The Impact of Reduced Solder Alloy Powder Size on Solder Paste Print Performance

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Abstract

From the Apple Watch and body cameras for law enforcement to virtual reality hardware and autonomous transportation, the opportunities for electronics to improve our lives are limited only by our imaginations. The capability of existing PCB assembly technology needs to advance rapidly to meet the mission profile of these new devices. The demand common to all of these devices is increased functionality in a smaller space. For the solder paste manufacturer, this path inevitably leads to incorporating finer metal powder into solder paste to facilitate ultra-fine pitch printing. This study evaluates the benefits and implications of finer mesh solder powder on critical aspects of solder paste performance.

Type 4, 5 and 6 SAC305 solder pastes were tested and their characteristics in several key areas were measured and studied. The key input variables included powder size, effect of room temperature storage, pause time and PCB feature types. Output included print transfer efficiency, volume repeatability and performance stability over time.

The goal of the study was to measure the benefits derived from smaller particle size and identify possible negative implications. With this information, assemblers and technical support personnel will better understand how to apply their resources to ensure the most robust process and optimized performance. The study was undertaken in two parts to measure both print characteristics and reflow characteristics. The print results are reported in this paper.

Background

The study represents a natural progression of a 2011 study in which the benefit of incorporating Type IV (T4) solder powder into solder paste versus the largely incumbent Type III (T3). Results from this study indicated that T4 powders provided a modest improvement in volume consistency versus T3. The conclusion was that other variables including paste formulation, stencil coatings and understencil wipe materials could have as significant an impact on transfer efficiency performance as powder mesh size. As print features continue to miniaturize, there is drive for further reduction in mesh size to accommodate ever decreasing aperture size as well as increasing aperture density. This study will help to define the transfer efficiency advantages of reduced mesh size of and between T4, T5 and T6 SAC305 solder powders and to identify any compromises that may arise from reducing the mesh size.

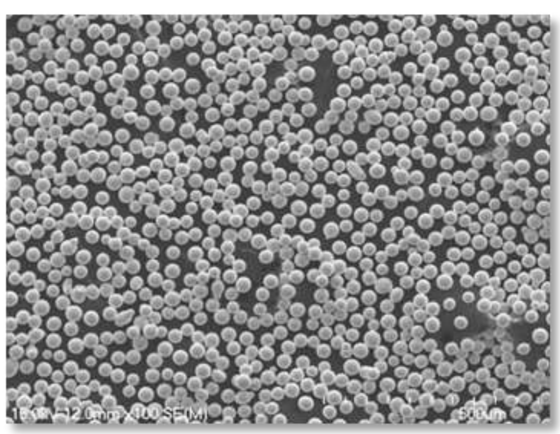

Figure 1 – Type 4 solder paste particles

It is important to understand that as particle size shrinks, print capability is improved, but the effects of surface oxides on the particles begin to factor into shelf life and reflow properties. The IPC J-STD-005 standard for particle size is shown in Table 1.

Table 1 –IPC J-STD-005 standard for solder paste particle sizes

Type Designation	Mesh Size (lines per inch)	Particle Size, um (at least 80% in range)*
1		150-75
2	-200/+325	75–45
3	-325/+500	45–25
4	-400/+635	38–20
5	-500	25–10
6	-635	15–5
7		11–2
8		8–2

Figure 2 demonstrates the extraordinary difference between the largest solder particle sphere diameters for T3 through T6 solder pastes.

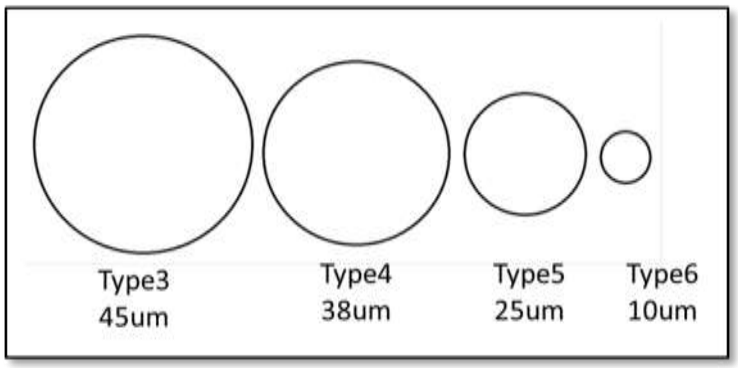

Figure 1 - A comparison of largest sphere size in a given powder type

There are two long held tenets of solder paste printing, the "5 Ball Rule" and 0.66 area ratios. The 5 Ball Rule indicates that the smallest aperture that can be printed by a given mesh size is 5x the largest solder sphere for that mesh size. In the case of T5 powder this would be 4.5 mil aperture, and for T6 it would be 2 mil and so on. Similarly, area ratio calculators indicate that any stencil aperture with area ratios less than 0.66 are on the edge of the T3 performance window and additional strategies or a redesign need to be incorporated to ensure consistent print performance. This study will reveal if these rules are applicable with Ultra Fine Powder (UFP) pastes and if they should be reconsidered.

Finally, it is important to consider the advancements in solder paste chemistry technology; stencil foil alloys; cutting, coating and mounting technologies; as well as printer and solder paste inspection technology. All of these advancements are occurring in parallel and are undoubtedly shifting the existing paradigms and advancing the print process.

Experimental Method

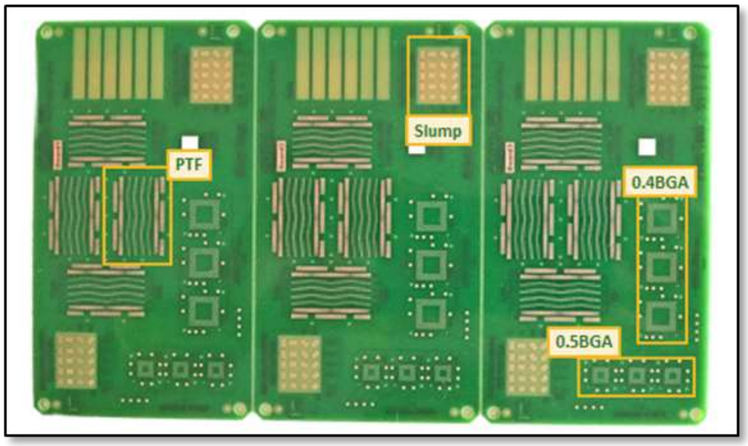

Figure 2 - Solder Paste Evaluation Board [1]

The **test vehicle** (TV) selected for the solder paste print study was a Solder Paste Evaluation Board [1] that is commercially available from a dummy component and test kit supplier. The TV shown in Figure 3 was chosen specifically for the range and depth of test points specific to transfer efficiency. It is thoughtfully designed with many test-friendly characteristics:

- Print-to-Fail (PTF) patterns that combine pad sizes ranging from 3 to 15 mils with shapes including circular, square and rectangular pads, defined with both copper and solder mask
- 0.4 and 0.5 mm BGA patterns
- Slump patterns from 10 to 4 mil (0.25 to 0.1 mm) spacing
- Markings on the PCB are etched in copper rather than silkscreened with ink to eliminate the stand-off effect of PCB nomenclature

The TV was modified for this project by removing the 3, 4 and 5 mil pads from the PTF patterns. The smallest feature size tested in this study was 6 mil. The smaller features would add cost to the TV, would not provide useful insights when printing with a 4 mil stencil foil, and would be challenging to measure accurately and reproducibly using current SPI technology. 300 panels of the modified design were fabricated specifically for this test run. The data was collected using a new panel for each print. No PCBs were cleaned and reprinted.

The pad and aperture sizes, area ratios and theoretical volumes are shown in Figure 4.

Pad Sizes, Area Ratios and Theoretical Aperture Volumes – 4mil Foil

Pad Size (mil)	Area Ratio	Ap Vol Circle	Ap Vol Square
6	0.38	113	144
7	0.44	154	196
8	0.50	201	256
9	0.56	254	324
10	0.63	314	400
11	0.69	380	484
12	0.75	452	576
13	0.81	531	676
14	0.88	616	784
15	0.94	707	900
0.4mm BGA	0.63	(sq with	383
0.5mm BGA	0.73	rnd corners)	531

Figure 4 - Calculated theoretical area ratios and aperture volumes for each aperture size tested.

The **bridging/slumping** test patterns are shown in Figure 5. Each pattern offers opportunities to assess slump in horizontal, vertical or angular positions at line/spacing resolutions from 0.1 to 0.25 mm. The PCB contains two sets of patterns; one set per board (3 per panel) was read for each print, approximately 10-20 minutes after the print. The laboratory environment was consistently controlled at 25.4°C (77.4°F) and 59% RH. The slump patterns were photographed and the locations of any bridges were noted as part of the data collection process.

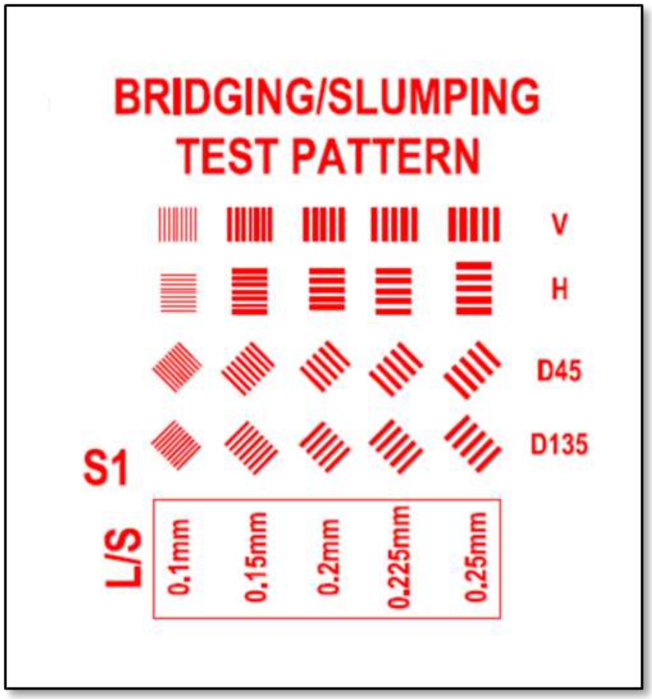

Figure 3 - Slump test pattern

The stencils employed current state-of-the-art technology which would typically be used for ultra-fine feature applications that demand finer powder solder pastes. They were cut from fine grain stainless steel on a modern, diode laser by a high-quality, US-based stencil supplier who then applied a proprietary polymer nanocoating. Three identical stencils were produced; one was used to perform some pre-screening test runs, and two new ones were used in the actual print tests. All apertures were sized one to one (1:1) with the test pads, with no reductions on any apertures.

The test equipment included a new printer, SPI machine and video microscope in the company Applications Laboratory. The test area is climate controlled and can be manipulated to simulate production environments around the globe. Test conditions were optimized at 25.4°C-77.4°F at 59% RH for these tests, and recorded twice daily.

Figure 6 –Company Applications laboratory

The facility is staffed with full-time SMTA Certified process engineers with over 50 years of combined experience in SMT assembly processes. Figure 6 shows the laboratory manager preparing the production printer and production Solder Paste Inspection machine for the test run. The **print parameters** were as follows:

- Squeegee speed: 40 mm/sec (~1.6 in/sec)
- Squeegee pressure: 10 kg (~1.5 lb/in on 14" blades)
- Separation speed: 1 mm/sec (~0.040"/sec)
- Separation distance: 3 mm (~120 mils)
- Under wipe sequence: Wet-Vacuum-Dry (WVD), using production wiper paper and production company solvent. Stencils were automatically underwiped before the first print of each set of 5.

A flat tooling support block was used to provide solid support for the PCB, and new squeegee blades were used for the tests.

Solder Paste Inspection (SPI) parameters were modified to improve the accuracy of the measurements. Typically, a 30-40µm measurement threshold is used in production environments to eliminate noise from PCBs' topographical features like silkscreen markings, mask over trace, etc. Because the design of this TV limits topographical feature noise, it enabled a 15µm measurement threshold, to improve measurement fidelity and aid in detecting subtle variations in print behavior.

The solder paste test matrix included Types 4, 5 and 6 powders in a modern, no-clean flux medium. The pastes were blended, shipped and stored under recommended refrigeration conditions. One jar of each type was removed from refrigeration and allowed to age, unopened, at room temperature for two weeks in the climate-controlled laboratory. The pastes were labeled "Fresh" for products stored under refrigeration and "Aged" for pastes that were stored at room temperature.

Prior to manufacturing the solder pastes for the tests, pre-screening print tests helped determine the ideal metal load for the T5 and T6, as shown in Table 2. Pre-screening tests were also used to optimize the final print parameters used in the tests.

Table 2 -Paste type, metal loading and lot numbers of solder pastes print tested

Fresh	Aged
T4 – 88.5% SAC305 Lot# 42613	T4 – 88.5% SAC305 Lot# 41560
T5 – 88.3% SAC305 Lot# 42619	T5 – 88.3% SAC305 Lot# 41557
T6 – 88.2% SAC305 Lot# 42622	T6 – 88.2% SAC305 Lot# 41553

Experimental Design

Input variables in the experiment included:

- Paste Type (4, 5, 6)

- Paste condition (Fresh, Aged)
- Pause time between print tests (0, 30, 60 and 90 minutes)
- PCB pad size (6-15 mil)
- PCB pad shape (circular, square, modified square with rounded corners)
- PCB pad definition (copper, mask)
- Slump (line/space size, angle)

Output variables included:

- Deposit volume
- Deposit height
- Deposit area at measurement threshold
- Transfer efficiency (% volume)

Statistics calculated from the output readings were:

- Means (or averages)
- Standard deviations
- Coefficients of variation (CV, or the standard deviation divided by the mean and expressed as a percentage). CV is preferred over Cpk when comparing different SPI datasets because it normalizes the variation with respect to the mean.

The tests were executed using both fresh and aged pastes in concurrent runs by employing two stencils, two sets of squeegees and two timers. The stencils, squeegees and timers were all labeled “Fresh” or “Aged” to prevent any opportunities for cross contamination. During the run they were abbreviated “F” or “A.” A single Type of paste was tested each day for three days. Stencil under wipes were performed before each set of 5 prints, but not between prints. SPI readings were taken immediately after each print, and slump readings were taken 10-20 minutes after each print. The full runs that included 0, 30, 60 and 90 minute pauses took approximately 4 hours from start to finish. The tests were nested as follows:

Time 0
Install "F" stencil and "F" squeegees
Stir "F" solder paste and apply to stencil
Print 5 boards
Start timer "F" for 30 minutes
Remove "F" stencil and squeegees, leave paste on stencil

Install "A" stencil and squeegees
Stir "A" solder paste and apply to stencil
Print 5 boards
Start timer "A" for 30 minutes
Remove "A" stencil and squeegees, leave paste on stencil
Install "F" stencil and squeegees

At 30 minute mark on timer "F" run WVD wipe
Print 5 boards
Start timer "F" for 60 minutes
Remove "F" stencil and squeegees, install "A" stencil and squeegees
At 30 minute mark on timer "A" run WVD wipe
Print 5 boards
Start timer "A" for 60 minutes
Remove "A" stencil and squeegees, install "F" stencil and squeegees

At 60 minute mark on time "F" run WVD wipe

Print 5 boards
Start timer "F" for 90 minutes
Remove "F" stencil and squeegees, install "A" stencil and squeegees
At 60 minute mark on timer "A" run WVD wipe
Print 5 boards
Start timer "A" for 90 minutes
Remove "A" stencil and squeegees, install "F" stencil and squeegees

At 90 minute mark on timer "F" run WVD wipe
Print 5 boards
Start timer "F" for 120 minutes
Remove "F" stencil and squeegees, install "A" stencil and squeegees
At 90 minute mark on timer "A" run WVD wipe
Print 5 boards
Remove "A" stencil and squeegees
Clean both "F" and "A" stencil and squeegees

Slump readings were taken at approximately 12-15X magnification using a video microscope, as shown in Figure 7.

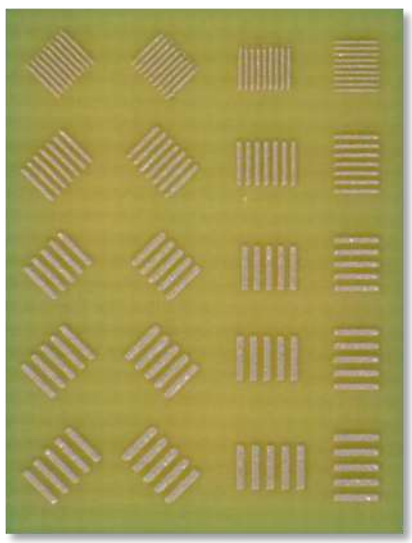

Figure 7 - Test vehicle slump pattern

Visual evidence of slump was recorded and location noted in a spreadsheet that contained information on all the experimental data, including board labeling, SPI file names, start and stop times and print parameters. The number of bridges on the slump patterns was noted and the locations were inserted as comments. All bridges in the slump patterns were photographed for future reference. An example of the data recording sheet is shown in Table 3.

Table 3 - Data management spreadsheet

Refriger-ation	Powder Size	Time	Board #	Board Label	SPI File Name	Start/Stop Time	Comments	Slump Board 1	Slump Board 2	Slump Board 3
Fresh	Type 4	0	1	F4-T0-#1	F4-T0-bd 1-5	10:40	Print Params:	0	0	0
			2	F4-T0-#2			- 40mm/sec	0	0	2
			3	F4-T0-#3			-10 kg/14" blades	0	1	0
			4	F4-T0-#4			- 1mm/sec sep spd	0	0	0
			5	F4-T00-#5		10:47	- 3mm sep dist	1	1	2
		30	1	F4-T30-#6	F4-T30-bd 6-10	11:19	Print Params:	0	0	0
			2	F4-T30-#7			Same	0	0	0
			3	F4-T30-#8				0	0	1
			4	F4-T30-#9				1	3	2
			5	F4-T30-#10		11:25		0	0	0
		60	1	F4-T60-#11	F4-T60-bd 11-15	12:27		0	0	0
			2	F4-T60-#12				0	0	1
			3	F4-T60-#13				0	0	0
			4	F4-T60-#14				0	0	0
			5	F4-T60-#15		12:33		0	0	0
		90	1	F4-T90-#16	F4-T90-bd 16-20	2:06		0	0	0
			2	F4-T90-#17				0	0	1
			3	F4-T90-#18				0	0	0
			4	F4-T90-#19				0	0	1
			5	F4-T90-#20		2:12		0	0	0

Results and Discussion

One of the most challenging components facing mainstream PCB assemblers is 0.5 mm BGA devices. Figure 8 shows the measured transfer efficiency (TE), or the percentage of theoretical aperture volume that was deposited and the associated CVs. Each data point represents the average of 3780 deposit readings – 84 I/Os per device, 3 devices per board, 3 boards per panel and 5 panels per test. Figure 9 details the pad layout of the device.

Notice the TEs are all slightly higher than 100%. This is not uncommon and can be due to numerous factors relating to gasketing breaches and/or paste pump out due to the 1:1 aperture:pad ratio and the combination of round pad with square-shaped apertures (these particular apertures are squares with rounded corners). The pads on this device are copper defined, and, given this method of definition, shape differences naturally lend themselves gasketing issues, and the 1:1 aperture:pad ratio in general is highly susceptible to positional errors in the stencil or PCB, alignment error in the printer, or slightly undersized pads or oversized apertures.

Figure 8 - 0.5 mm device TE and CV by paste type over time on copper defined (NSMD) pads

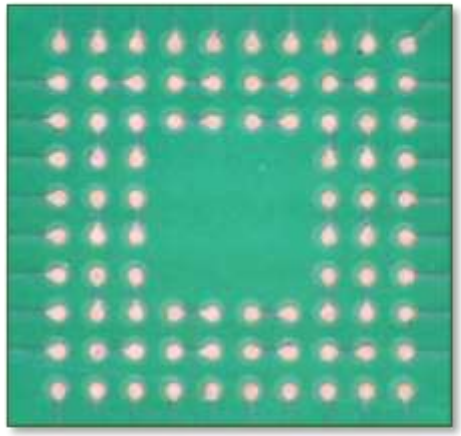

Figure 9 - 0.5 mm BGA pad layout

The CVs are all less than 10%, which is a common industry benchmark. They are actually all less than 5%, which represents very high consistency in the deposit volumes, and is attributable to both a well-printing solder paste and the polymer coating inside the stencil apertures. Note that on this TV, the 0.5mm BGAs have 11.5mil round pads, and 11.5mil square apertures (with rounded corners), with ARs of approximately 0.72. 0.72 ARs are relatively easy to print, especially with T4 and T5 solder pastes, given that the standard industry guidelines for printing with T3 pastes are ARs >0.66.

The T5 paste produced slightly higher volumes than the T4, which is expected due to the tighter particle packing density of the smaller particle sizes and the greater propensity for pump out of smaller particles, particularly with the geometric incongruities between apertures and pads.

The next area array pitch size to reach mainstream production is 0.4 mm. It has been in miniaturized electronics for more than 5 years as the base of POP packages, and is expected to extend to widespread use by 2018. This device has 360 I/Os with 9 per panel for a total of 16,200 measurements per data point reported. The TEs and CVs are shown in 10, and the device's footprint is shown in Figure 11.

The TEs are again slightly over 100%, but less than the TEs of the 0.5 mm BGAs. These circular, copper defined pads are 10mil diameter, and the apertures are 10 mil squares with rounded corners; their AR is estimated at 0.63. The CVs are also well under 10%, but slightly higher than those of the 0.5 mm BGA.

Figure 10 - 0.4 mm device TE and CV by paste type over Time for copper defined pads

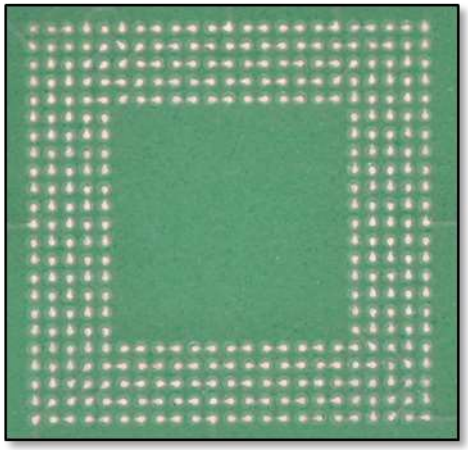

Figure 11- 0.4 mm BGA pad layout

The 0.63 AR provided by this device makes for an easy comparison of aperture shape release characteristics among aperture shapes of the same size, AR and pad definition. The square apertures with rounded corners are also known as “squircles.” Figures 12a-12d compare the TEs and CVs of circles, squares and squircles at different pause times for 10 mil, copper defined pads on the 4 mil foil.

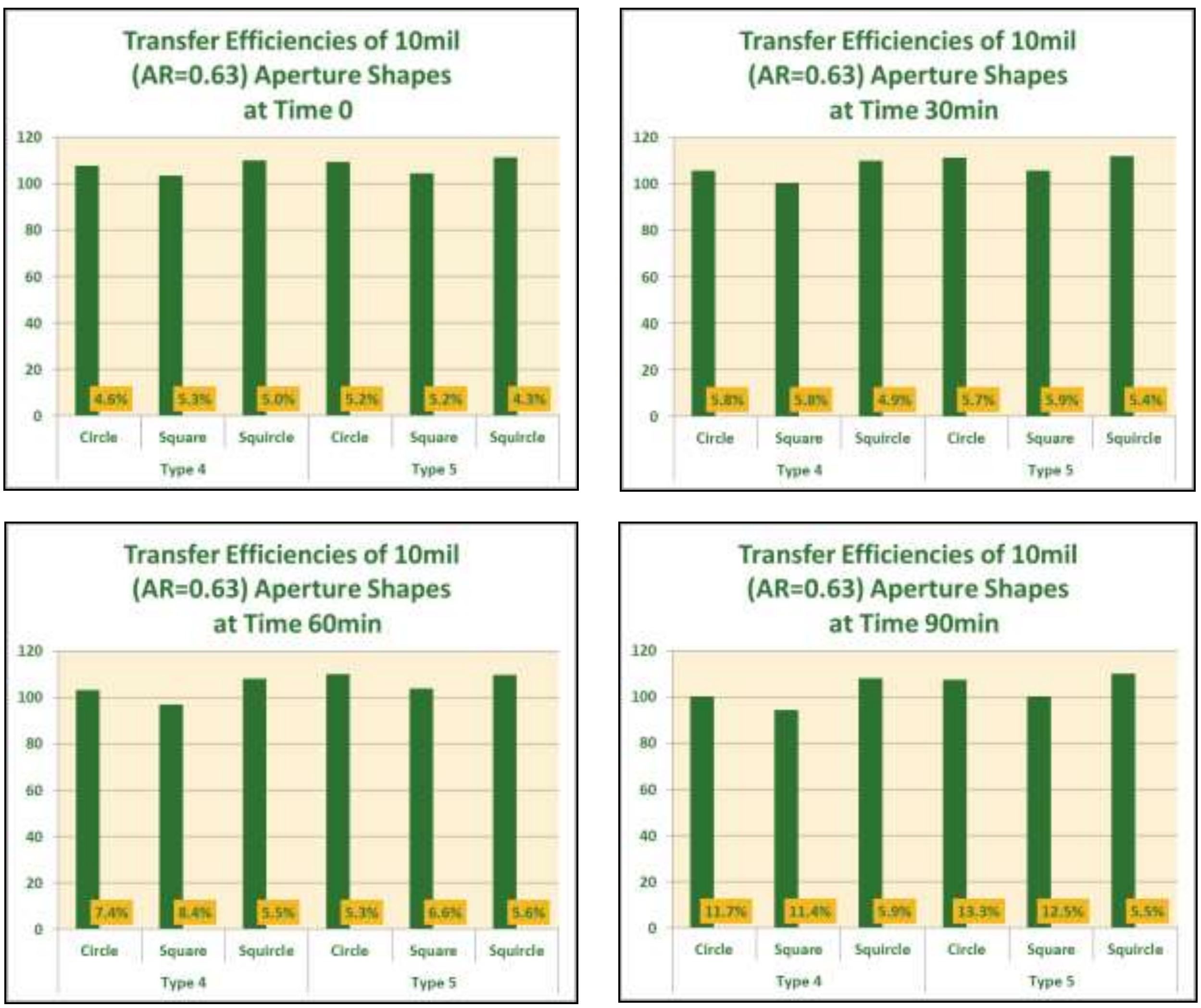

Figure 12a-d - TEs and CVs various aperture and mesh types on 10 mil NSMD pads

At Time 0, little difference is noted in the release performance of the different aperture shapes, although squares exhibit slightly less transfer efficiency. Squares typically show lower TE as paste particles tend to stick in tight corners, but squares also typically deposit more volume than circles of similar sizes because they have more area than their circular counterparts. In the case of Time 0, the actual volume deposits are 339, 412 and 421 $mils^3$ for circles, squares and squircles, respectively. The TE trends are repeatable at Times 30, 60 and 90 minutes, but the CVs increase as pause time increases for both the circular and square apertures. The CVs of the squircles remain relatively stable as pause time increases.

The data for circular and square apertures used in this comparison was generated from the PTF patterns on the TV, and each point represents 480 readings (8 per pattern, 4 patterns per board, 3 boards per panel, and 5 panels per time condition).

The data from the PTF patterns was also analyzed for volume and CV.

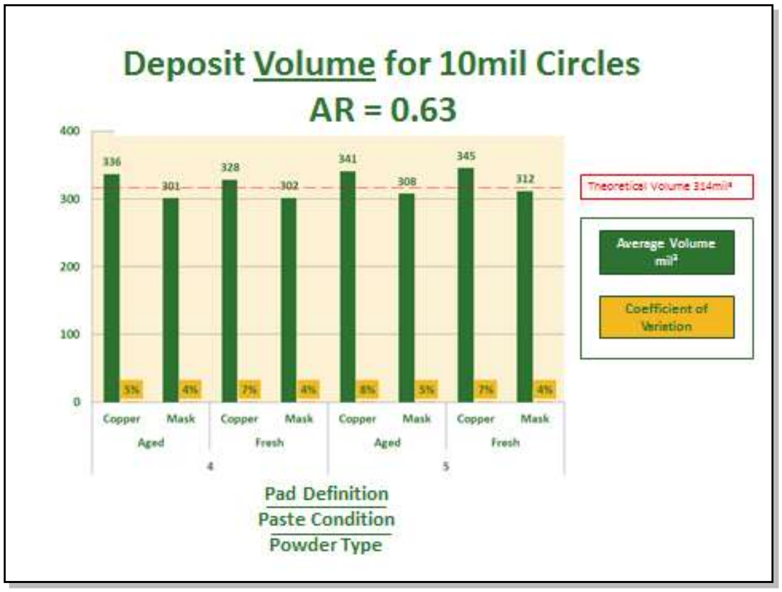

Figure 13 - Actual volume measurement comparisons for 10 mil circles on both copper and mask defined pads, and fresh and aged T4 and T5 solder pastes

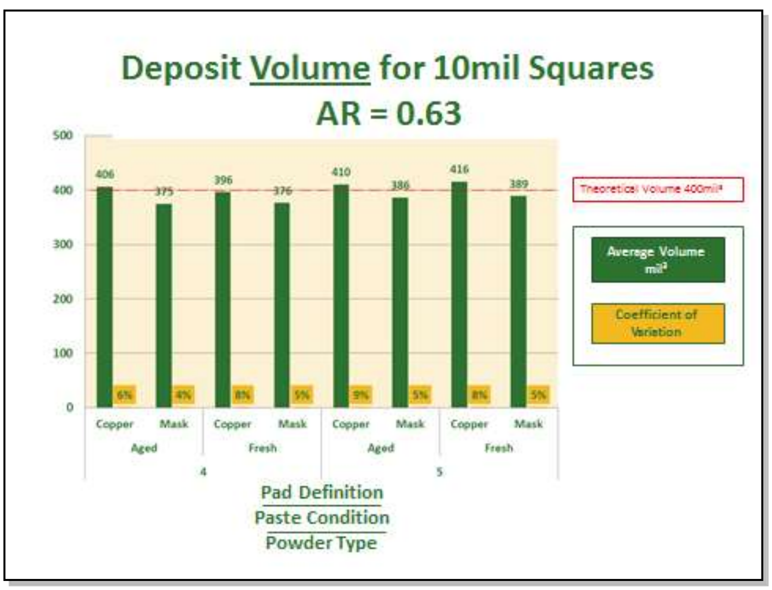

Figure 14 - Actual volume measurement comparisons for 10 mil squares on both copper and mask defined pads, and fresh and aged T4 and T5 solder pastes

Figures 13 and Figure 14 show the actual measured volumes for 10 mil squares and circles. These aperture sizes and shapes are typically associated with 0.5 or 0.4 mm BGAs and 0201s. Squares always show higher volumes than circles, as previously described. Copper defined pads generally show higher volumes and CVs due to gasketing and pump out issues, also described earlier, particularly at 1:1 aperture:pad ratios. Mask defined pads demonstrate lower volumes and less variation because the mask definition improves gasketing. Typically BGA, LGA or BTC pads are copper defined for improved reliability of the solder wrap around the pad edge. Discretes, however, are more easily mask defined because they typically exhibit higher reliability with thermal cycling and drop shock than more complex component types.

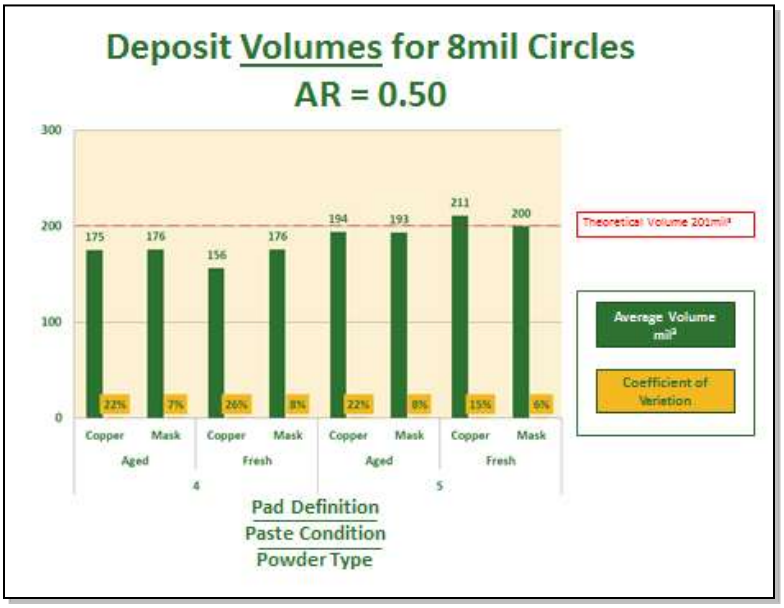

Figure 15 - Actual volume measurement comparisons for 8 mil circles on both copper and mask defined pads, and fresh and aged T4 and T5 solder pastes

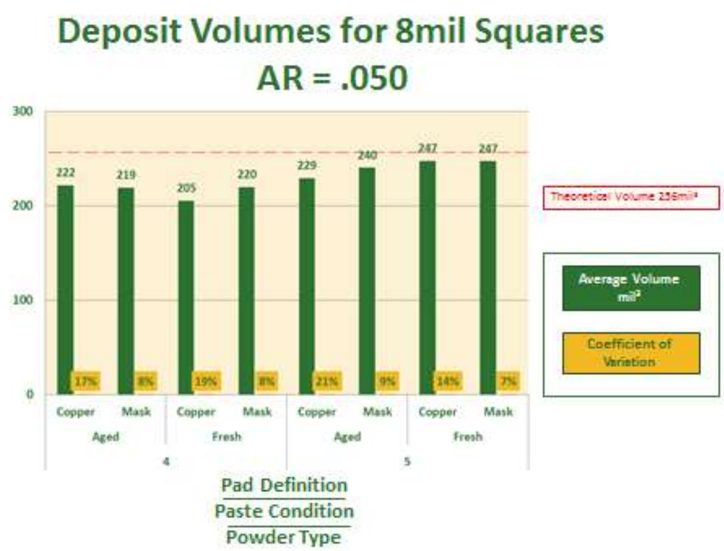

Figure 16 - Actual volume measurement comparisons for 8 mil squares on both copper and mask defined pads, and fresh and aged T4 and T5 solder pastes

Figure 15 and Figure 16 show the measured volumes for 8 mil squares and circles, which are typically associated with 01005 and emerging 0.35 mm pitch devices. Following similar trends demonstrated by the 10 mil features, squares deposited higher volumes than circles and mask defined pads exhibit less variation than copper defined pads. T5 solder paste deposited higher overall volumes and comparable CVs compared to T4. The volumes of the T5 prints, however, did not explicitly duplicate the same trends as the T4, illustrating the fact that features sized this small have 0.5ARs and are more susceptible to noise in the printing process.

At time zero, no substantial differences were noted between the fresh and aged pastes. Not reported in this paper, however was the divergence of volume variation noted at Time 60 min and Time 90 min. Aged pastes consistently produced higher CVs at the longer pause times than fresh paste, but did not demonstrate significantly different average volumes.

The increased volumetric variation can be attributed to the interaction of flux on the powders' surface oxides which occur at room temperature storage. Cooler temperatures retard the reaction of oxide reduction by the flux on the particle surfaces; higher temperatures accelerate it.

Table 4 - Number of bridges found in slump patterns

Powder Type	Fresh	Aged
T4	17	0
T5	3	2
T6	23	1

The data collected from the slump testing (15 patterns per paste type and condition) exhibited reduced slump on the aged samples of paste versus the fresh samples. This indicates a thickening of the paste due to increased interaction between the flux medium and alloy powder when stored at room temperature rather than refrigeration. All the bridges on the slump patterns were in the 4 mil (0.1 mm) line/space area, and were randomly distributed throughout the rotations, with no clear trends toward horizontal, vertical or angled patterns.

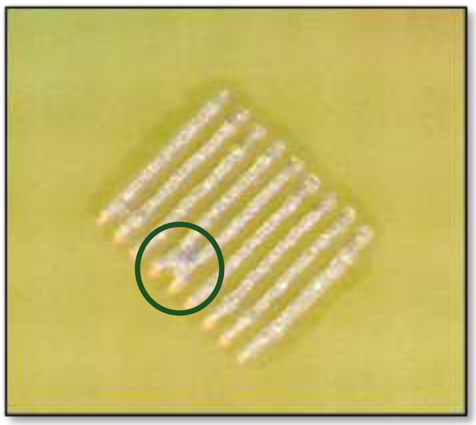

Figure 17 - Solder Bridge on 45° slump pattern

Further investigation will include querying the height information collected by the SPI to determine if the lower or higher viscosity pastes create more peaks or "dog ears" that can be discerned statistically.

Type 6 pastes were also tested in the matrix, but not reported for 1) the sake of brevity, 2) the lack of current market requirements, and 3) to emphasize the importance of the decision process between T4 and T5.

Conclusions

With the overwhelming amount of data collected and analyzed, several key conclusions can be drawn. These conclusions can benefit SMT process engineers confronted with fine feature assembly challenges.

1. The key to successfully printing AR <0.66 is a robust process foundation.   This study was structured and performed to isolate the effect of powder mesh with new, calibrated and maintained equipment and highly skilled personnel. Achieving similar results in a production environment is possible but not probable. It is highly recommended to solicit on-site technical support from paste and equipment suppliers who can assist with process audits and technical guidance to ensure successful outcomes.
2. Aperture design: Square stencil apertures provide the most paste volume, but introduce the most variability. Round apertures provide less volume with equal variability. Squircles provided more volume than either circles or squares and less variability, especially after long pause times.
3. Reducing mesh size from T4 to T5 provides a modest benefit for both transfer efficiency volume and consistency on apertures with ARs <0.66. This benefit is marginal and may be negated in a production environment. Additionally, sourcing fine mesh paste may introduce burdensome cost and supply chain consequences.
4. Reducing mesh size had a modestly adverse effect on pause-to-print TE performance over time and with extended pauses in the print process. However, minor process adjustments, such as kneading after long pauses, could

alleviate these implications. While the first prints after the long pauses were considered acceptable with respect to volume control limits, they were not optimal, which is critical to a well-controlled process.

5. NSMD pads provide more paste volume with considerable variability. Mask defined pads significantly reduce both paste volume and deposit variability.
6. The current requirements for Type 6 solder powder for SMT solder paste printing are still under development and production viability is being determined. However, Type 6 powders are well suited to new solder paste dispense and jetting formulas.

Future Work

The next planned phase of the test is the reflow portion, which will use the company PCB2009 TV that includes component sizes down to 0.4 mm area array and 01005 discretes. The reflow tests will be performed in air, using Ramp-to-Spike and Ramp-Soak-Spike profiles. It will include both fresh and aged pastes in T4, T5, and T6 powder sizes. Results will be reported in a future paper.

Also planned is a repeat of the print tests on the Solder Paste Evaluation TV [1] using fresh T4 and T5 pastes, and uncoated stencils. Two stencil alloys will be tested in this phase, which will also be reported in a future paper.

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1. Jabil Solder Paste Evaluation Board and Kit.

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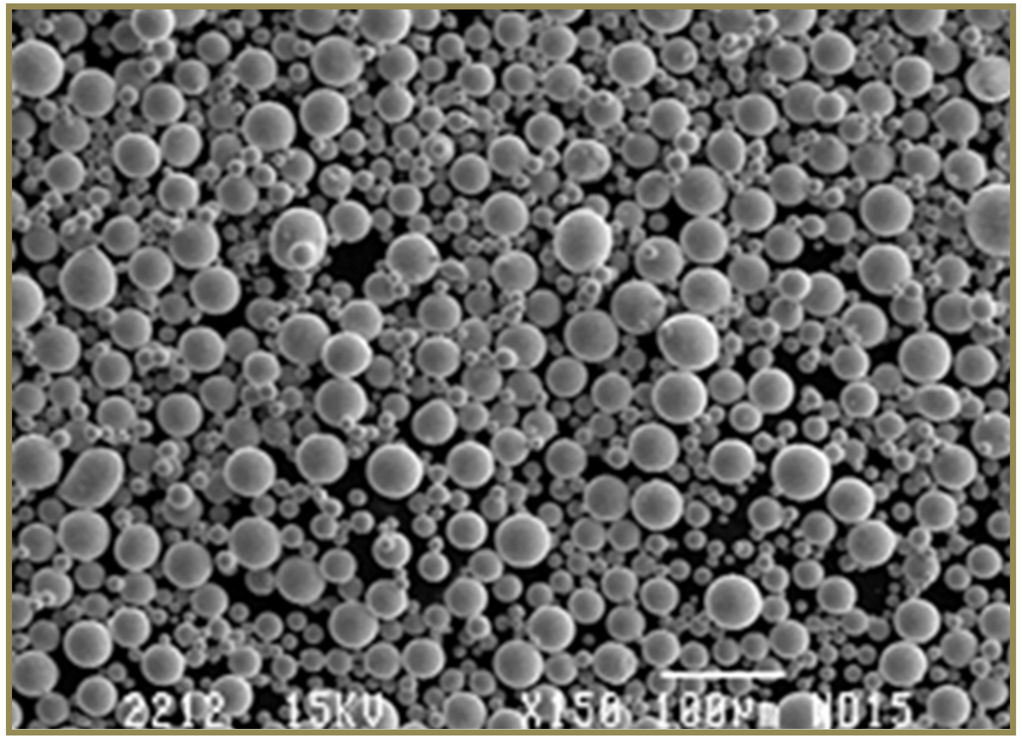

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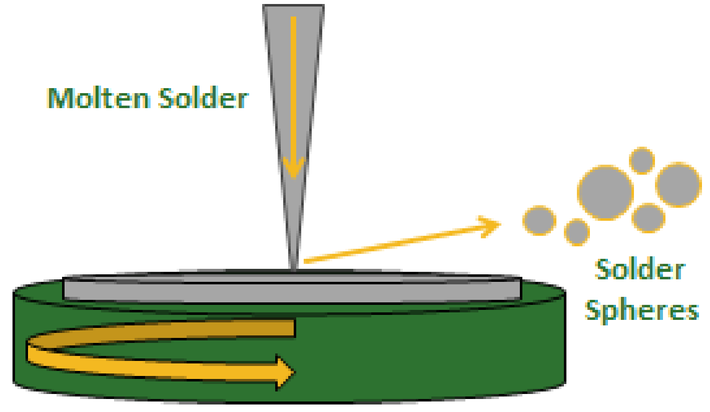
Solder Powder Manufacturing and Classification

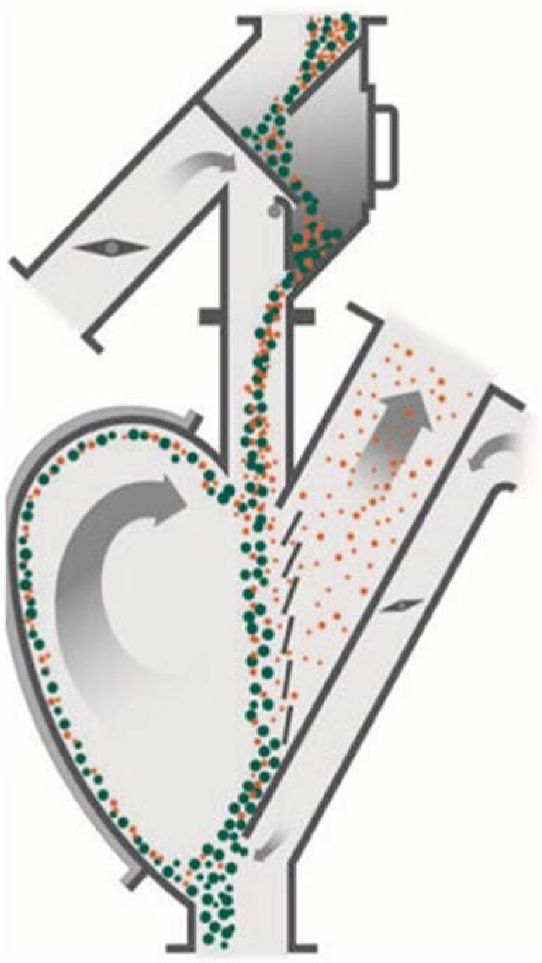
Type Designation	Mesh Size (lines per inch)	Particle Size, um (at least 80% in range)*
1		150-75
2	-200/+325	75–45
3	-325/+500	45–25
4	-400/+635	38–20
5	-500	15-25
6	-635	15–5
7		11–2

J-STD 005 Powder Size Designations

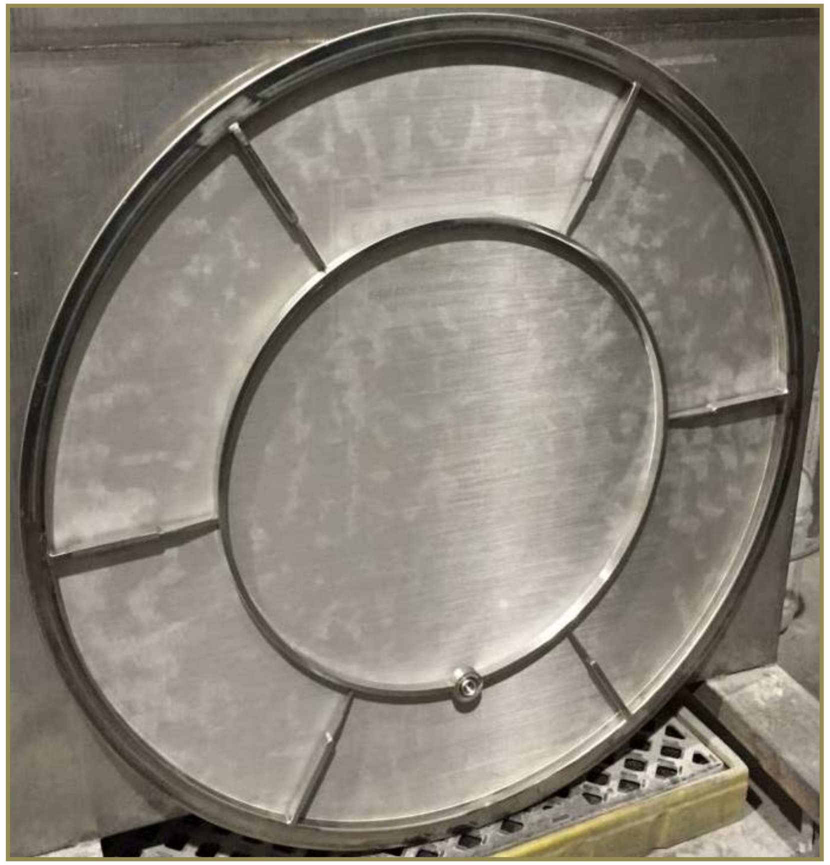
Spinning Disk
Solder Powder Atomization



Solder Powder Classification Process

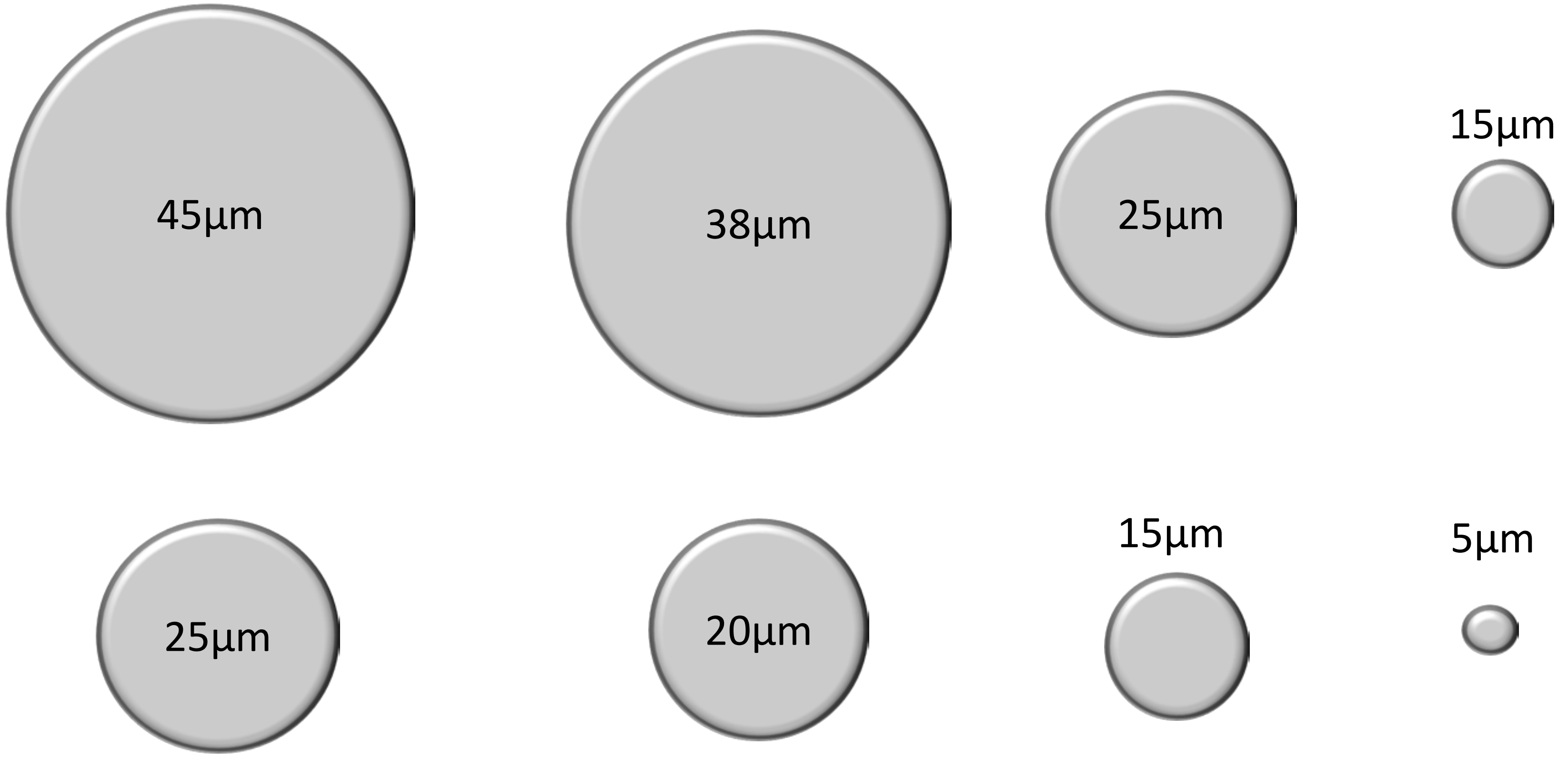


Air Classifier



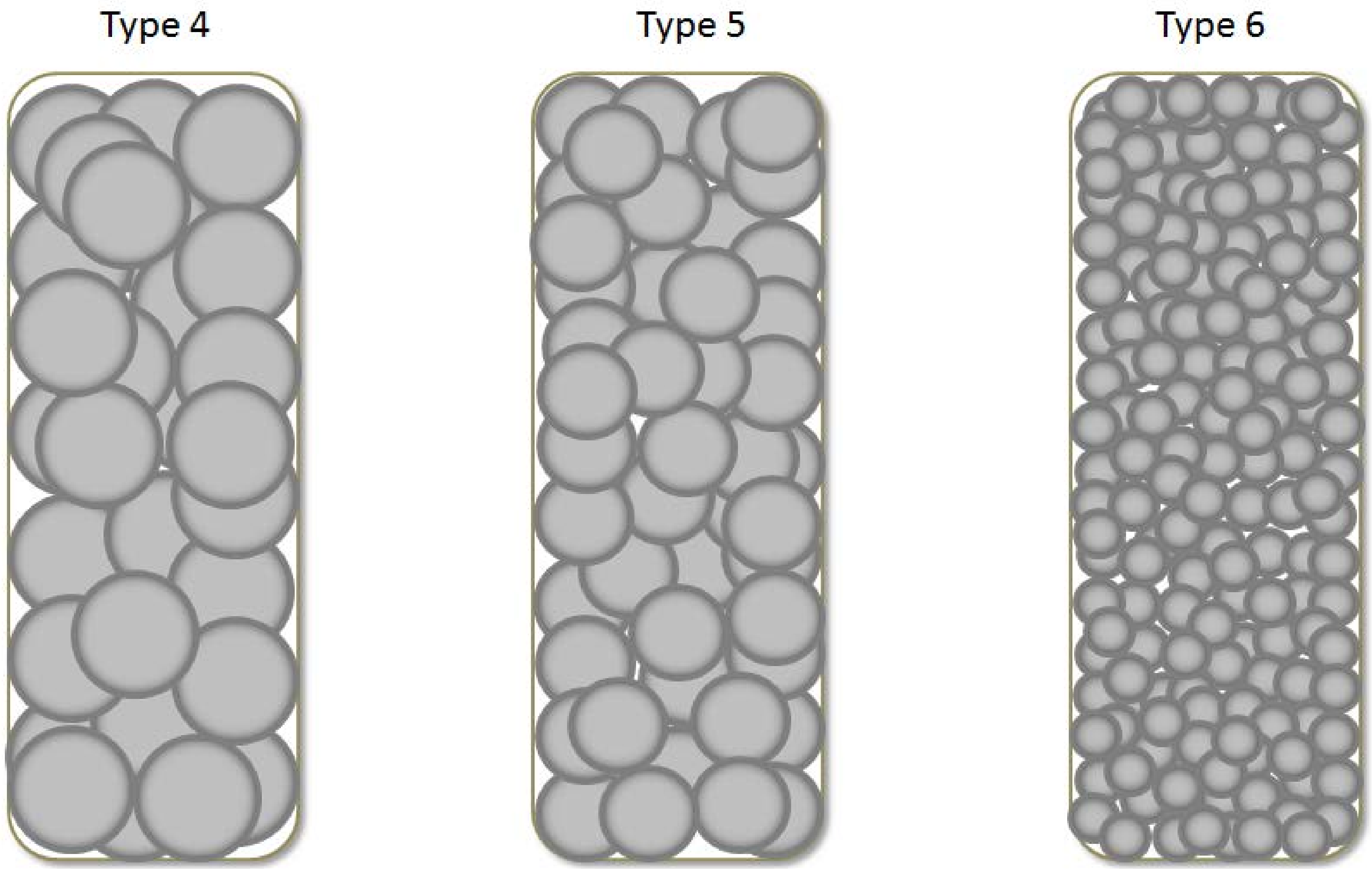
Powder Sieve

Solder Powder Mesh Size

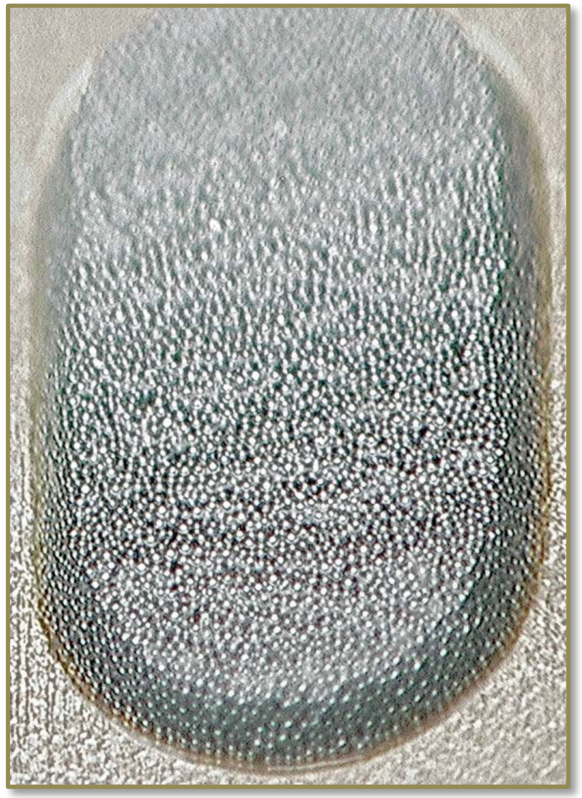


Type 3	Type 4	Type 5	Type 6
-325+500	-400+635	-500	-635
45-25µm	38-20µm	15-25µm	15-5µm

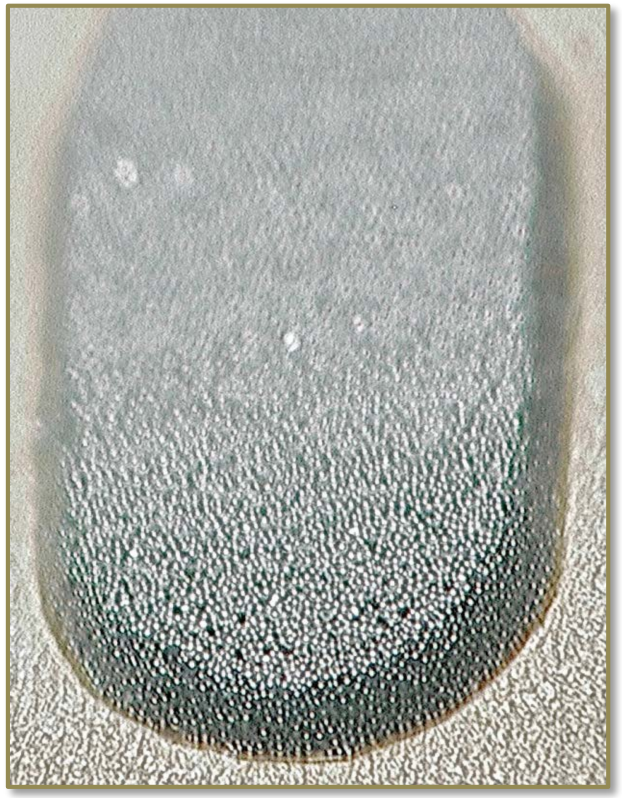
Powder Types Tested



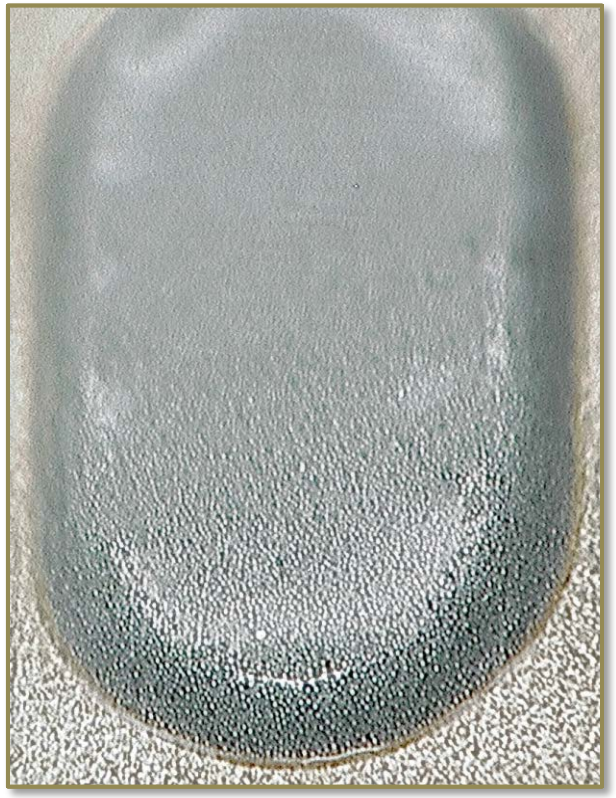
Powder Types Tested



Type 4

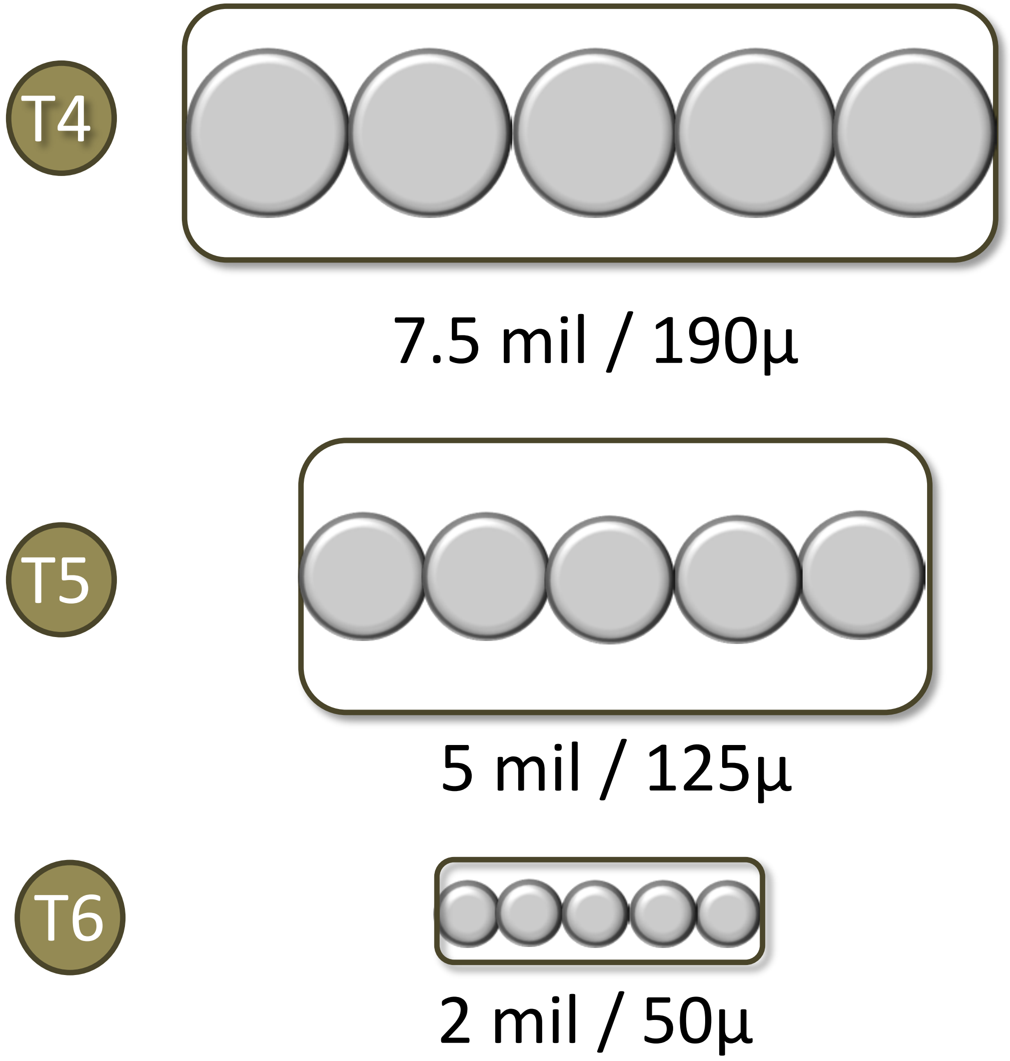


Type 5



Type 6

The "5-Ball" Rule



The smallest aperture that can be printed with any type of paste is no smaller than 5 times the largest particle in the paste.

Print Test

Input variables:

- Powder size
- Effect of room temperature storage – Refrigerated and 2 weeks @ room temperature (max. exposure – 80° F/22° C)
- Pause time – 0-30-60-90 minutes
- PCB feature types – Mask and non-mask defined pads (Copper)
- Aperture shape – Square, Circle, Squircle

Output variables:

- Print transfer efficiency
- Volume repeatability
- Performance stability over time

Goal: Quantify the benefits and drawbacks derived from smaller particle sizes.

Pad Sizes, Area Ratios and Theoretical Aperture Volumes – 4 mil Foil

Pad Size (mil)	Area Ratio	Ap Vol Circle	Ap Vol Square
6	0.38	113	144
7	0.44	154	196
8	0.50	201	256
9	0.56	254	324
10	0.63	314	400
11	0.69	380	484
12	0.75	452	576
13	0.81	531	676
14	0.88	616	784
15	0.94	707	900
0.4 mm BGA	0.63	(sq with rnd corners)	383
0.5 mm BGA	0.73		531

For more information on calculating area ratios

[Design For Success - Stencil Spec Advisor]

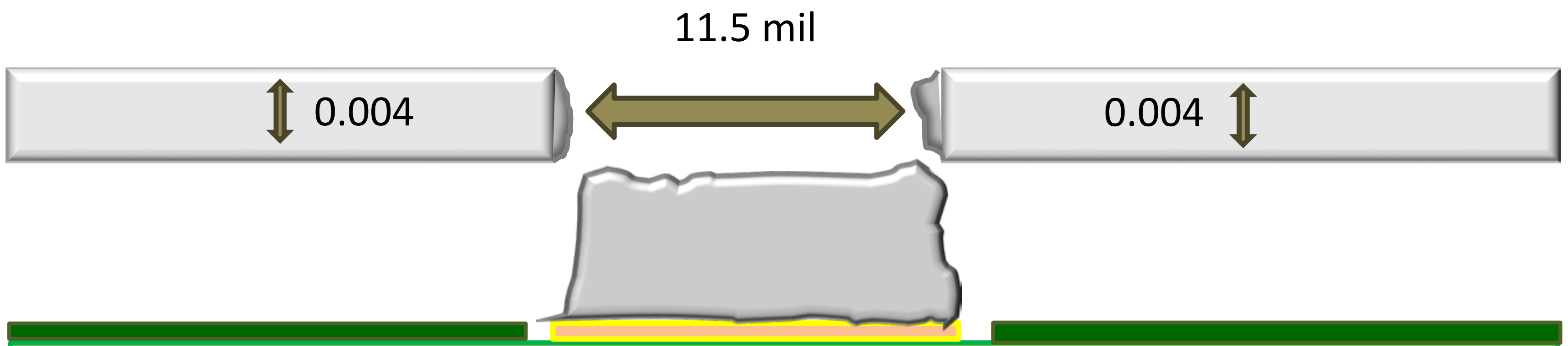
Area Ratio and Transfer Efficiency

AR = D/4T

Squares & Circles

11.5/(4x4 mil)

AR=72

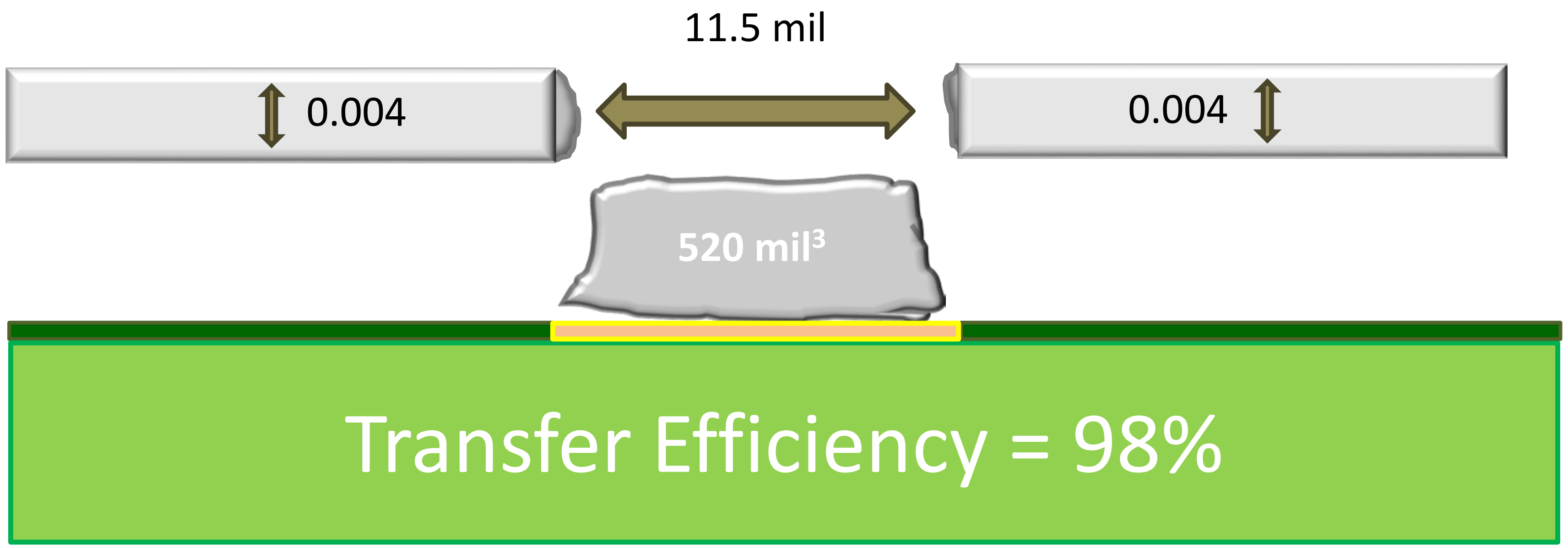


Transfer Efficiency = Theoretical Aperture Volume vs. Solder Deposit

Area Ratio and Transfer Efficiency

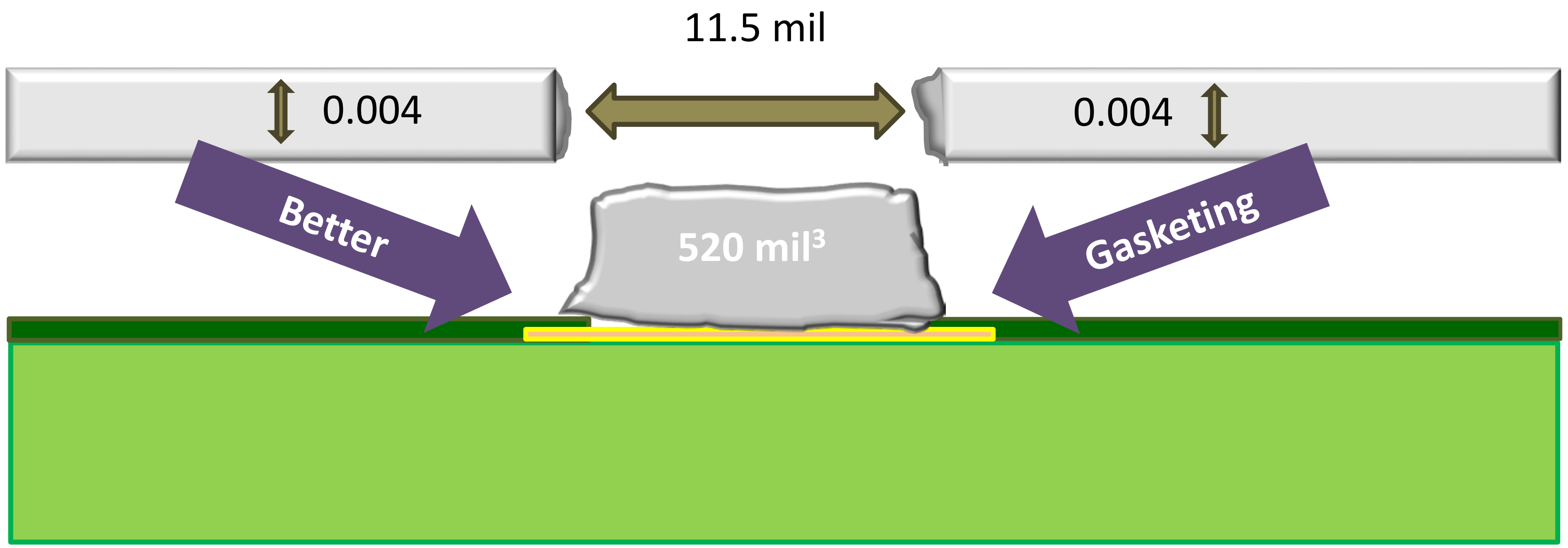
Aperture Volume

~530 mil^3



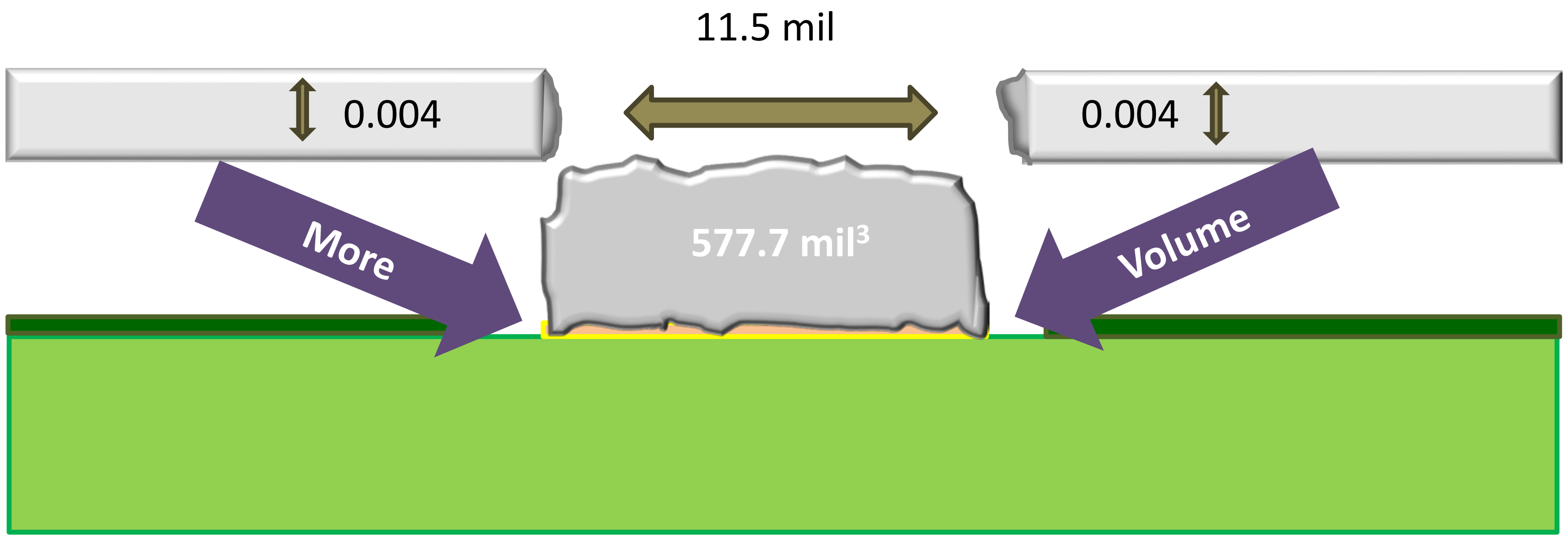
Solder Mask Defined Pads

Solder mask defined pads offer more consistent deposits with lower volume.

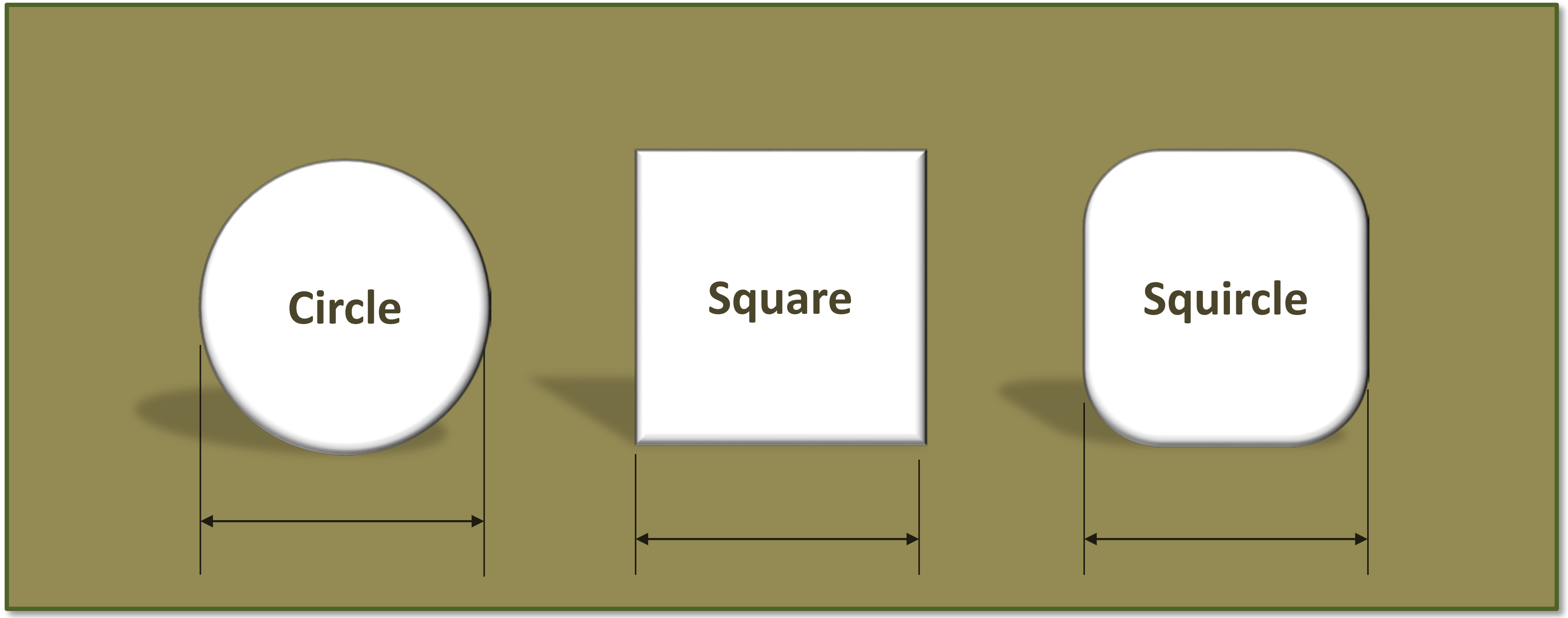


Non-Solder Mask Defined Pad

Non-solder mask defined (NSMD) pads offer higher volume with more inconsistent deposits.

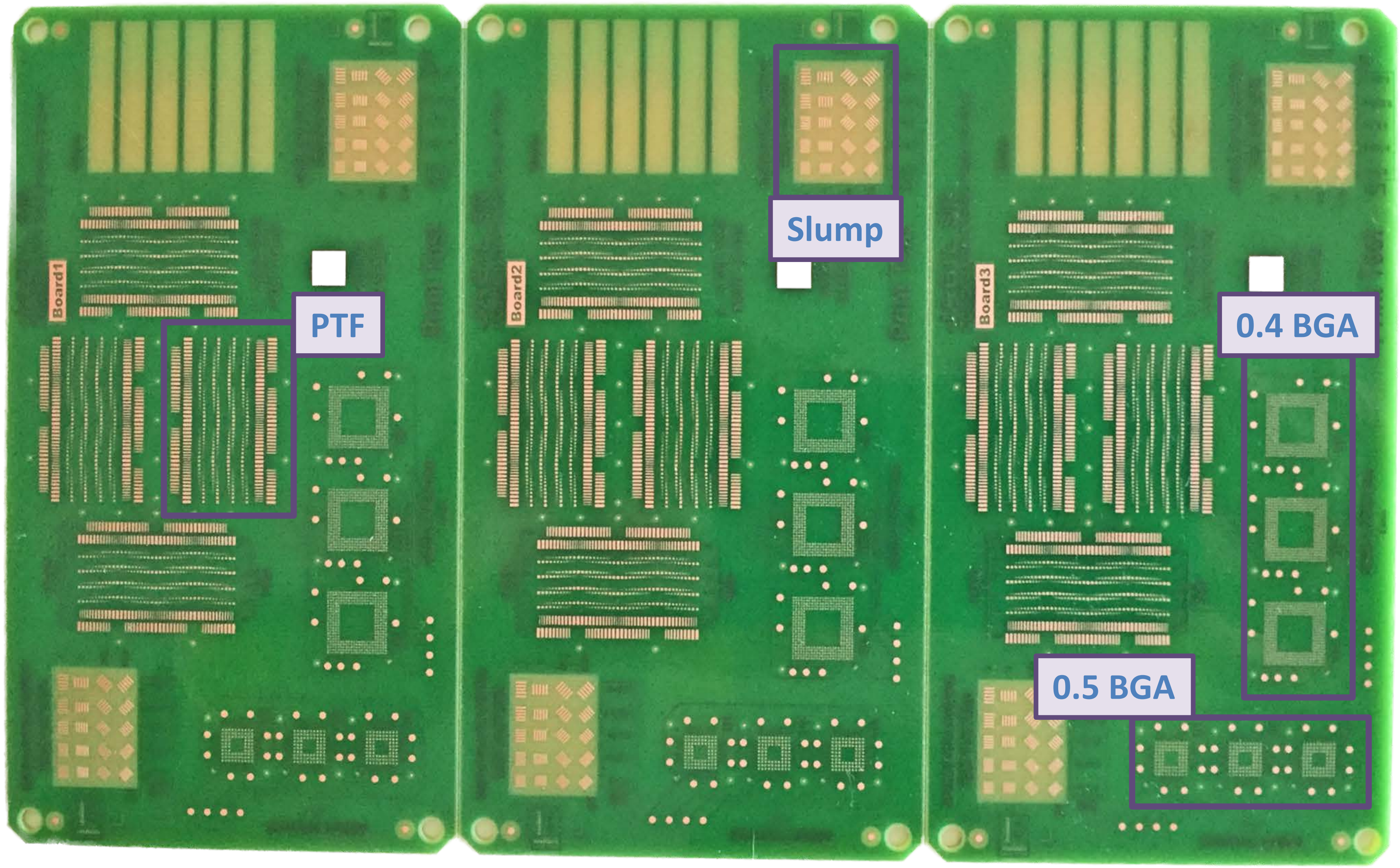


Aperture Shapes Tested



All Apertures are 1:1 with Pad Design

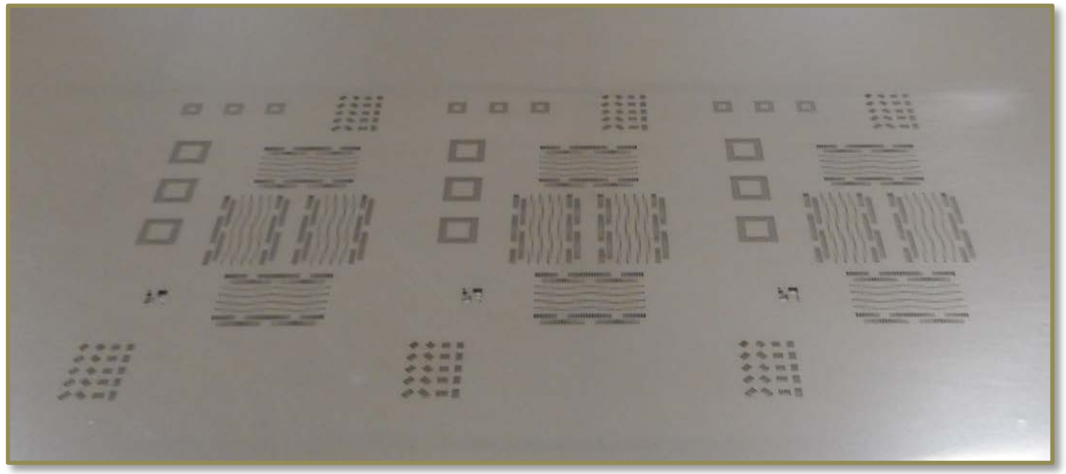
Test Vehicle



Test Vehicle Features

- Print-to-Fail (PTF) patterns that combine pad sizes ranging from 6 to 15 mils with shapes including circular, square and rectangular pads, defined with both copper and solder mask
- 0.4 and 0.5 mm BGA patterns with round, circular NSMD pads and squircle stencil apertures
- Slump patterns from 10 to 4 mil (0.25 to 0.1 mm) spacing
- Markings on the PCB are etched in copper rather than silkscreened with ink to eliminate the stand-off effect of PCB nomenclature
- Nearly 12,000,000 (twelve million) data points recorded during testing

Test Stencil & PCB Fabrication



- 4 mil/100µm thick
- All apertures 1:1
- Fine Grain foil
- Polymer nano-coating
- Paste-compatible wiper solvent

Extensive in-process inspection during fabrication

Test Pastes

Fresh	Aged
T4 – 88.5% SAC305 Lot# 42613	T4 – 88.5% SAC305 Lot# 41560
T5 – 88.3% SAC305 Lot# 42619	T5 – 88.3% SAC305 Lot# 41557
T6 – 88.2% SAC305 Lot# 42622	T6 – 88.2% SAC305 Lot# 41553

Test Facility

Environment controlled at
25.4° C (77.4° F)
59% RH

Print Parameters

Print Parameters	
Squeegee Speed	40 mm/sec (~1.6 in/sec)
Squeegee Pressure	10 kg (~1.5 lb/in on 14" blades)
Separation Speed	1 mm/sec (~0.040"/sec)
Separation Distance	3 mm (~120 mils)
Wipe Sequence	Wet-Vacuum-Dry (WVD), Print 1/each set
Wipe Solvent	Engineered Solvent
Board Support	Flat Block Tooling

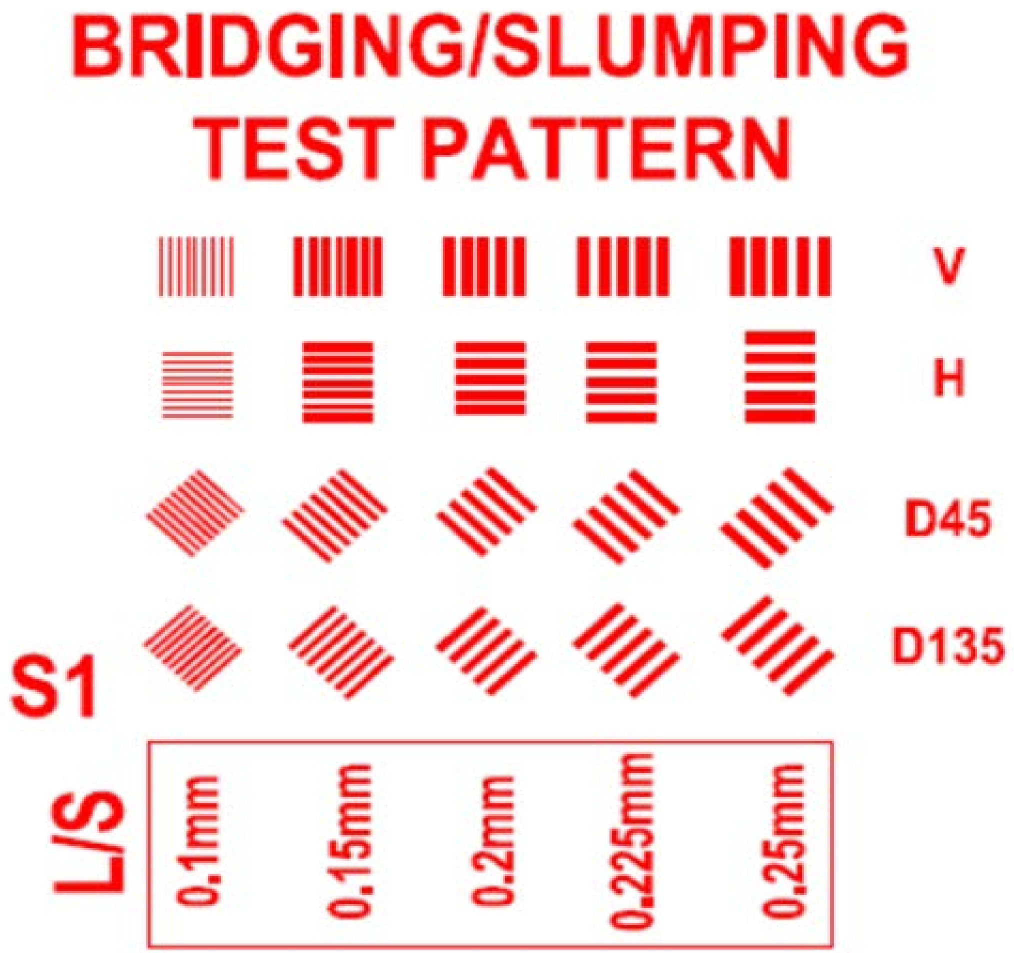
Solder Paste Inspection Settings

- SPI threshold limit set to 15µm
- Production limits typically 40µm to mitigate the effect of PCB topography (i.e. nomenclature, mask irregularities, traces etc.)
- Threshold settings <40µm not recommended outside of study environment

Goal – Isolate powder mesh size implications from other input variables.

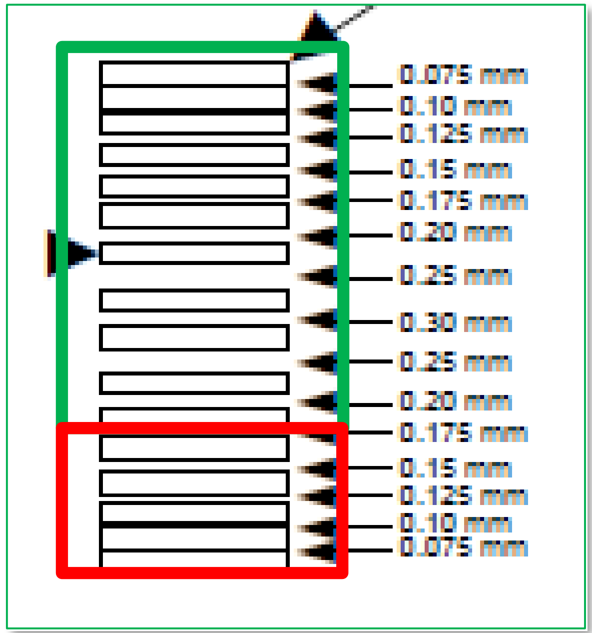
Test Vehicle Slump Test Pattern

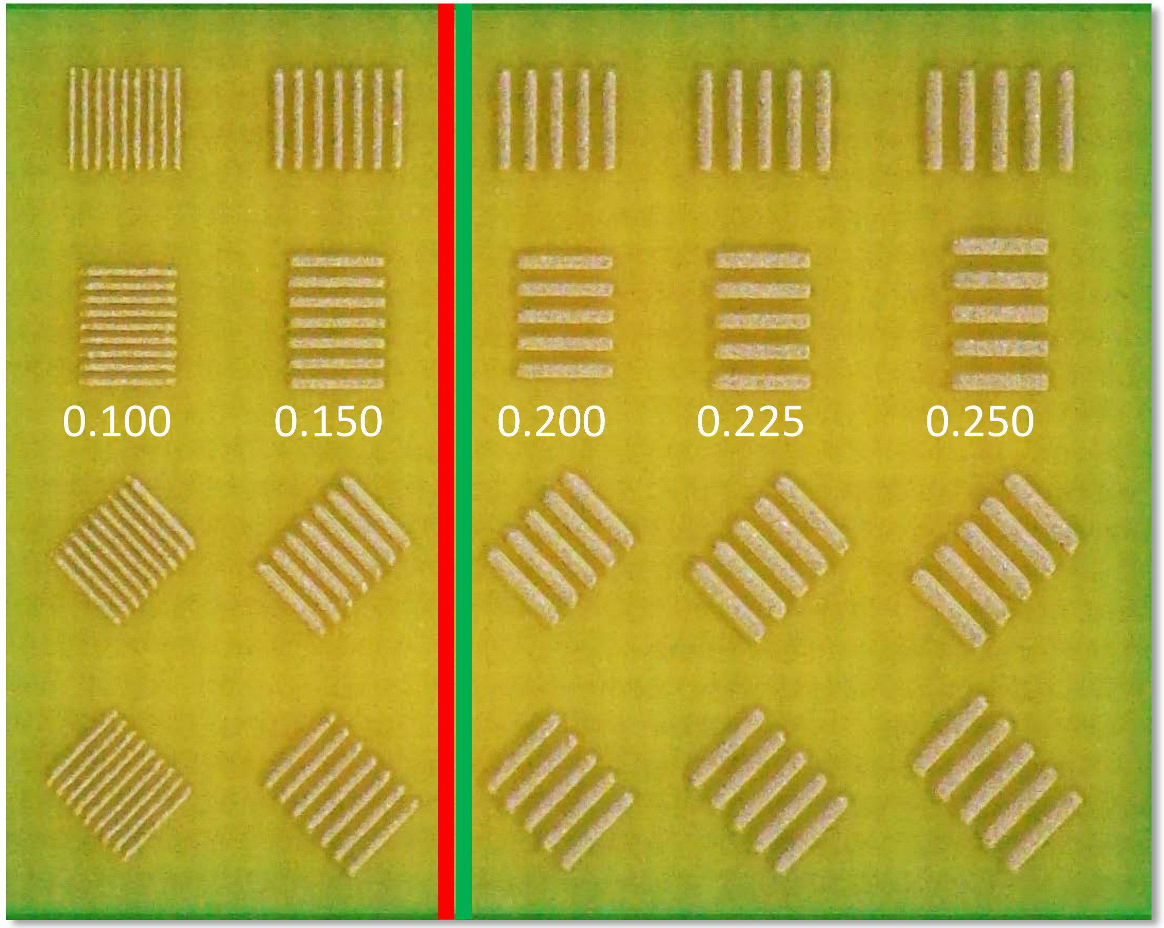
- Two sets of patterns; one set per board (3 per panel)
- Inspected 10-20 minutes after print
- Environment - 25.4° C (77.4° F) and 59% RH



One set of slump patterns read per board – 3 per panel

IPC Slump Test Pattern





Red = Below IPC Threshold
Green = Above IPC Threshold

Recording Slump Test Results

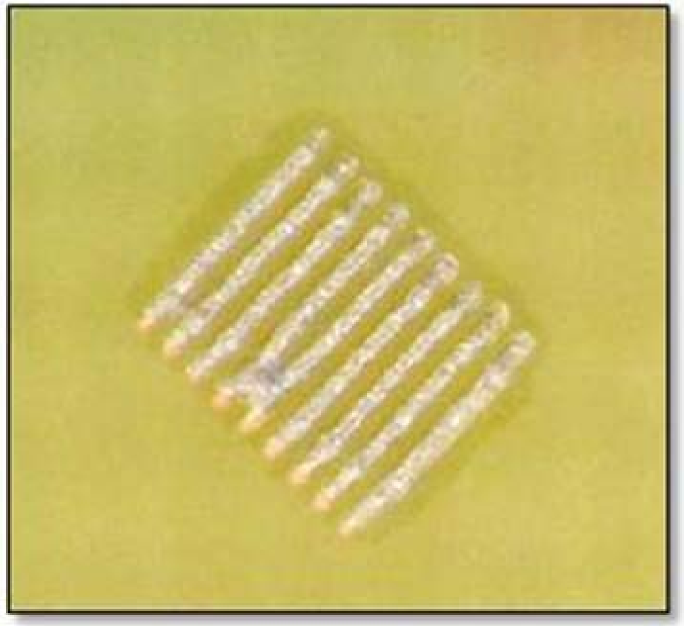
Refriger-ation	Powder Size	Time	Board #	Board Label	SPI File Name	Start/Stop Time	Comments	Slump Board 1	Slump Board 2	Slump Board 3
Fresh	Type 4	0	1	F4-T0-#1	F4-T0-bd 1-5	10:40	Print Params:	0	0	0
			2	F4-T0-#2			- 40mm/sec	0	0	2
			3	F4-T0-#3			-10 kg/14" blades	0	1	0
			4	F4-T0-#4			- 1mm/sec sep spd	0	0	0
			5	F4-T00-#5		10:47	- 3mm sep dist	1	1	2
		30	1	F4-T30-#6	F4-T30-bd 6-10	11:19	Print Params:	0	0	0
			2	F4-T30-#7			Same	0	0	0
			3	F4-T30-#8				0	0	1
			4	F4-T30-#9				1	3	2
			5	F4-T30-#10		11:25		0	0	0
		60	1	F4-T60-#11	F4-T60-bd 11-15	12:27		0	0	0
			2	F4-T60-#12				0	0	1
			3	F4-T60-#13				0	0	0
			4	F4-T60-#14				0	0	0
			5	F4-T60-#15		12:33		0	0	0
		90	1	F4-T90-#16	F4-T90-bd 16-20	2:06		0	0	0
			2	F4-T90-#17				0	0	1
			3	F4-T90-#18				0	0	0
			4	F4-T90-#19				0	0	1
			5	F4-T90-#20		2:12		0	0	0

All bridging was at 0.1 spacing; no orientation trends were identified.

Slump Test Results

Powder Type	Fresh	Aged
T4	17	0
T5	3	2
T6	23	1

All pastes tested passed IPC criteria. The only failures noted were at half the finest IPC pitch.



Aged Paste shows evidence of thickening after 2 weeks at room temperature

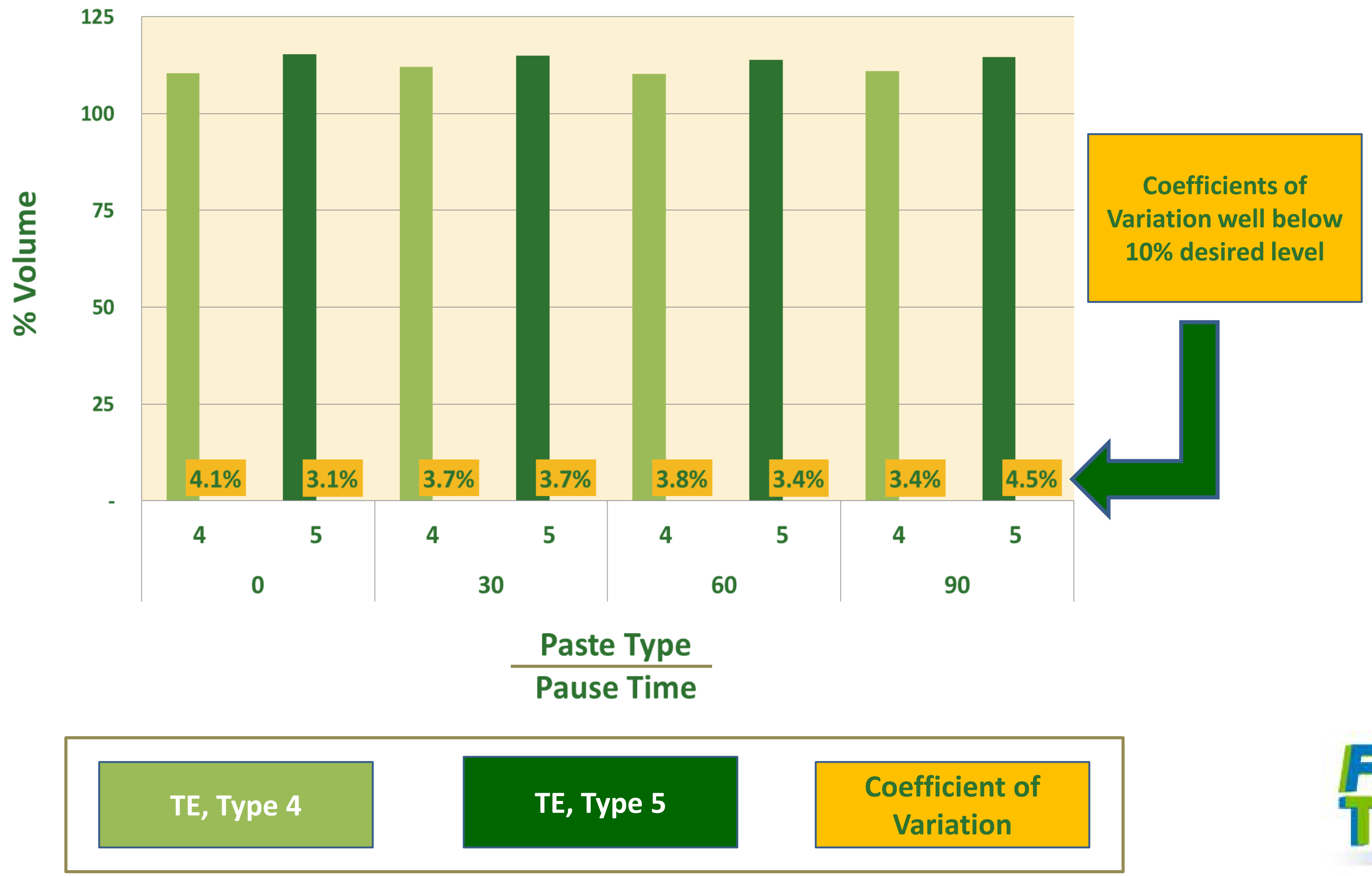
Print Test Results

Reporting Methods:

- Average Volume
- Average Transfer Efficiencies
- Coefficient of Variation (CV) = 1 Std. Deviation/Average
  - Normalizes data for easy comparison
  - More effective than CpK for differing devices
- Sample Size:
  - 3780 data point per 0.5mm BGA (all squircles)
  - 16200 data point per 0.4mm BGA (all squircles)
  - 480 data point for Print-to-Fail Pattern (square, circle, rectangle)

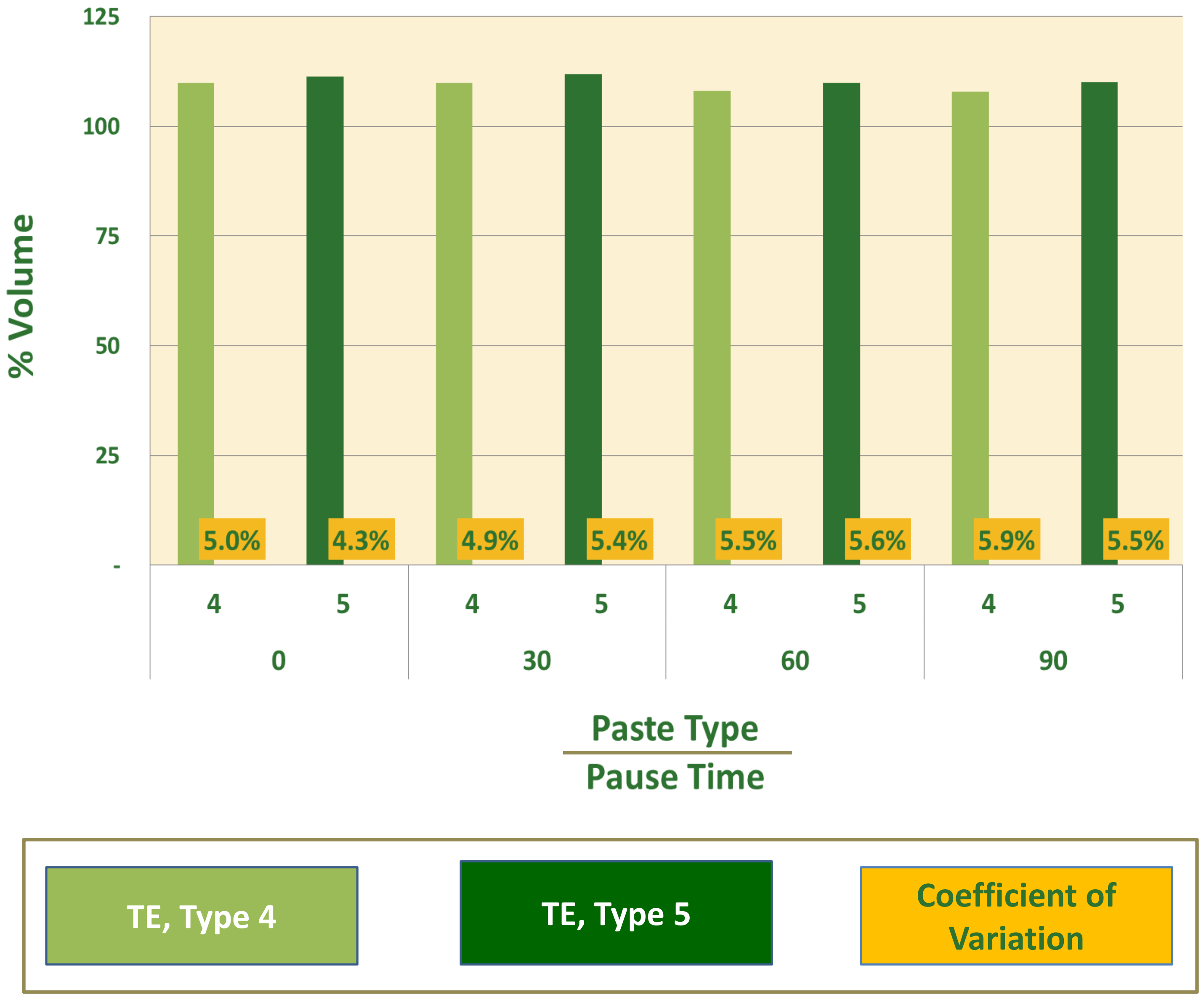
0.5 mm BGA Transfer Efficiency

11.4 mil Squircle Aperture/11.4 mil NSMD Pad

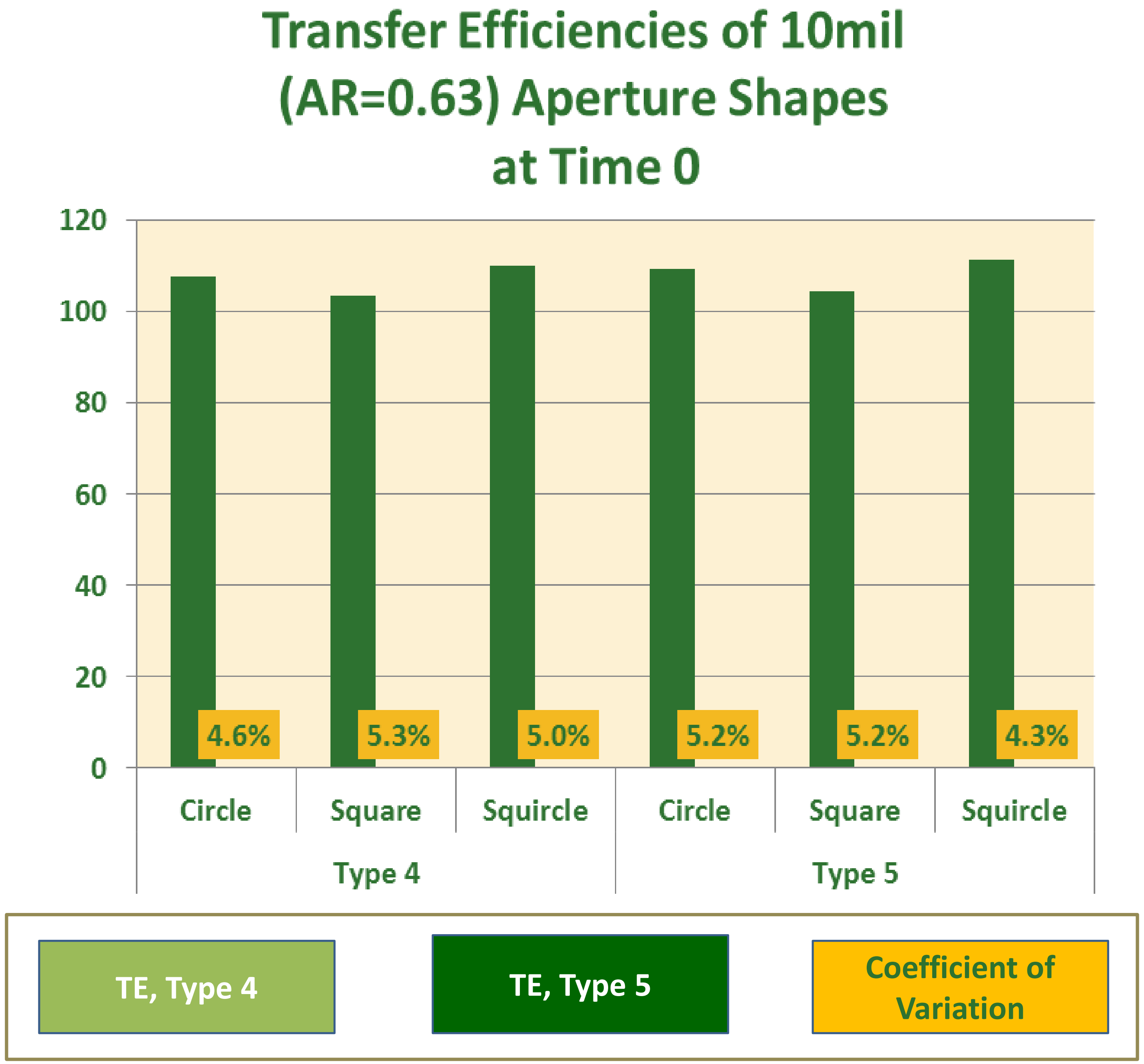


0.4 mm BGA Transfer Efficiency

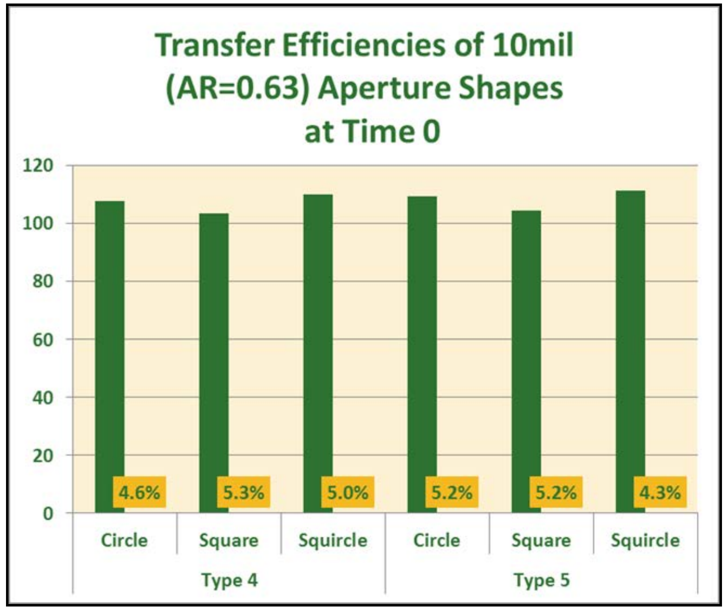
10 mil Squircle Aperture/10 mil NSMD Pad

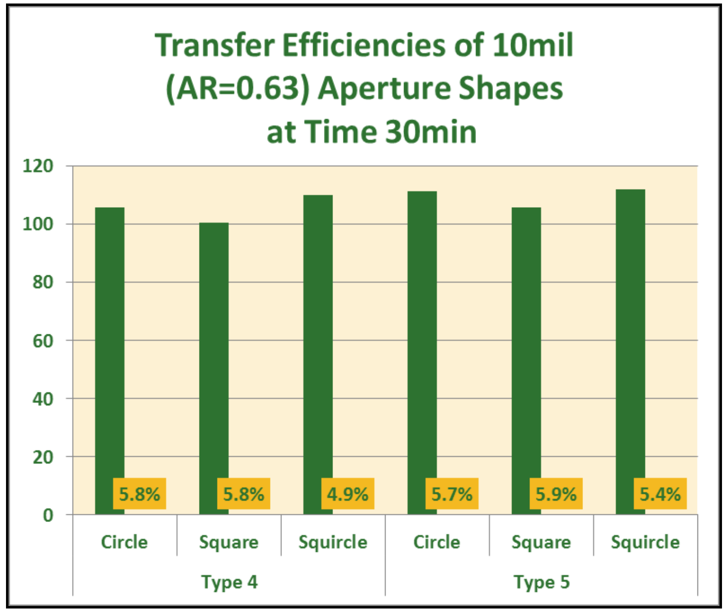


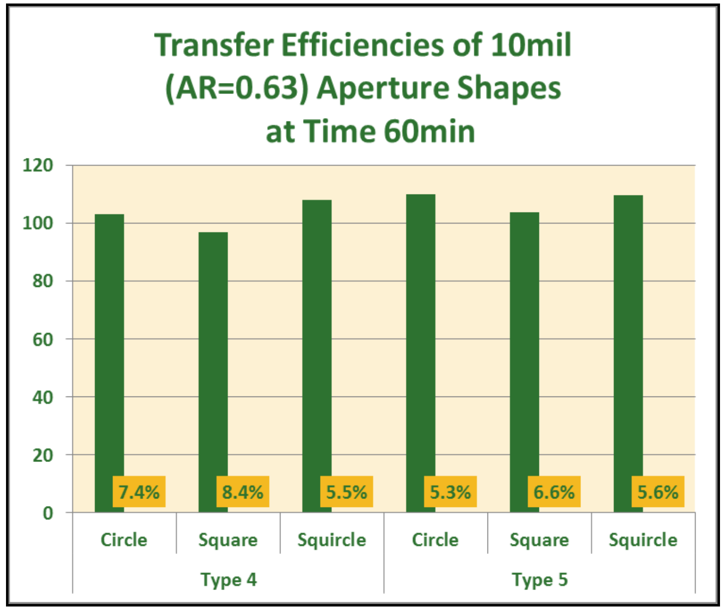
Aperture Shape Transfer Data

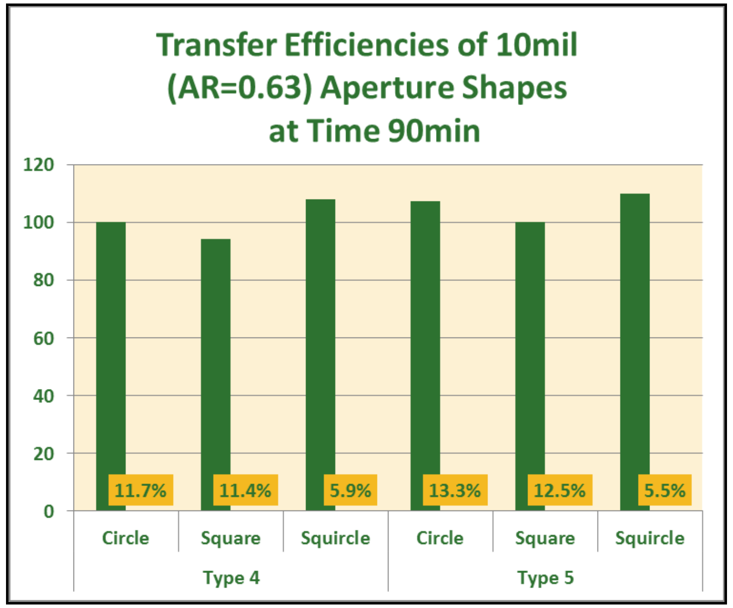


Aperture Shape Transfer Data – Over Time

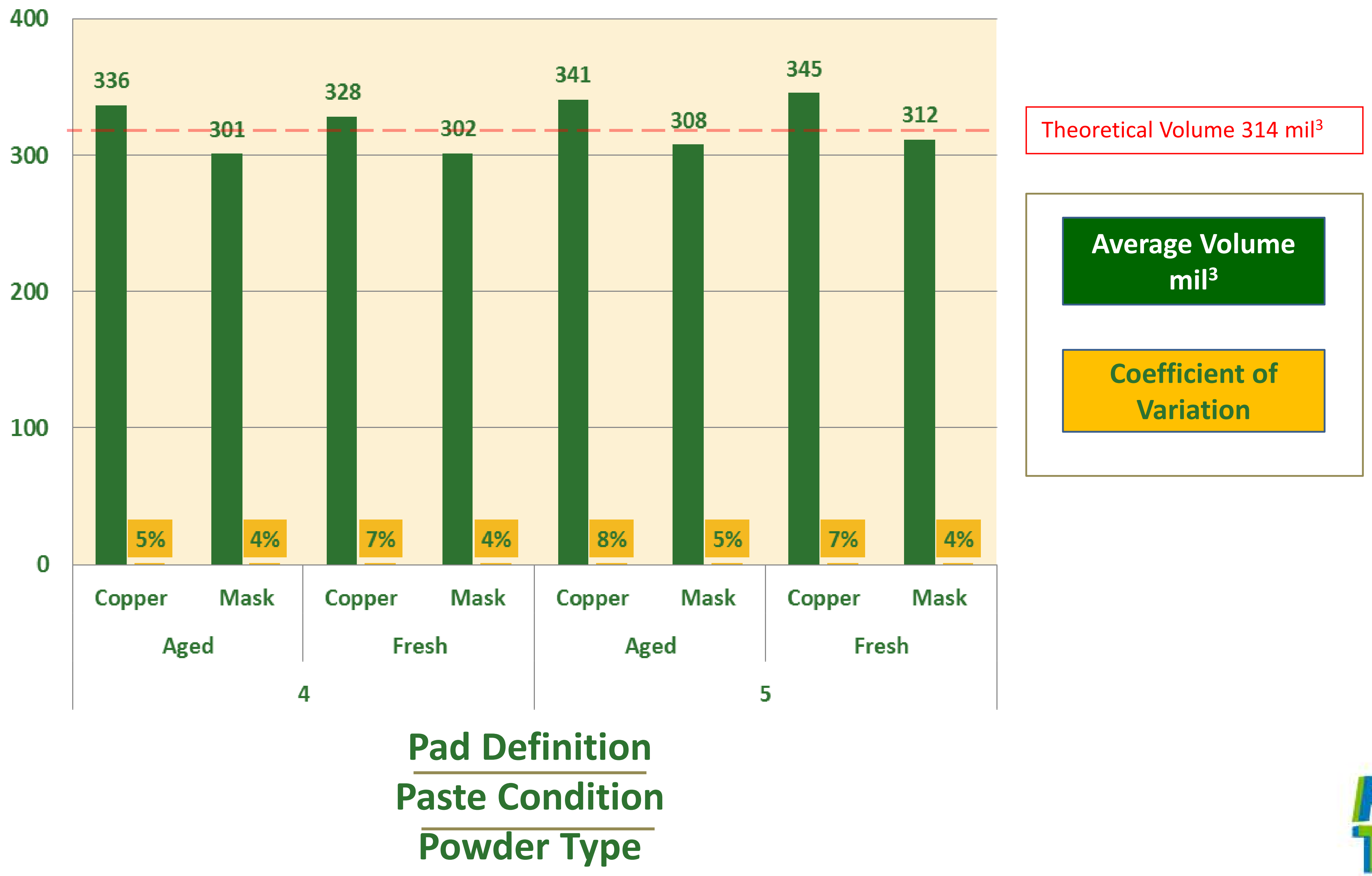




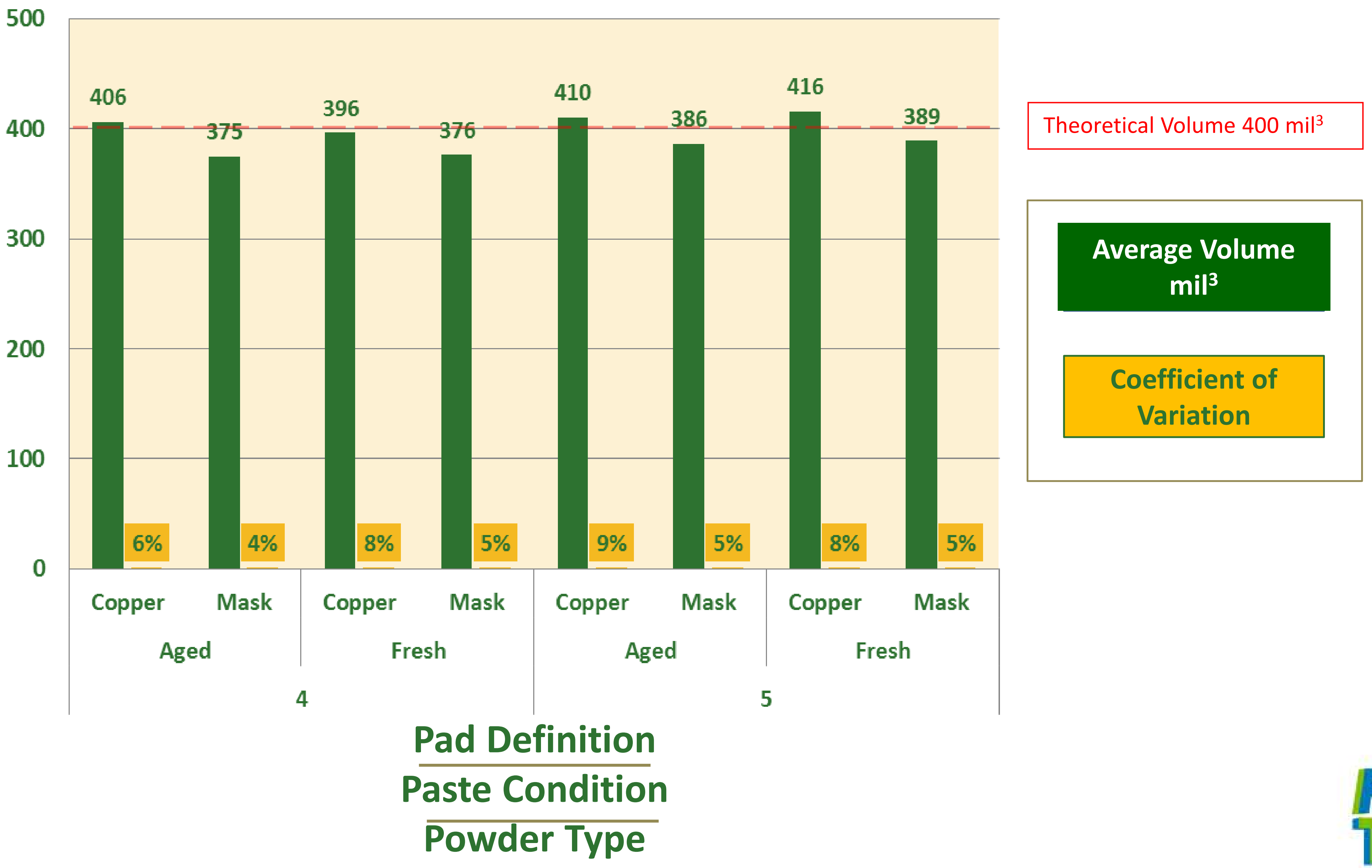




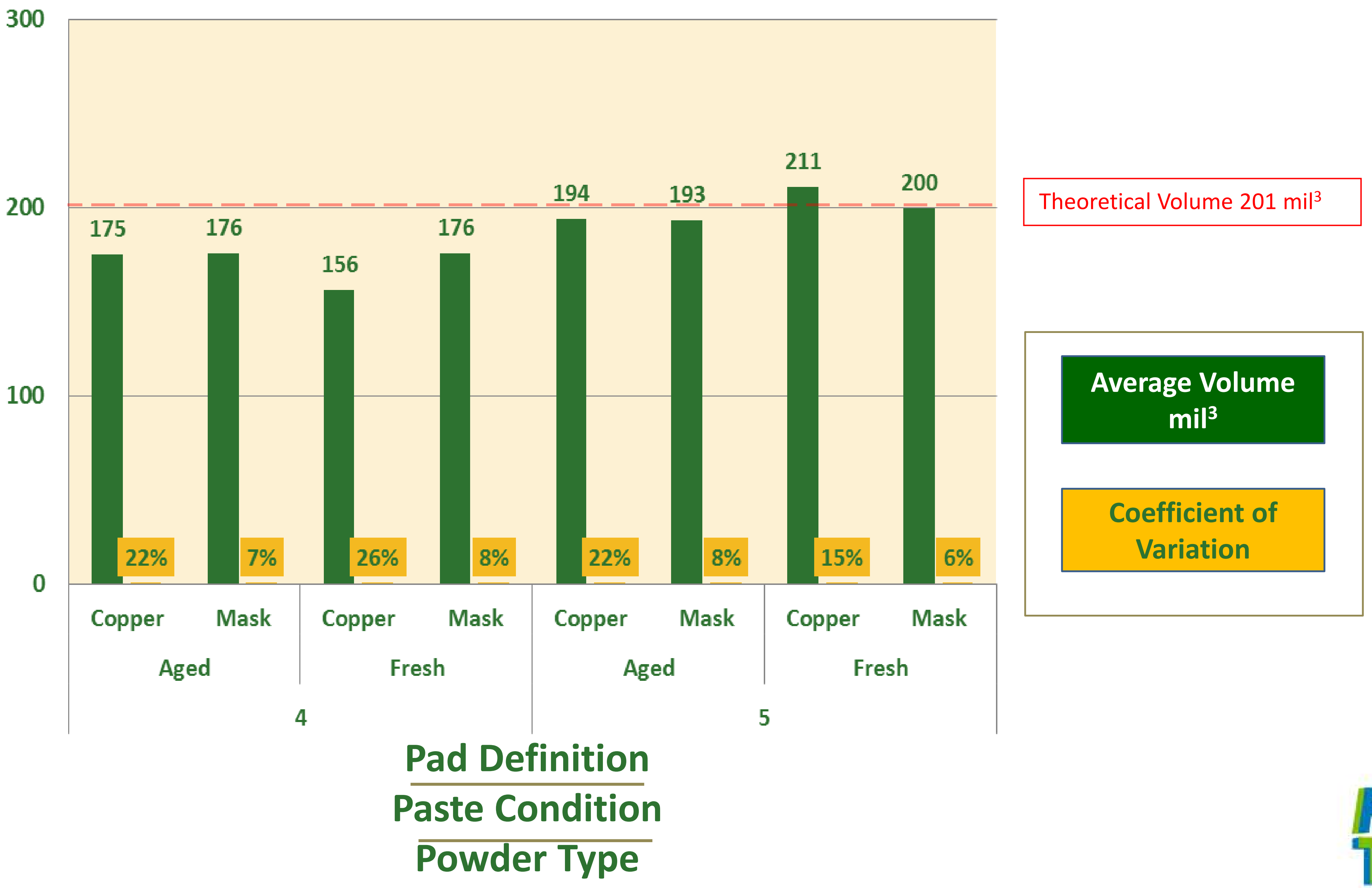
Deposit Volume for 10 mil Circles AR = 0.63



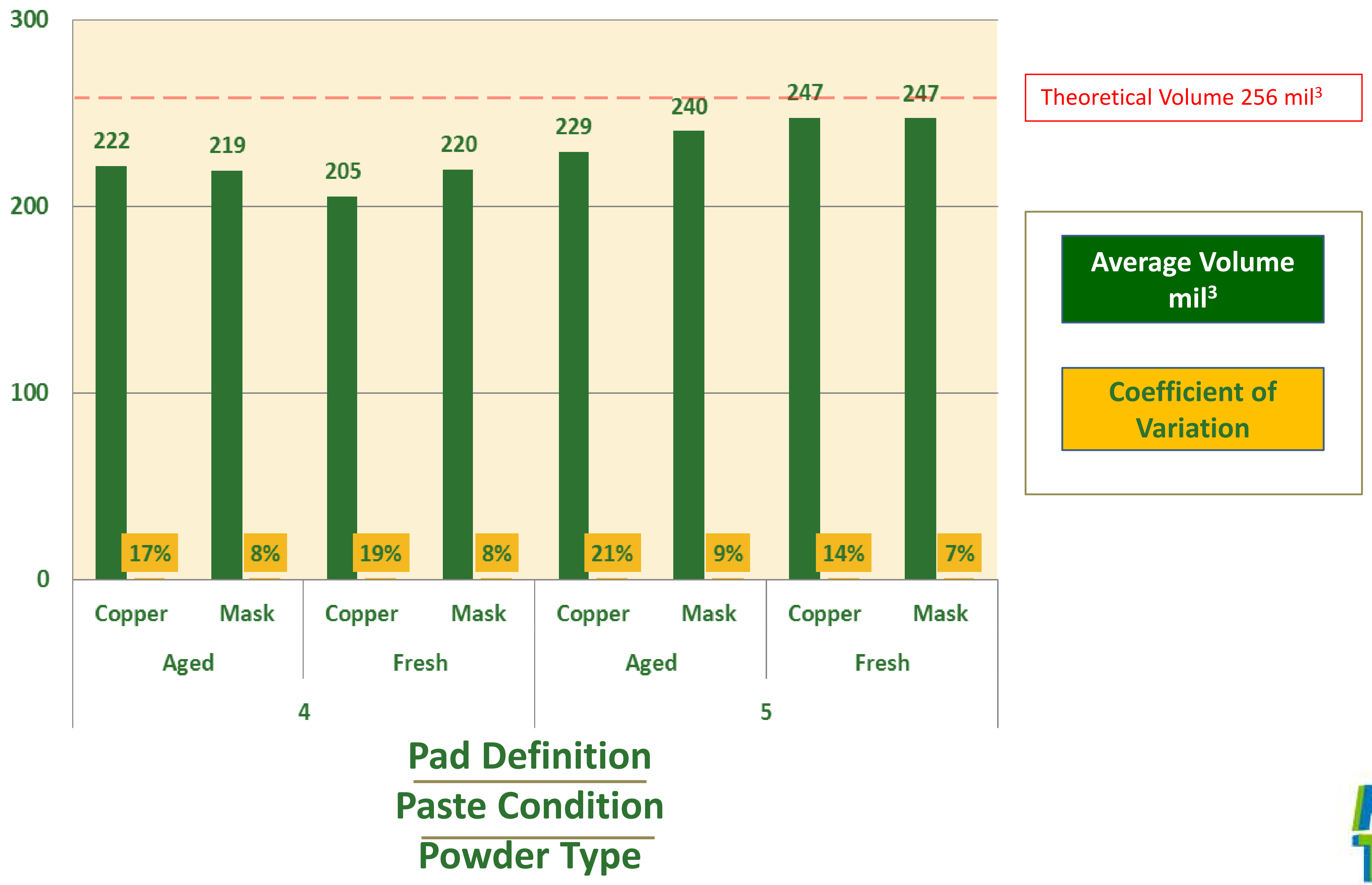
Deposit Volume for 10 mil Squares AR = 0.63



Deposit Volumes for 8 mil Circles AR = 0.63



Deposit Volumes for 8 mil Squares AR = 0.63



Conclusions (1)

Powder Size

- Reducing from T4 to T5 provides modest benefit at low ARs
- Tests performed on new and calibrated equipment in lab – ideal situation
- Prior to downsizing powder, check equipment and setup; T4 paste demonstrated excellent print capability at low ARs - even down to 0.50, using nano-coated stencils
- T6 solder powder was print tested, but is not currently a consideration in SMT printing; however, T6 is well suited to new solder paste dispense and jetting operations

Room Temperature Aging

- Had no considerable effect on prints down to 8 mil (AR=0.50)
- Appeared to slightly raise viscosity of paste
- Differences were noted only in 4 mil (0.1 mm) slump test

Conclusions (2)

Pause Time

•For 10 mil NSMD features, T4 and T5 pastes all met the benchmark of 80% TE and CV<10% up to 60 min pauses

•At 90 min, TE remained acceptable - the squircle aperture maintained <10% CV benchmark while the other apertures edged slightly above it

•At pauses over 60 min, first prints are always acceptable but not optimal; hence the recommendation to knead or print dummy boards for best process control

Pad Definition

•Printing on NSMD pads can produce excess volume (>100% TE) with considerable variability, mainly due to difficulty in gasketing, especially with 1:1 aperture:pad ratios

•Printing on mask defined pads better controls paste volume and deposit variability

•As feature sizes shrink, more pads will migrate to mask definition

Conclusions (3)

Aperture Shape

- When printing at 1:1 aperture:pad ratios, the squircle outperformed the square or circle
- The squircle minimized variation, even at extended pause times
- Squircles offer the higher volume of the square, without as much corner area to enable pump out or accumulate dried solder paste