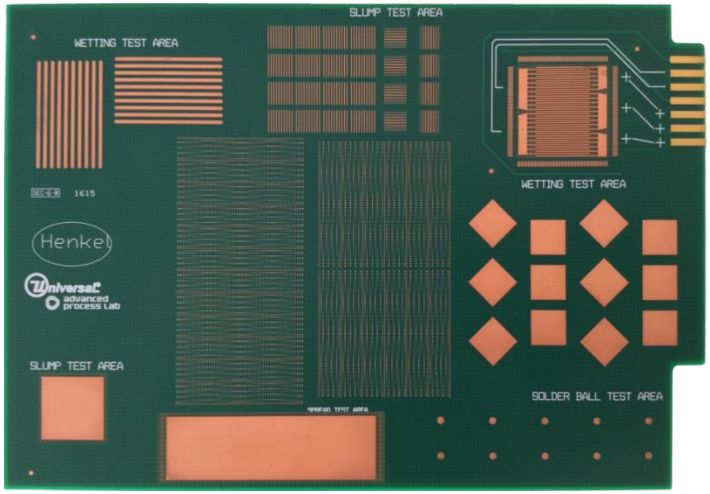
- Print characteristics
  - Transfer efficiency, repeatability, abandon time, print definition
- Stencil & assembly line behavior
  - Slump, stencil life, tack
- Reflow properties
  - Wetting, voiding, spread, mid-chip balls, graping, HIP, tombstones, skews, cosmetics
- Testability
  - Residue, contact resistance
- Cleanability
  - Ease of residue removal with common chemistry
  - Even no-cleans are often cleaned
  - Cleaning under low standoff components

A total of 22 properties, and more information on them, are listed in the paper.

How to Test?

- ***Very Efficiently***
- Combine many tests into single run
- Use test vehicle (TV) that has multiple tests built into it.



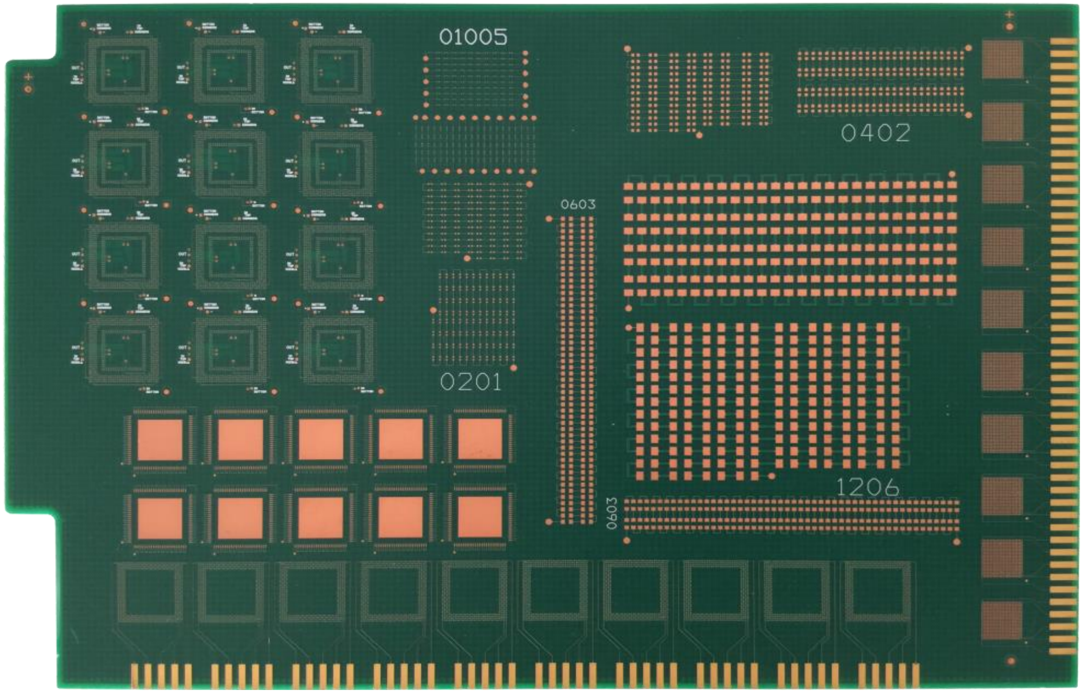


Test Vehicle

- Developed for laboratory work
- Excellent for quick characterization on assembly line

Side A has:

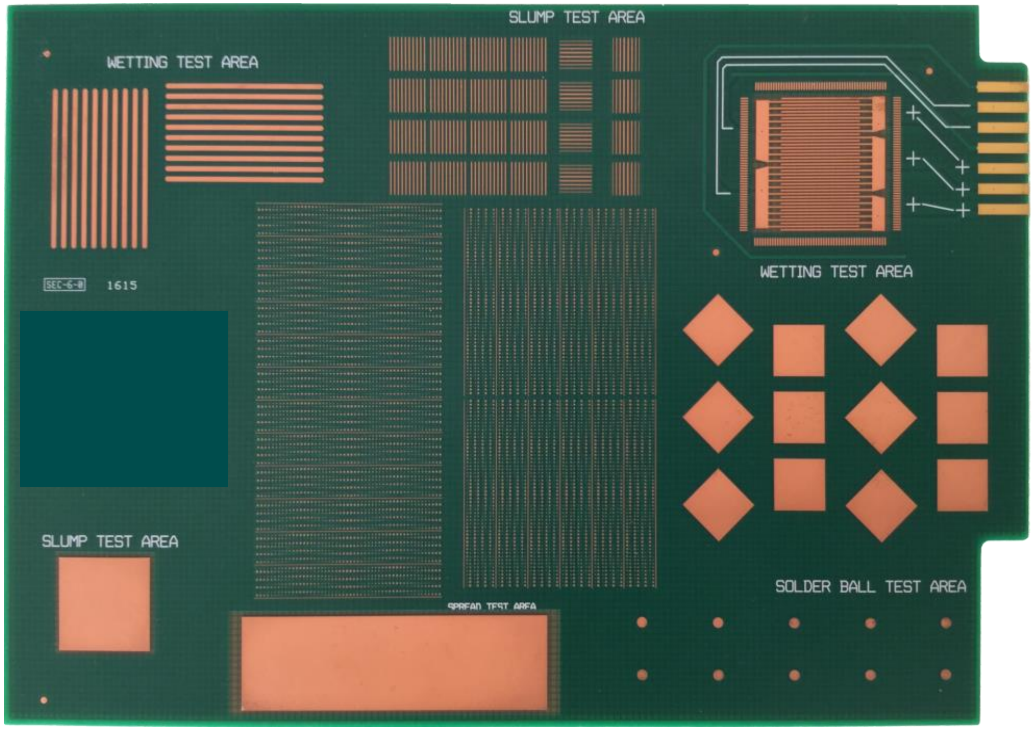
- 0.3 and 0.4 mm area arrays
- 0.4 mm MLFs
- 01005, 0201, 0402, 0603 and 1206 chips
- Daisy chains to gold fingers for reliability testing



Test Vehicle

- Developed for laboratory work
- Excellent for quick characterization on assembly line

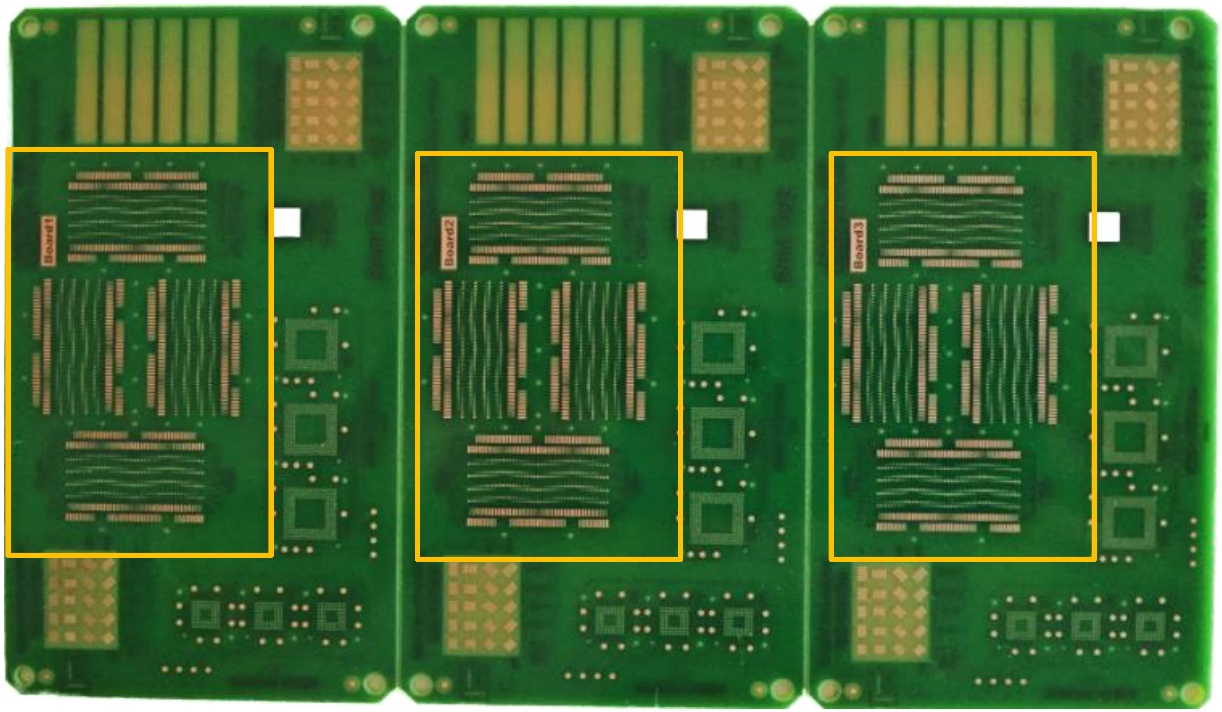
Side B has:
- Wetting
- Spread
- Slump
- SIR
- Solder ball
- PTF (Print to Fail): pads in 3-15 mil sizes with different shapes and pad definitions



Original Test Plan

- Test 22 properties in 4 hours of line time
- Problem with PCBs
  - Over etch and stretch from fab shop
  - Not going to get accurate representations on printability
- Plan B
  - Use original test board for reflow
  - Purchase substitute test board for print

Substitute Print Test Vehicle



Aka, the Jabil board.
PTF patterns have round, square and rectangular pads in both mask and metal-defined pads in sizes 3-15mil. Each print has 48 of each shape, size and definition combination.
Each 10-print test has 480 readings in each reported data point

Production Line

- Print: MPM Momentum HiE
- SPI: Koh Young 8030
- Place: Panasonic NPM-W
- Reflow: Vitronics 820 XPM3 oven
- AOI: Koh Young Zenith AOI

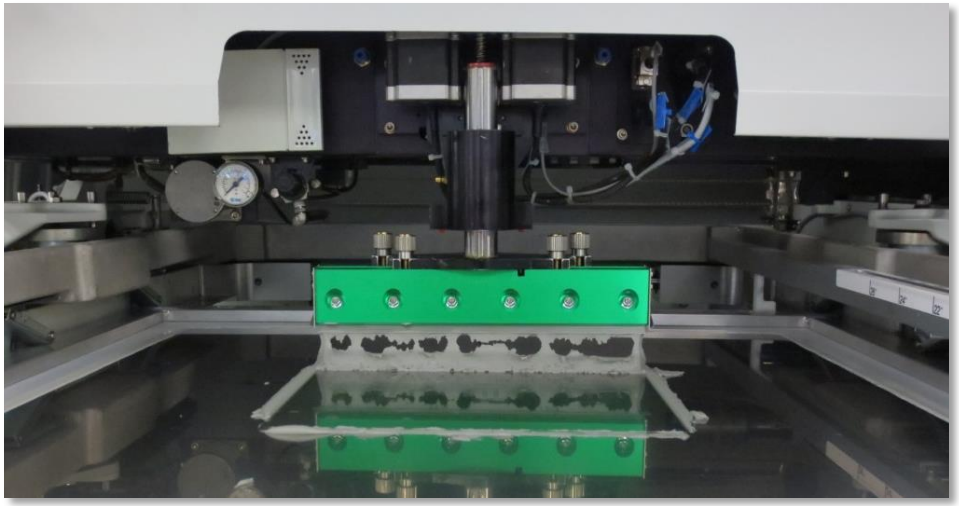
All equipment is relatively new, well maintained and in excellent condition.

Test Execution

Reflow Board	Print Board
▪ Knead ▪ Print 3 new PCBs ▪ SPI ▪ #1 not unpopulated and reflowed without components to look for signs of spattering, wetting, spread or fusion issues ▪ #2 populated and reflowed immediately to simulate a typical production run ▪ #3 populated and held 4 hours at ambient environmental conditions before reflow ▪ Both populated PCBs were processed though AOI ▪ Five MLFs on each PCB were X-rayed for voiding analysis	▪ Knead, clean stencil under side ▪ Print 9 new PCBs ▪ Standard Solvent-Vacuum-Vacuum wipe ▪ Print 10th board on new PCBs ▪ 11th board used for cold slump ▪ 12th board used for hot slump ▪ Approximately 20 more (previously printed and cleaned PCBs) were printed to work the paste prior to abandon ▪ 4 hour abandon, in factory, lightly ▪ Standard Solvent-Vacuum-Vacuum wipe applied ▪ Print boards 101, 102…110 to gage response to abandon and number of prints to get the paste back into its working viscosity

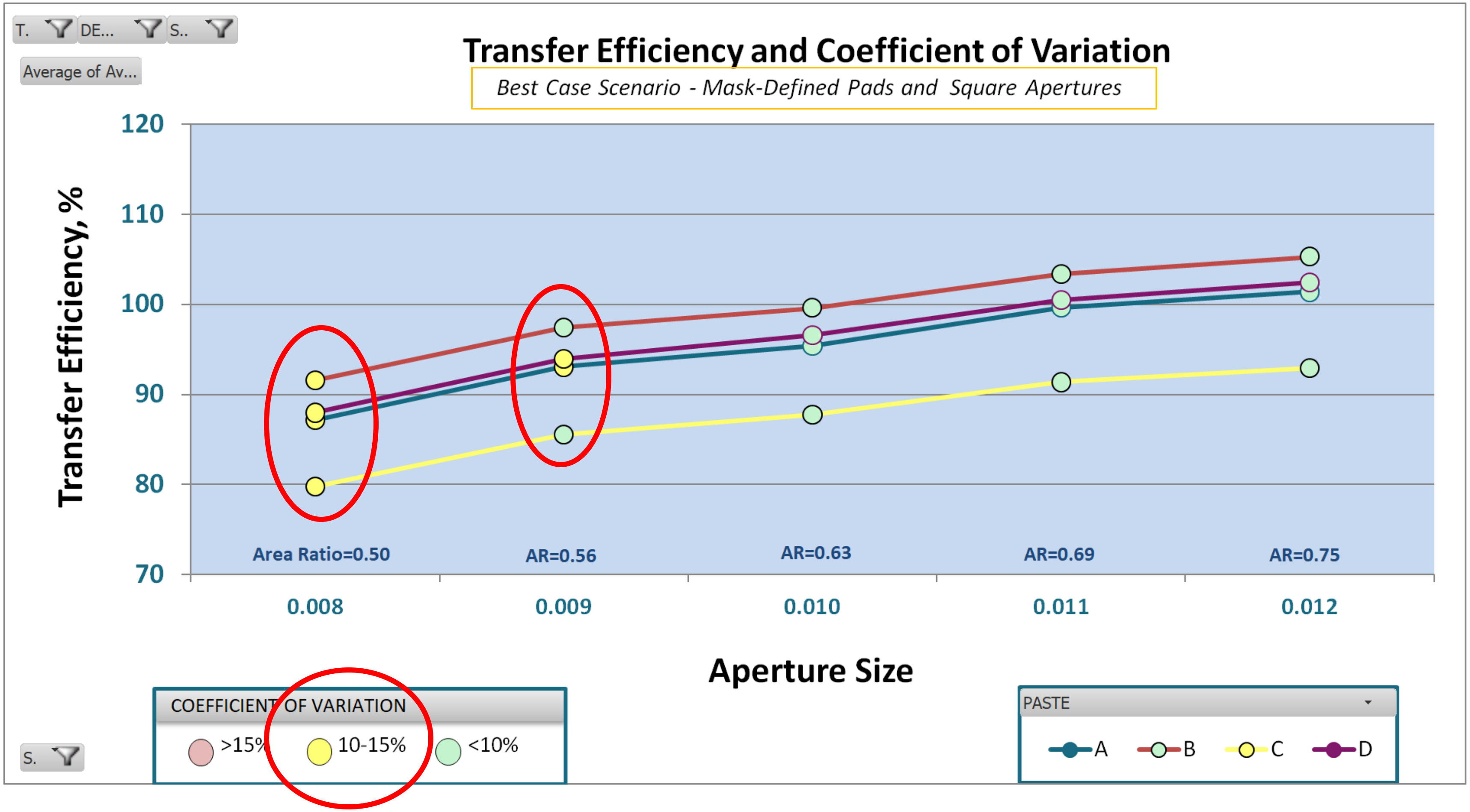
Results

- Printability
  - Find out where the edge of the process window is and mine data there
  - Will quickly separate the stronger printing pastes from the weaker ones



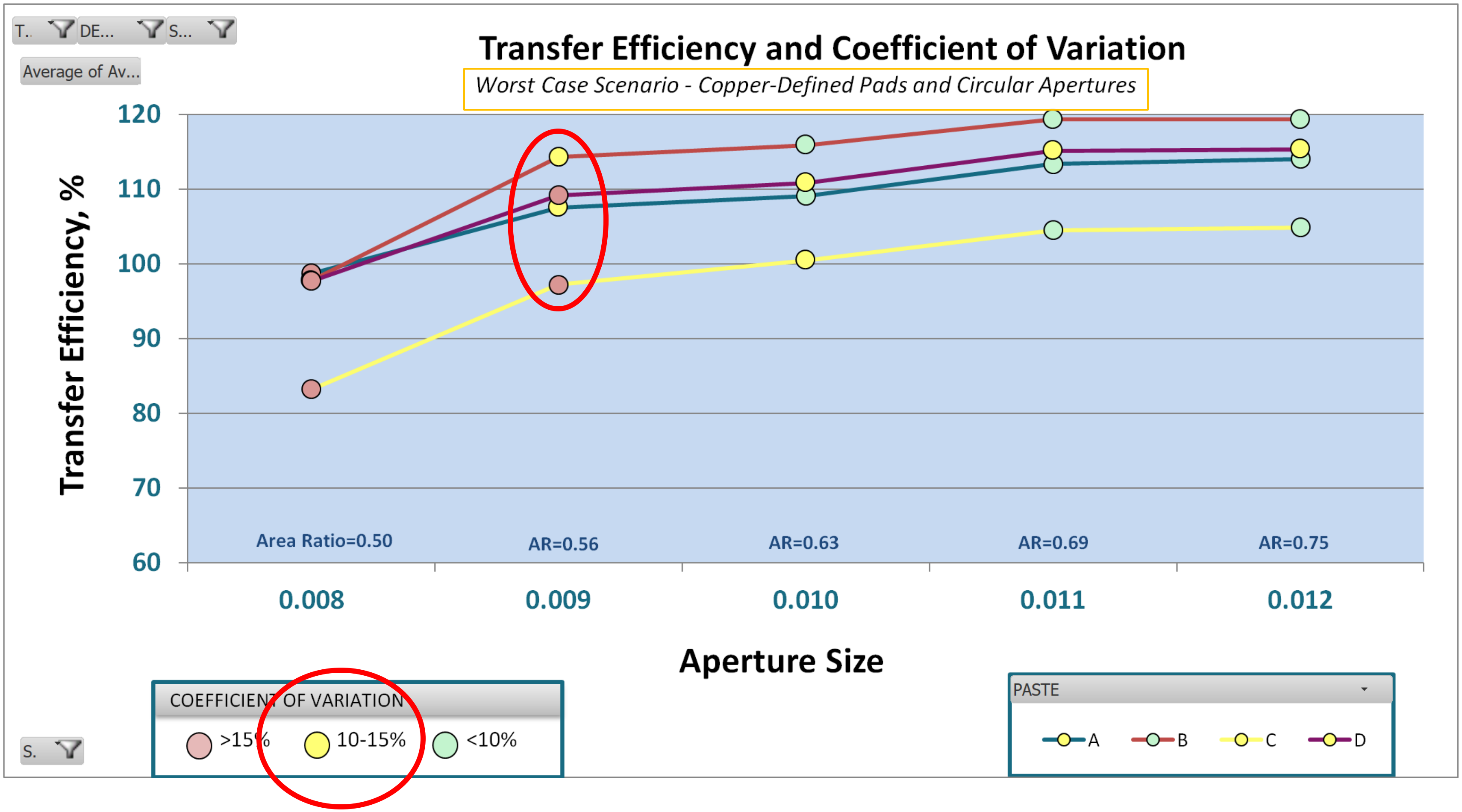
Edge of Process Window

Where variation exceeds 10%



Edge of Process Window

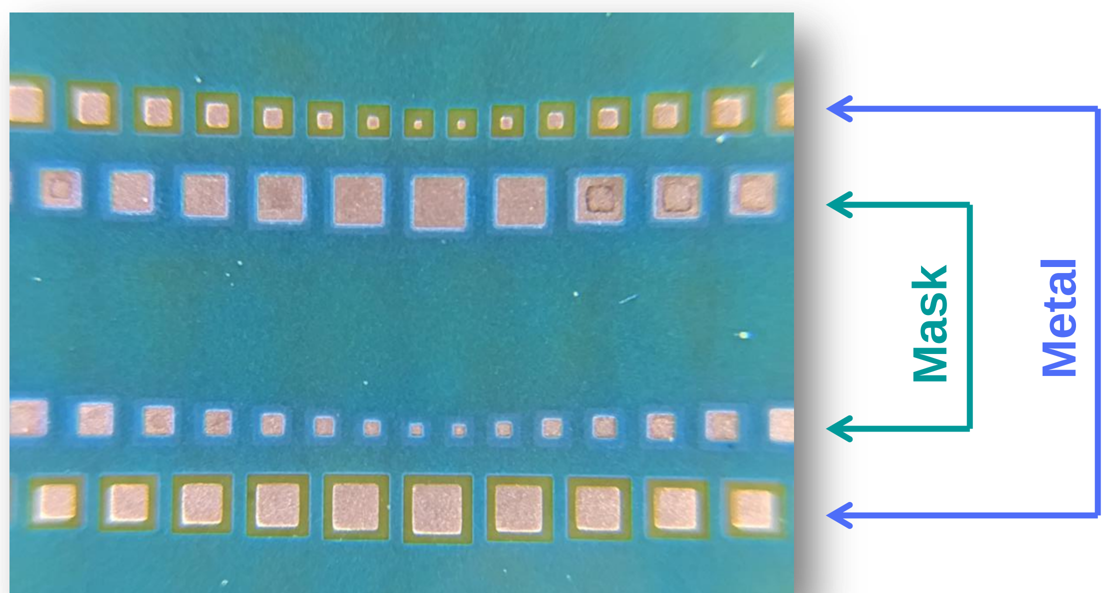
Where variation exceeds 10%



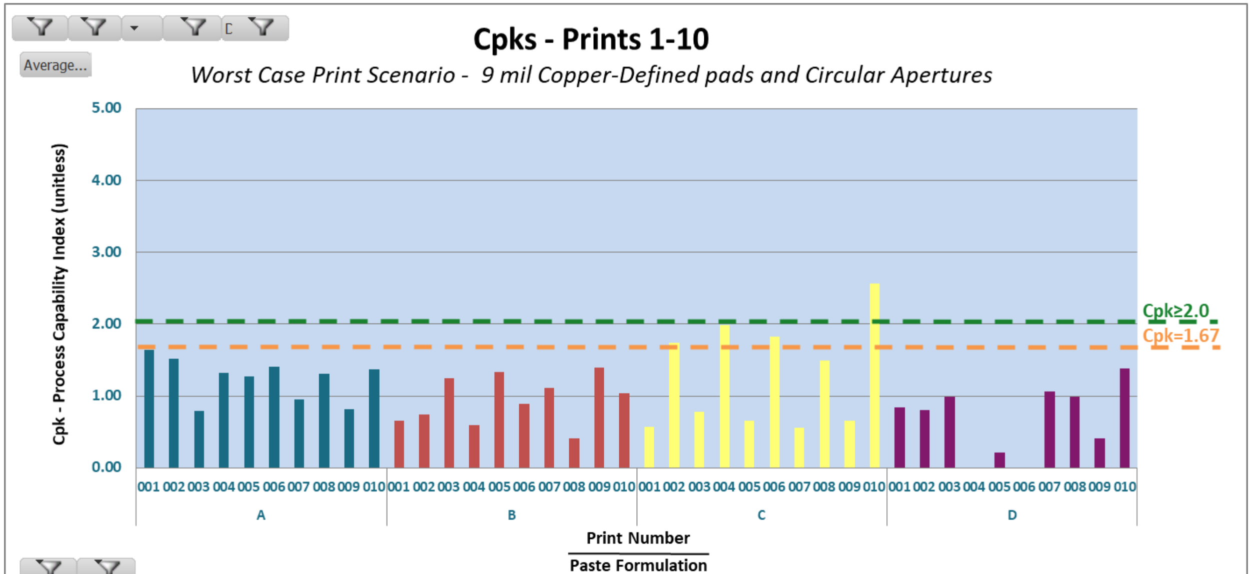
Best and Worst Cases

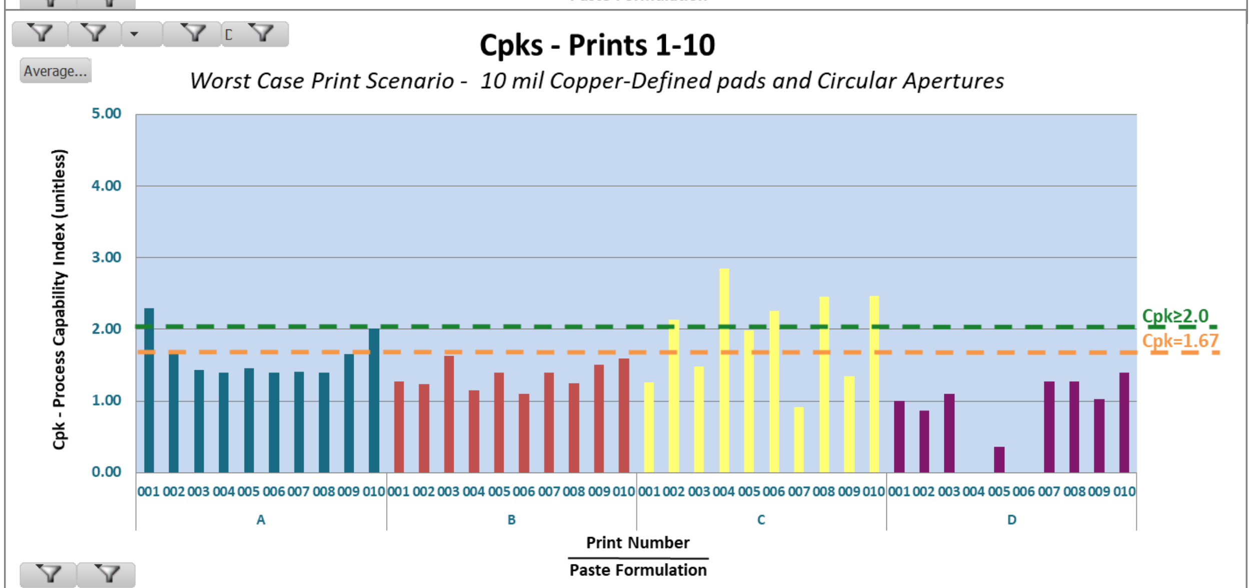
- Round, metal defined pads are the most difficult to print
  - **Edge of window at 9 mil (AR=0.56) to 10 mil (AR=0.63)**
- Square, mask defined pads are the easiest to print
  - **Edge of window at 8 mil (AR=0.50)**
- Round, mask defined and square, metal defined always fall somewhere in the middle

There's a DFM lesson here…
Use mask defined pads on the small stuff!



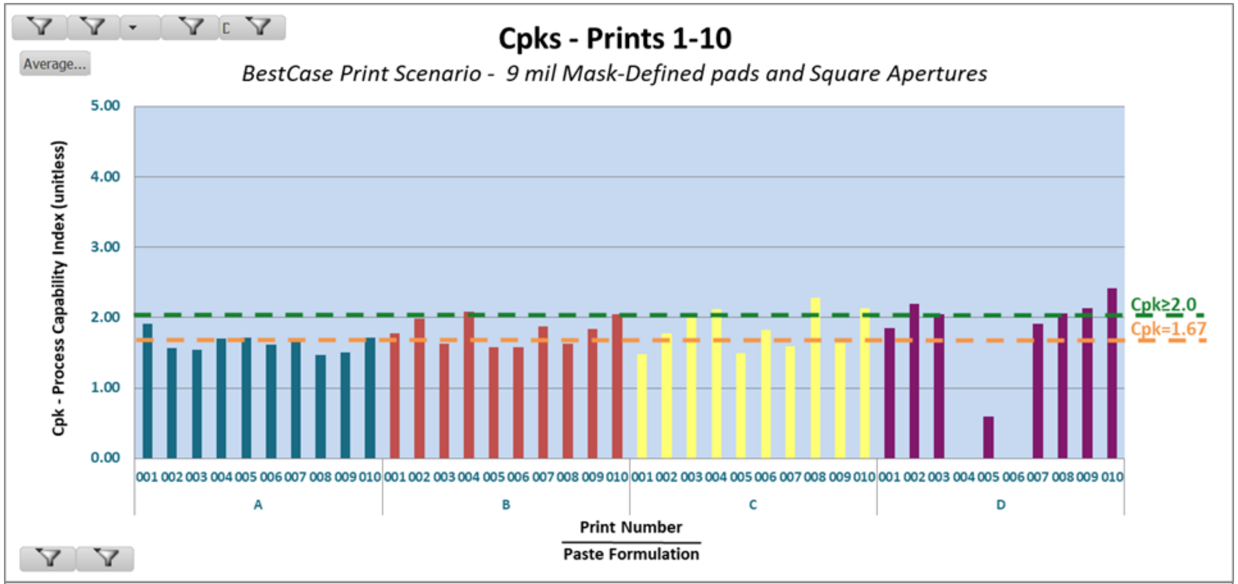
Cpk Values at Edge - Worst

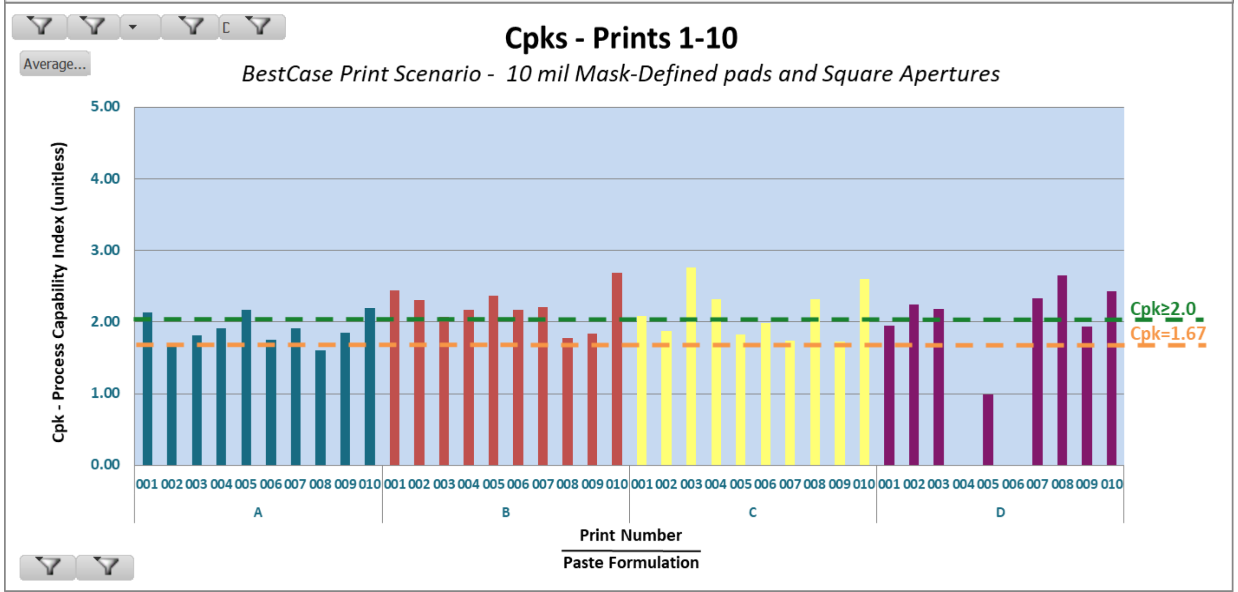




Another DFM note:
Big capability jump from 9 mil to 10 mil

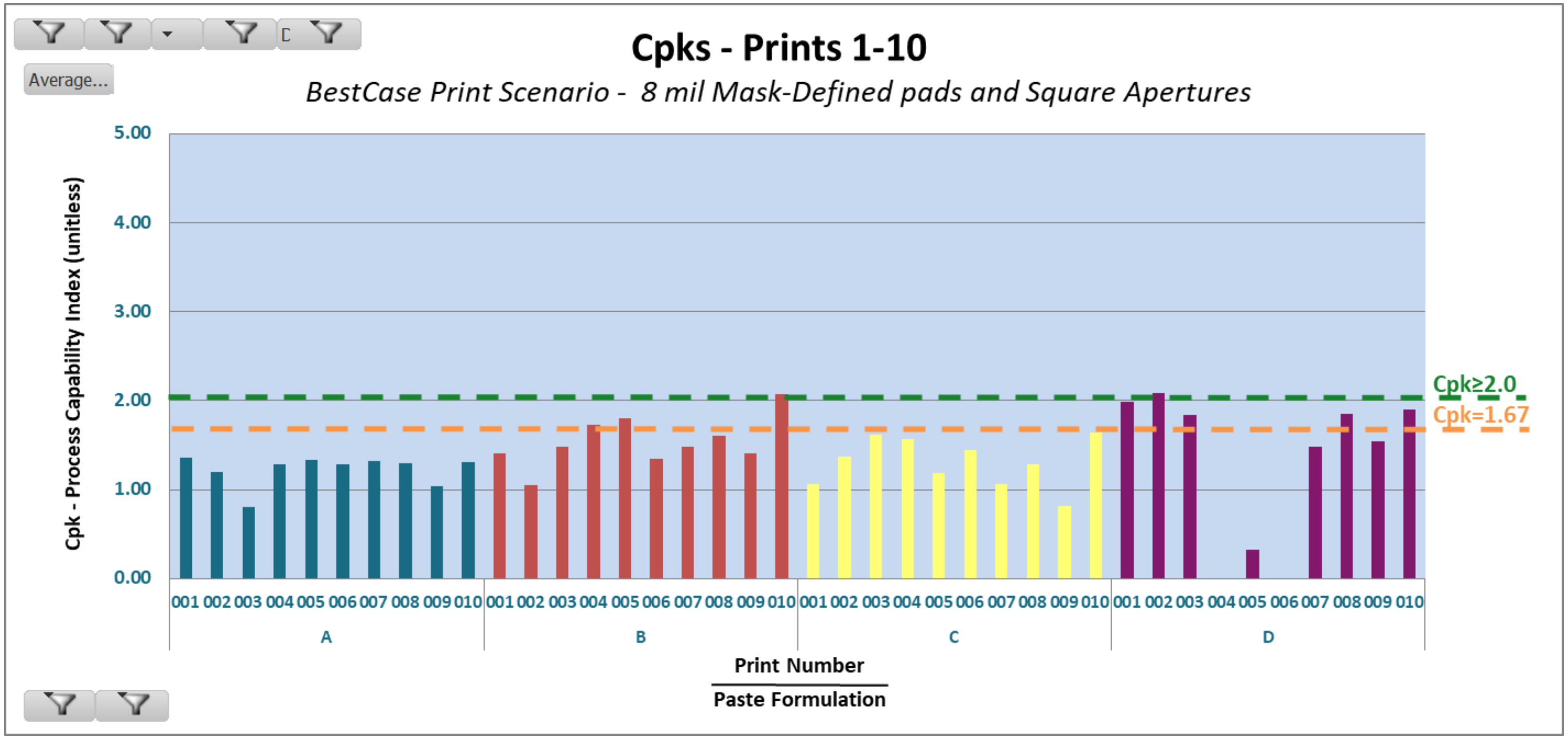
Cpk Values at Same Size - Best





Data behind DFM note: Mask defined works great at edge of metal defined window

Cpk Values at Edge - Best

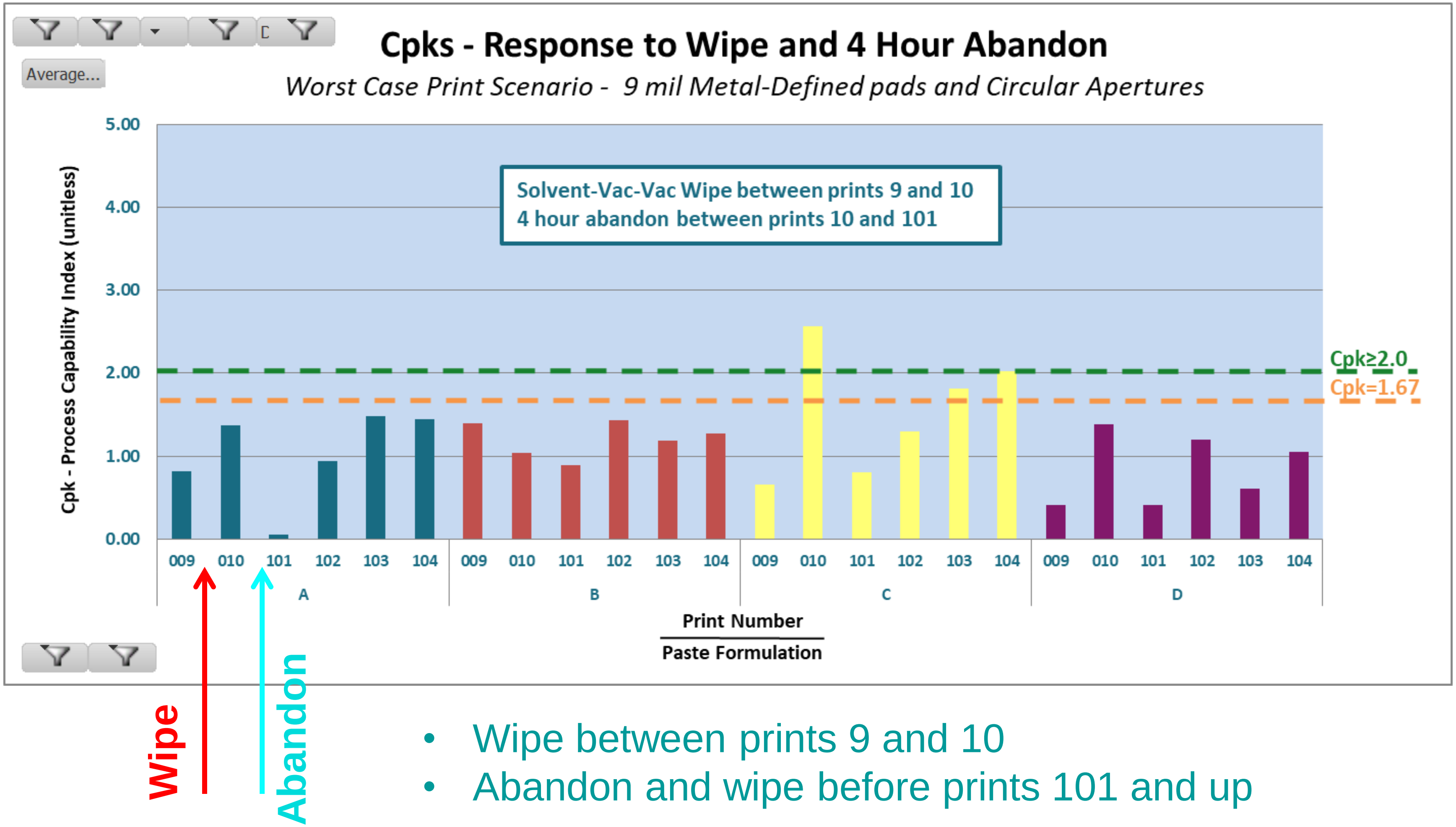


- 8 mil square, mask defined prints better than 9 mil round, metal defined
- Paste B is still printing pretty respectably
- Paste A is very consistent

Observations

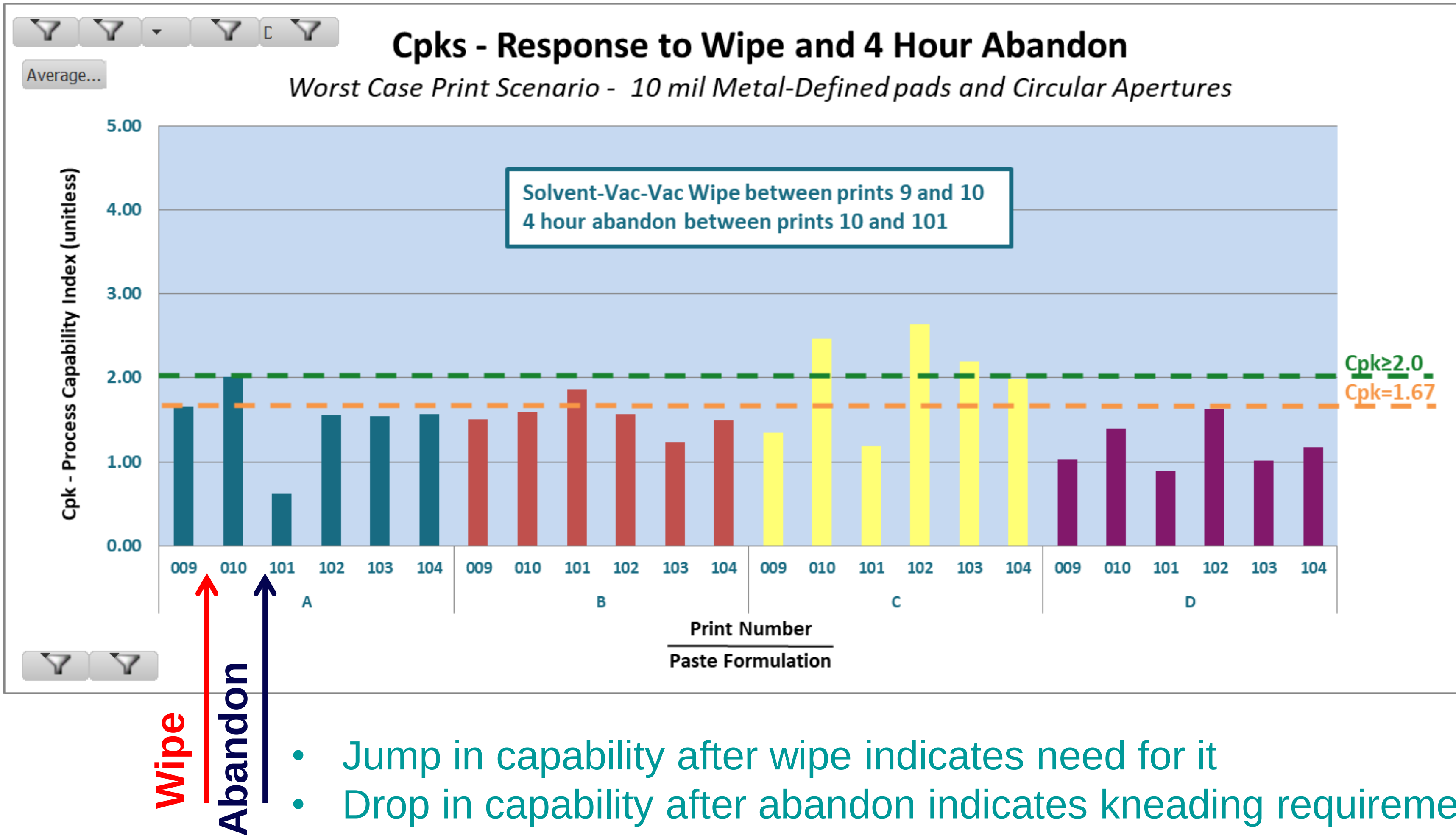
- Paste D had negative Cpks on boards 4 and 6 because their means fell below the lower specification limit of 50% aperture volume.
- Paste C showed far more inconsistencies on the metal-defined pads.
- On the more challenging circular pad stacks, Paste A had higher Cpks than Paste B, but Paste B had higher release and similar variation. *Because both released over the target value of 100%, the higher release is farther from the center of the process window and therefore has a lower Cpk.*
- Paste B consistently released more than Paste A regardless of pad and aperture design, but statistically, they were both equally consistent in the spread of the data.

Wipe and Abandon Sensitivity



- Wipe between prints 9 and 10
- Abandon and wipe before prints 101 and up

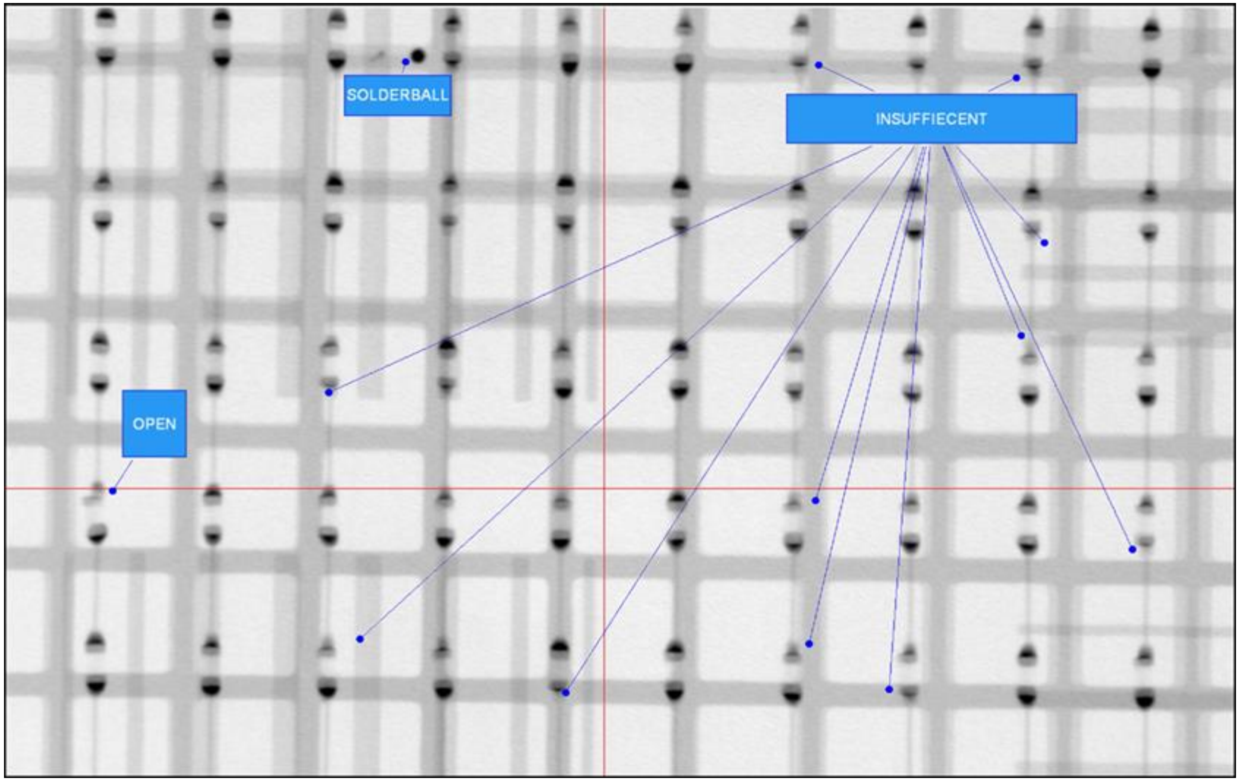
Wipe and Abandon Sensitivity



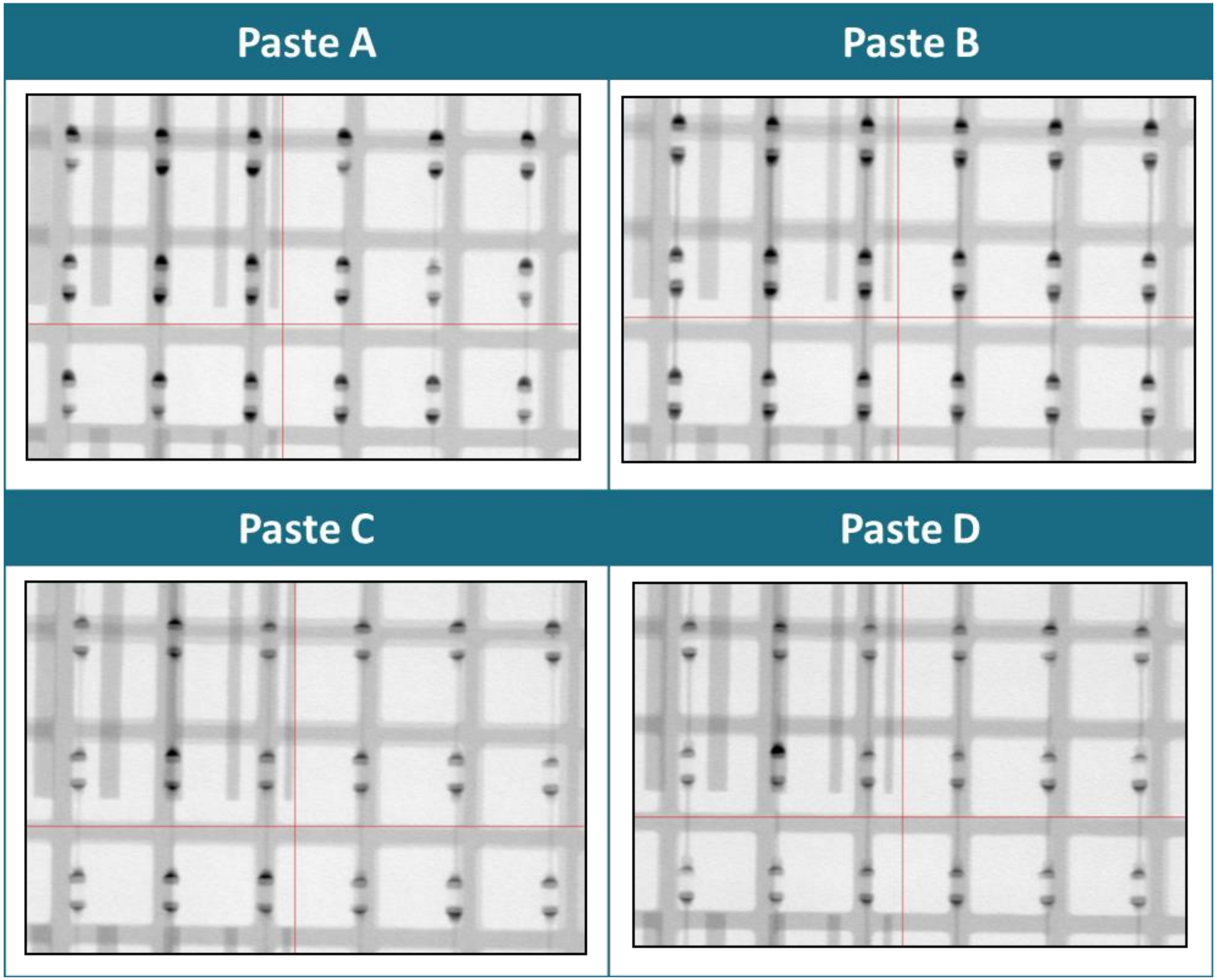
- Jump in capability after wipe indicates need for it
- Drop in capability after abandon indicates kneading requirement

01005s

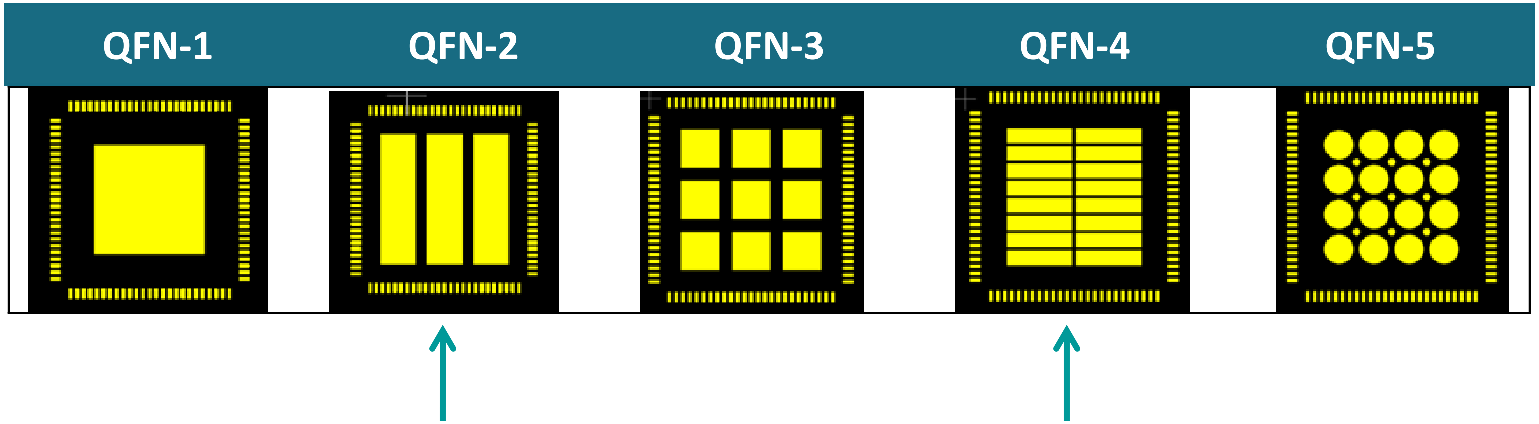
- Solder deposits too small to effectively measure without SPI upgrade
- Can qualitatively judge deposition by viewing X-ray images



01005 X-rays

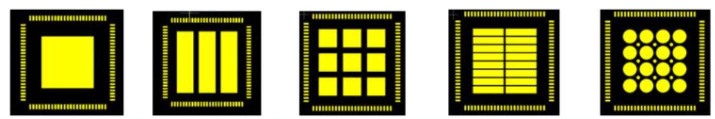
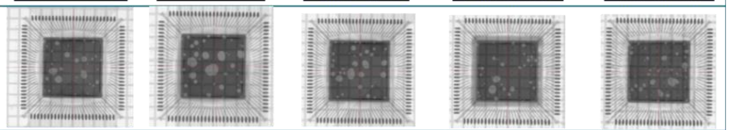
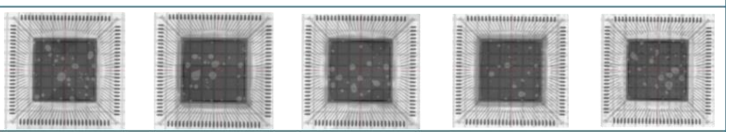
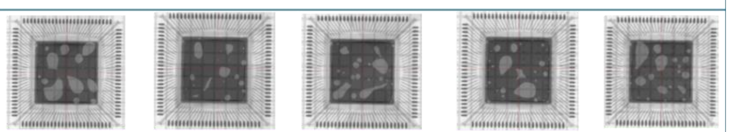
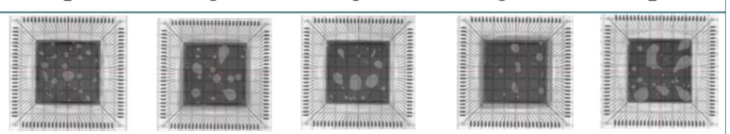


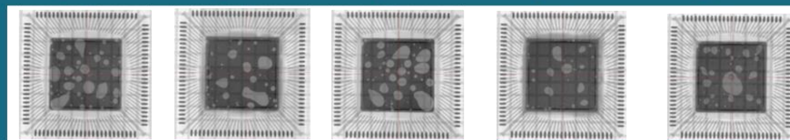
Reflow Tests – QFN Voiding



- Five different ground pad designs
- 2 assemblies populated and X-rayed per paste
- Lowest voiding aperture designs are QFN-2 and QFN-4

Voiding Analysis - Qualitative

	QFN-1	QFN-2	QFN-3	QFN-4	QFN-5
Aper-ture Design					
AH002					
Rank	8	6	7	8	8
AH003					
Rank	8	8	8	8	7
BH002					
Rank	1	8	5	3	2
BH003					
Rank	6	3	6	6	1

	QFN-1	QFN-2	QFN-3	QFN-4	QFN-5
CH002					
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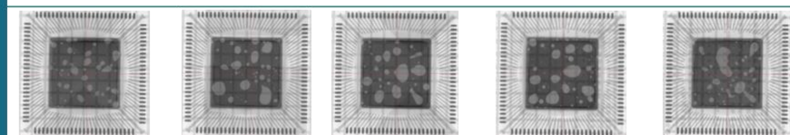
CH003					
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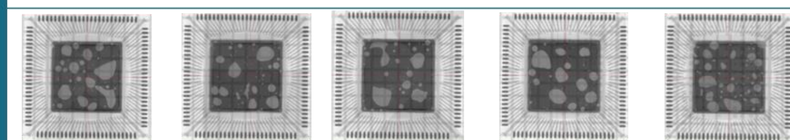
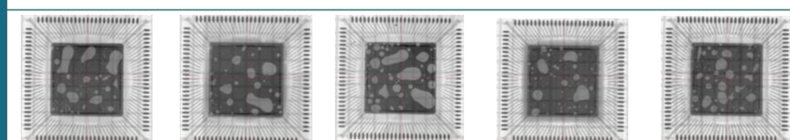
DH002					
Rank	2	2	4	2	3
DH003					
Rank	1	5	1	4	4

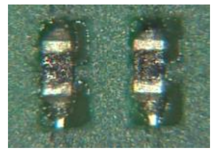
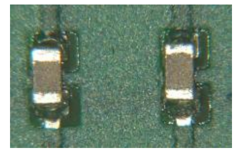
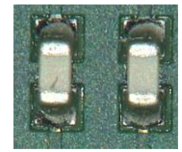
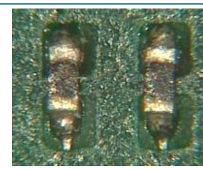
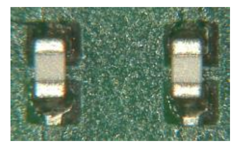
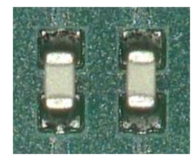
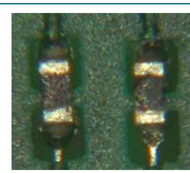
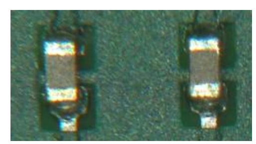
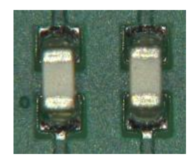
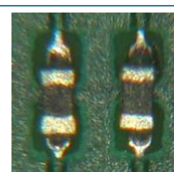
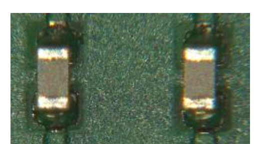
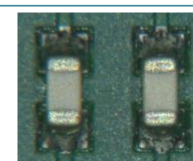
Voiding Analysis - Quantitative

Paste	Pattern	Void %	# Voids	Avg Void Size
A	1	9.6	53	0.2
	2	15.7	50	0.3
	3	12.8	52	0.2
	4	8.1	52	0.2
	5	10.6	57	0.2
Average		**11.36**	**52.8**	**0.22**
Rank		**4**	**4**	
B	1	27.9	14	2
	2	10.3	19	0.5
	3	17.4	28	0.6
	4	15.6	34	0.5
	5	21.7	26	0.8
Average		**18.58**	**24.2**	**0.88**
Rank		**3**	**2**	
C	1	22.6	45	0.5
	2	18.4	51	0.4
	3	29.9	47	0.6
	4	10.3	29	0.4
	5	20.1	37	0.5
Average		**20.26**	**41.8**	**0.48**
Rank		**2**	**1**	
D	1	24.3	98	0.2
	2	18	65	0.3
	3	34.1	84	0.4
	4	15.3	90	not shown
	5	21.6	76	0.3
Average		**22.66**	**82.6**	**0.3**
Rank		**1**	**3**	

BEST

WORST

Reflow – Coalescence and Graping

Paste	01005	0201	0402
A			
Comment/ Rank	Propensity for graping on 01005 and some 0201		Graping: 1 Wetting: 2 Appearance: 2
B			
Comment /Rank	No evidence of graping on 01005; nice cosmetics on 0201,		Graping: 4 Wetting: 4 Appearance: 4
C			
Comment /Rank	Overall very good reflow, slight propensity for graping on 01005, but less than A		Graping:3 Wetting: 3 Appearance: 3
D			
Comment /Rank	Minor evidence of graping, wetting not great, poor cosmetics on 0402, some solder beads		Graping: 2 Wetting: 1 Appearance: 1

Visual Inspection

Nagging Issues

- Side-mount LEDs floating and skewing
  - Mounted on 1206 pads
  - None found with any of the test pastes
- Mid-chip solder balls on 0201
  - Recent aperture change improved situation
  - No mid-chip balls on 0201s with either new aperture or suggested one from paste supplier
- AOI programs found no missing, skewed, tombstoned, tilted or misplaced parts on the 0201 or larger components
- No signs of spatter, wetting or coalescence issues on unpopulated boards

Testability

- Residues of all pastes were visually reviewed by test engineering
  - None were rejected based on initial appearance and a flying probe test was planned
- Paste D was disqualified for compromised performance and Paste A was disqualified for poor reflow
  - Field is narrowed to two, with paste B being heavily favored
  - No need for flying probe comparison
- Paste B will be introduced to production and test fixture maintenance will be monitored and adjusted accordingly
  - May be more or less frequent

Cleanability

Discussion with cleaning chemistry provider

- All candidate solder paste residues are compatible with current chemistry
  - Easy to implement; familiarity with product
- Supplier provided reports on internal tests with all candidates
- Concentration may need tweaking, depending on which candidate is chosen

Score Card

Weighting key:
10- critical
7.5-Very Important
5-Important
2.5-Less Critical/ Important
1-not Critical

Rank Order
4=Best
1=Worst

Solder Paste Score Card - Rank Order for Each Solder Paste Characteristic

Weight %		Category	Paste A	Paste B	Paste C	Paste D	Criteria	Comments
		Printability						
30	10	Volumes	3	4	2	1	TE and CV, Cpk	Volumes of 8-12 mil features
	10	Heights (peaking)					TE and CV, Cpk	Heights on QFN I/Os
	5	Wipe frequency requirements	2	4	1	3	Compare Cpks before and after wipe	9 prints
	2.5	Recovery from Abandon Time	3	4	2	1	Compare Cpks before and after abandon	4 hours
	2.5	Slump					Compare prints pattern before and after 20 min	Cold - room temp; Hot - 185°C
		Weighted Category Results	*47.5*	*70*	*30*	*27.5*		
		X-Ray/Voiding						
25	5	Visual - rank order	4	3	2	1	<30% (IPC), the smaller the better	Average for all gnd pad patterns for each paste, but check each design for BIC
	10	Voiding %	4	3	2	1	The fewer the better	
	10	Void Size/Count	4	2	1	3	The smaller the better; more small ones better than one big one	
		Weighted Category Results	*100*	*70*	*50*	*60*		
		Reflow/AOI on chips						
41	10	Coalescence / Graping	1	4	3	2	Presence and amount of graping on 01005	Visual
	10	Wetting	2	4	3	1	Angle and height on terminations, pad spread	Visual
	5	Appearance	2	4	3	1	Residue, reflectivity, inspectability	Visual
	10	Defects	3	4	2	1	Total quantity	AOI
	5	Solder balls (maybe)	4	4	4	4	Total quantity	
	1	False Call	0	0	0	0	Total quantity	AOI
		Weighted Category Results	*90*	*160*	*115*	*65*		
7.5		**Testability**						
	7.5	Residue effect on test fixture	tbd	tbd	tbd	tbd	Test Engineering to rank order based on their physical review of residues	
		Weighted Category Results						
		Cleanability						
20	10	Solvent Compatibility	4	4	4	4	1) ionograph - Pass/Fail (averages ionic contamination over entire board)	
	10	Solvent Compatibility	tbd	tbd	tbd	tbd	2) ion chromatography under QFN - Pass/Fail	looks specifically under the low standoff components
		Weighted Category Results	*40*	*40*	*40*	*40*		
		Supplier and Value Proposition						
29.5	5	Price per Gram (10,000gr. / yr base)	3	4	3	3	Cost per gram based on 10,000 gr. Break	
	5	Distribution/ Supply Chain	4	4	3	3	Local Distributor channels to maintain inventory-	
	5	Technical Support	4	4	4	3	Technical Support Resonse/ access ability/ resources	
	1	Shelf Life/ Storage	3	3	4	4		
	1	Reclaim Services	4	4	3	4	Available reclaim with cost recovery	
	10	Compaitibility w/ under stencil chemistry	4	4	4	4	Flux dissolution into current chemistry for under stencil cleaning	
	2.5	Lead version available same flux vehicle	4	4	4	4	Lead and lead-free have same flux vehicle	
		Weighted Category Results	*112*	*117*	*107*	*103*		

Total points
153

	Paste A	Paste B	Paste C	Paste D
OVERALL WEIGHTED TOTAL:	**390**	**457**	**342**	**296**
Normalized on 1-4 scale (4=best)	**2.5**	**3.0**	**2.2**	**1.9**

Best Paste for this Operation

Conclusions

Performance difference among pastes demonstrates the tradeoffs in solder paste selection:

- Paste A had a fatal flaw in reflow
  - Very good at print transfer and repeatability
  - Extremely low voiding
  - Poor reflow performance – excessive graping on 01005s
  - Poor recovery after abandon time
- Paste B was the overall top performer
  - Best at print and reflow
  - Above average at voiding
  - No sensitivity to wipe frequency or abandon time
  - Excellent for low- to medium-volume manufacturing

Conclusions

- Paste C printed well
  - Very consistent with the best repeatability
  - Release properties weren’t as good as two other pastes
  - Voiding was average
  - Reflow was good
  - Weak spots: under wipe sensitivity and abandon time
  - Overall it is a good general purpose solder paste because while it does not excel in any particular area, it has no fatal weaknesses
- Paste D appears to be compromised from the beginning
  - Extremely bad print and reflow properties
  - Below average voiding performance
  - Extremely uncharacteristic of a top tier solder paste

Cost Sensitivity

Solder paste qualifications can be costly and lengthy

- Test vehicle boards, stencils and component inventory
- Line time, labor and lost revenue opportunity
- Compatibility with other processes and chemistries
- Cost differential between incumbent and new products – will the upgrade be worth it?

Cost Sensitivity

Considerations

- Low cost PCB – test boards <$10 with lots of tests and significant sample sizes designed in
- Low cost BOM – options to save $ by not fully populating all components
- Minimal number of runs to extract maximum information by nesting tests in execution order (wipe, abandon, etc)
- Fast, easy data collection and analysis

Lessons Learned – Printing/Testing

- Mask defining small pads makes them far more printable
- Can extend lower end of process window to AR= 0.56 with T4 solder paste and no nanocoating
- Visual comparison of X-ray images concurred with quantitative results
- 01005 solderability easy to see with X-ray

Lessons Learned – PCB Test Kit

- Reduce Cost – reduce layer count
- Remove silkscreen
- Use the open real estate
- Add Go/No Go indicator
- Generate true CAD files for easy programming
- Integrate BOM into ODB++ file
- Name the PTFs
- Pre-design stencil and board support
- Generate SPI programs
- Create a configurator that calculates BOM cost and sample sizes and creates BOM

Questions

- ??

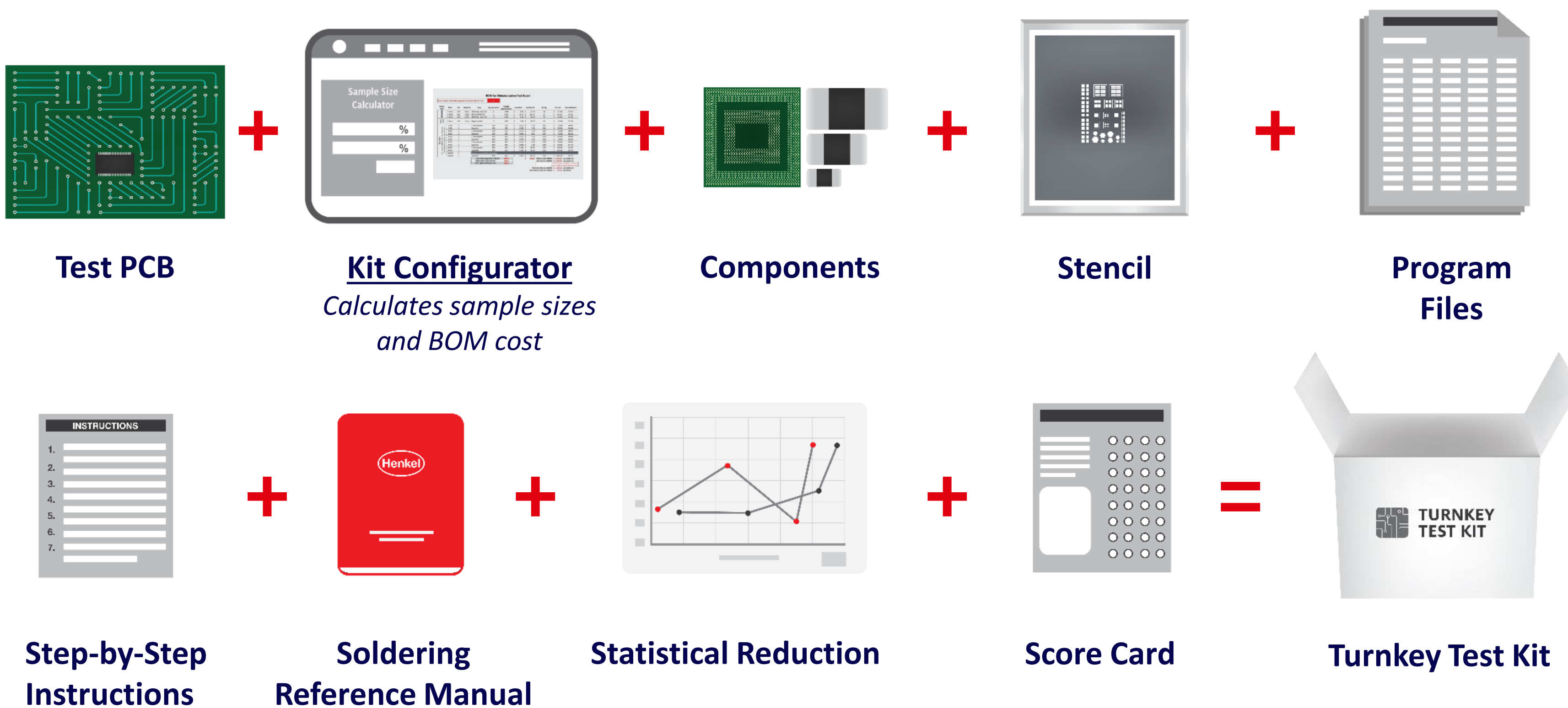
Great News!

- The next revision of this test board will carry the

SMTA

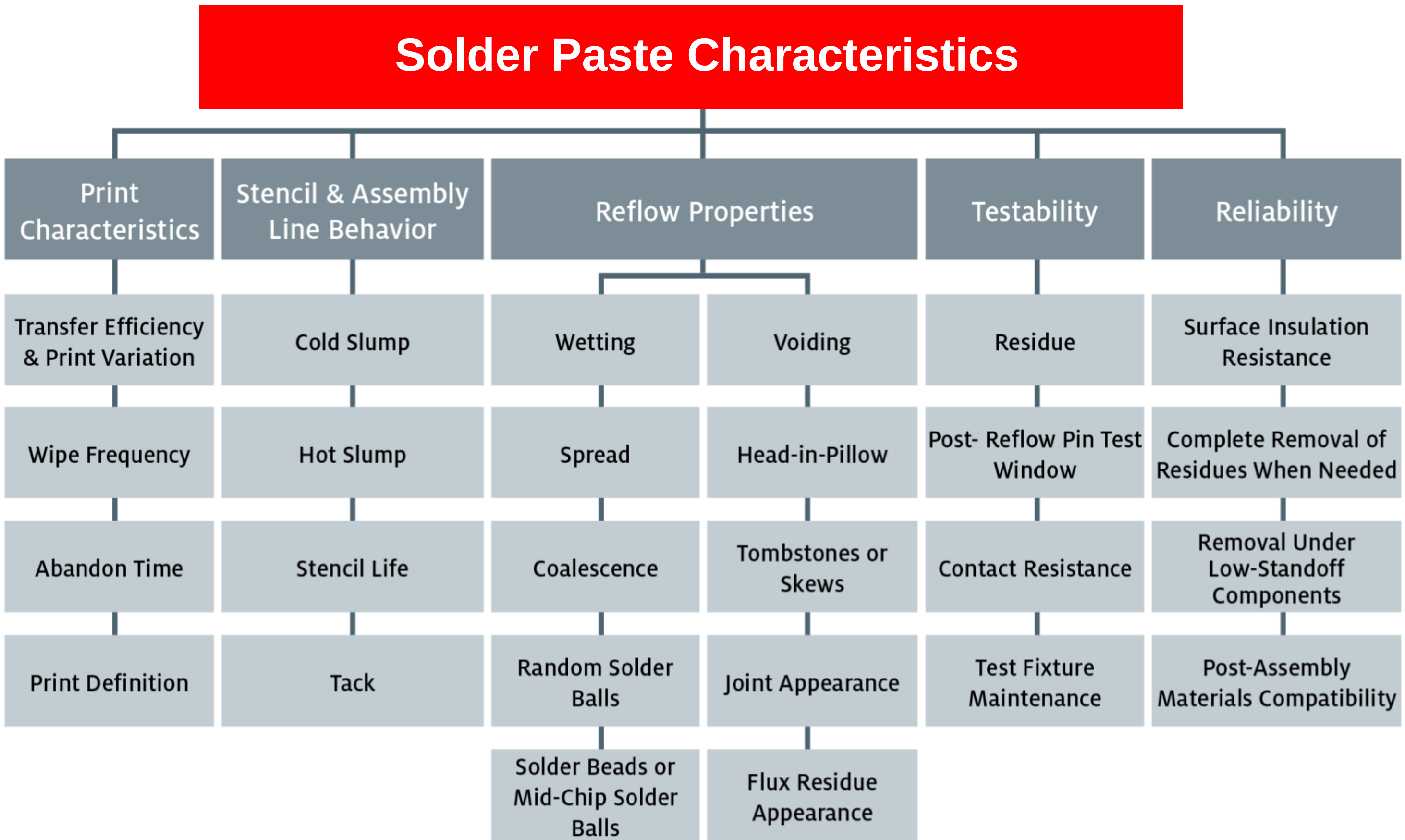
logo and the complete kit should be available through Practical Components by the end of 2Q18!

Miniaturization Test Kit



Hardware can be purchased; documentation can be downloaded for *FREE*

Solder Paste Characteristics



Solder Paste Characteristics (1of 5)

CATEGORY/ PASTE PROPERTY	IMPACT ON SMT PROCESS	HOW TO TEST	TEST CRITERIA
Print Characteristics			
Transfer Efficiency & Print Variation	• Insufficients, opens, bridges, solder balls, HIP, frequent wiping	1) Print solder paste and measure deposits with automated SPI 2) Analyze: • Volumes of small deposits • Areas • Heights of rectangular deposits • Positional offsets	Cpks using standard +/- 50% spec limits • Volumes: higher is usually better • Areas: higher is usually better • Heights: • < stencil thickness: higher is usually better • > stencil thickness, lower is often better
Wipe Frequency	• Solder defects, excessive use of consumables, line downtime during wipes	1) Analyze print statistics on 10 print test 2) Print 8 boards, wipe 3) Compare Cpks between prints 8 and 9	• Cpk pre-wipe vs. Cpk post-wipe in both print directions
Abandon time	• Poor quality first print • Requirement to knead paste before returning to production and clean/dry/ reuse PCB	1) Determine typical abandon time to test, usually 2-4 hours 2) Measure deposits with SPI	• Cpk pre-abandon vs. Cpk on first print post-abandon • Number of prints needed to return to steady state process
Print Definition	• Solder Defects, frequent wiping	Compare to visual scale *Often used when SPI is not available*	• Subjective observation: visual scale grades deposit appearance from 1-5

Courtesy Henkel Corporation

Solder Paste Characteristics (2 of 5)

Stencil & Assembly Line Behavior			
Cold Slump	• Bridges, random solder balls	IPC or proprietary slump patterns 1) Print, place in ambient environment for 20 minutes 2) Read pattern again visually or with SPI	• Visual: Smallest gap to bridge • Quantitative: Ratio of deposit area SPI readings before and after 20 minute wait
Hot Slump	• Bridges, HIP, Insufficents on PTH, solder buildup in oven from PTH drips	IPC or proprietary slump patterns 1) Print, place in oven at 182°C for 20 minutes 2) Read pattern again visually or with SPI	• Visual: Smallest gap to bridge • Quantitative: Ratio of deposit area SPI readings before and after 20 minute wait
Stencil Life	• Solder Defects, frequent wiping	1) Cold slump after extensive print or knead strokes and/or environmental conditioning 2) Print quality before and after extensive knead/environmental conditioning	• Visual: Smallest gap to bridge • Quantitative: Ratio of deposit area SPI readings before and after 20 minute wait • Cpk pre- and post-knead or exposure
Tack	• Positional errors on components, tombstones, solder balls, missing or transient components	1) Hold printed PCB for a period of time before placing and reflowing	• Quantitative: AOI or End of Line number and type of defects

Courtesy Henkel Corporation

Solder Paste Characteristics (3 of 5)

Reflow Properties			
Wetting	• Insufficients, opens, tombstones, solder balls, skews, non-wets, HiP, perceived voiding	1) Print test patterns with different coverage on substrate and examine wetting on 10x10 mm pad 2) Assemble PCB with known difficult-to-wet components and inspect solder joints	• Visual inspection: Wetting to PCB pads, spatter, wetting to components • Rank order in performance
Spread	• Insufficients, opens, solder balls	1) Print solder paste on exposed traces with increasing gaps between the paste deposits and observe the distance of the gaps that bridge closed in reflow	• Largest gap to flow closed on each trace
Coalescence	• Solder balls, graping, poor pull back on over prints	1) Print deposits of varying sizes onto small round pads on FR-4 substrate and reflow	• Visual: Inspect for coalescence and rate as Preferred, Acceptable or Unacceptable as IPC standards apply to ceramic substrate
Random Solder Balls	• May require manual removal	1) Print, populate and reflow PCB 2) Inspect for random solder balls, or satellites, near overprinted pads, around the leads of fine pitch devices or in random locations on the PCB 3) Check gold fingers, if applicable	• Quantitative: the number of balls larger than the smallest gap between conductors on the assembly, or, the assembler's or customer's internal specification
Solder Beads or Mid-Chip Solder Balls	• May require manual removal	1) Print, place and reflow small chip components 2) Inspect for solder beads visually or with X-ray	• Quantitative: Number of balls larger than the smallest gap between conductors on the assembly, or, the assembler's or customer's internal specification
Voiding	• Poor thermal heat sinking or electrical gounding on BTC, potentially weaker solder joints	1) Print, place, reflow, X-ray. 2) Analyze for: • Overall Void % • Number of voids	• Quantitative • < 30 % or customer specification • Lower is better

Solder Paste Characteristics (4of 5)

Reflow Properties			
Voiding	• Poor thermal heat sinking or electrical gounding on BTC, potentially weaker solder joints • Expensive and risky rework	1) Print, place, reflow, X-ray. 2) Analyze for: • Overall Void % • Number of voids • Average void size (%)	• Quantitative • < 30 % or customer specification • Lower is better *Note: For any overall void %, more, smaller voids are generally preferable to fewer, larger voids*
Head-in-Pillow (HIP)	• Expensive rework, scrap or warranty returns	1) Print, place and reflow BGAs 2) Inspect with X-ray	• Quantitative: Defect count
Tombstones or Skews	• Defect that requires rework. • Risk of defect increases as package size decreases	1) Print, place and reflow small chip components 2) Inspect visually or with AOI	• Quantitative: Defect count
Joint Appearance	• Inspection time and accuracy	1) Inspector-dependent based on wetting angle, flux residue, shine, other *Can be highly subjective*	• Visual grade among inspectors or rank order • Quantitative: False fails at AOI if applicable
Flux Residue Appearance	• Inspection time and accuracy • Customer perception	1) Inspector-dependent based on color, clarity and consistency *Can be highly subjective*	• Visual grade among inspectors or rank order • Quantitative: False fails at AOI if applicable

Solder Paste Characteristics (5 of 5)

Testability			
Residue Probe-ability Brittle or Ductile	False Fails & Retests ($)	Visual and tactile assessment Probe-ability testing if available	• Rank order the assessments • Quantitative if probe-ability testing
Post-reflow pin probe window	Easy-to-probe residues can become difficult to probe after a certain period of time False Fails and Retests ($)	Number of days in test window	• Minimum set by assembler • Rank order or pass/fail
Contact Resistance	False Fails & Retests ($)	Resistance measurements	• Quantitative: track resistance over period of days
Test Fixture Maintenance	False Fails & Downtime for maintenance	Evaluation by Test Engineering & Operations	• Quantitative: Number of points probed between required maintenance • Subjective: technician assessment

Reliability			
Surface Insulation Resistance (SIR)	• Post-SMT dendritic growth • Field failures and warranty returns	1) 3rd party verification in SIR chamber	• Quantitative: MUST pass with resistance > 10^8 Ohms per J-STD-004B
Complete Removal of Residues	• Dendritic growth, field failures, warranty returns	1) Resistivity of Solvent Extract (ROSE) - internal process tests the overall cleanliness of the wash/rinse water but not in specific areas of the PCB	• ROSE tester (ionic contamination) <6 µg NaCl equivalent per $inch^2$
Complete Removal *Under Low-Standoff Components*	• Dendritic growth, field failures • Very important but often difficult to achieve	1) Ion chromatography (IC) – quantitative, focused, conclusive test on cleanliness of the assembly under low standoff components	• Quantitative: IC under low standoff components. • Various ionic species have different allowable maximums
Post-Assembly Materials Compatibility	• Improper flow or cure of underfill, potting or conformal coating materials • Field failures and warranty returns	1) Various inspection methods: acoustic, X-ray, UV fluorescence or others depending on the material 2) Accelerated Life Testing (ALT) for high reliability products	• Complete flow, encapsulation and cure • No longer term interactions between the materials • Pass ALT

New Score Card

SMTA
Surface Mount Technology Association

Notice the new logo!

Weighting key:
10- critical
7.5-Very Important
5-Important
2.5-Less Critical/ Important
1-not Critical

Ranking:
4 - Best
1 - Worst
In case of tie both get equal rank and next one drops
(eg. 4,3,3,1)

Solder Paste Score Card - Rank Order for Each Solder Paste Characteristic

Note: the numbers in red are examples of user input

Weight		Category	Paste A	Paste B	Paste C	Paste D	Criteria	Comments
		PRINTABILITY						
	10	Transfer Efficiency and Variation - Cpk					Cpk - goal is >2.0; >1.66 is also acceptable	Volumes of 8-12 mil features (AR 0.50 to 0.75)
	5	Wipe frequency requirements					Compare Cpks before and after wipe	8 prints before wipe; 2 (or 12) prints after
	2.5	Recovery from Abandon Time					Compare Cpks before and after abandon	Cpk post-abandon *and* number of prints required to return to steady state
33.5	2.5	Print Definition (peaking or dog ears)					Average heights or visual scale	Heights on QFN I/Os at comparable Transfer Efficiencies or Visual Scale if no SPI
	1	Cold Slump					IPC or alternate patterns	Visual or SPI 20 minutes after printing (ambient)
	2.5	Hot Slump					IPC or alternate patterns	Visual or SPI 20 minutes after printing (182 C)
	5	Stencil Life					Cpk before and after 2 hour shear down	Cpk post-shear, also visual assessment of print definition
	5	Tack					Part locations on board held prior to placement	Needed for XY movement and transport of PCBs, pre-reflow AOI is helpful
		Weighted Category Results	*0*	*0*	*0*	*0*		
		REFLOW						
	7.5	Wetting					Wetting test on copper pad or wetting to components	Wetting and spread are different
	2.5	Spread					Spread test on copper traces	A component can wet but not spread, however, it will not spread if it doesn't wet
	5	Coalescence/graping					Assessment of joint surface, solder ball test	Smaller features more likely to grape, larger overprints less likely to coalesce
	7.5	Random solder balls					Total quantity violating solder ball criteria	IPC - not large enough to bridge the smallest I/O conductor gap on the PCB
	5	Solder beads or mid-chip solder balls					Total quantity violating solder ball criteria	*or* alternate criteria set by assembler or OEM
77.5	10	Voiding					Void % (typically <30%) and total number of voids	Usually, more smaller voids are preferable to fewer larger voids for any overall %
	10	Head-In-Pillow					# of defects found at X-Ray	Multi-chip packages show non-traditional warpage and HiP locations
	10	Tombstones/skews/positional errors					IPC Class 1, 2 or 3 defects or alternate criteria	Product dependent
	7.5	Joint Appearance					Wetting angle, reflectivity, ease of inspectability	Very subjective based on inspectors' eyes, example photos are important
	5	Flux Residue Appearance					Amber or clear, brittle or sticky, spread	Subjective but example photos are very important
	7.5	Compatiblity with current AOI					# of false calls	Too many false calls can require tweaking parameters for all production programs
		Weighted Category Results	*0*	*0*	*0*	*0*		
		TESTABILITY						
		Residue probe-ability					Visual or tactile; flying probe if available	Residues should comply but not shatter
0		Post-reflow pin probe time window					Number of days before false fails occur	Depends on paste, heat exposure, reflow environment, ambient environment
		Contact resistance					Resistance measurements	Initial, and track increase over days after reflow
		Test Fixture Maintenance					Test Engineering analysis or assessment	Can be subjective
		Weighted Category Results						
		RELIABILITY						
		Surface Insulation Resistance					>10^8 Ohms per J-STD-004B	3rd party verification in SIR chamber
0		Complete removal of residues					ROSE, <6 ug NaCl equiv/sq in, or Ion Chromatography	ROSE tests overall wash process; IC tests in specific areas
		Residue removal under low-standoff					Ion Chromatography	Upper limits vary by product and test method
		Post-assembly materials compatiblity					Specific to post-assembly process	Underfill, conformal coating, potting
		Weighted Category Results	*0*	*0*	*0*	*0*		
		SUPPLIER RATING AND VALUE PROPOSITION						
		Distribution/ Supply Chain					Local distribution channels to maintain inventory	2 different lots always available
		Technical Support					Tech support: responsiveness, accessability and resourc	Support during trials indicates capabilities
0		Shelf Life/ Storage Conditions					Assmembler sets criteria	WS shorter shelf life than NC. Some need refrigeration and others don't.
		Reclaim Services					Reclaim availability	Very important if wave soldering
		Compaitibility w/ under stencil chemistry					Flux dissolves in current chemistry for under wipe	IPA is not compatible with all NC lead-free pastes
		Lead version available same flux vehicle					Lead and lead-free have same flux vehicle	If using both alloys, both pastes would have similar print properties
		Weighted Category Results	*0*	*0*	*0*	*0*		

Total points
111

	Paste A	Paste B	Paste C	Paste D
OVERALL WEIGHTED TOTAL:	0	0	0	0
Normalized on 1-4 scale (4=best)	0.0	0.0	0.0	0.0

For More Information:

- Circuits Assembly Magazine http://circuitsassembly.com/ca/editorial/menu-features/28977-materials-selection-1803.html

- SMTA Webinar https://www.smta.org/knowledge/webinar_abstract.cfm?WEBINAR_ID=81

Thank You!

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