Meeting the Challenges of Ultra-Fine Feature Printing and Reflow Through Optimization of Pb-Free Solder Paste

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ABSTRACT
The trend of miniaturization of electronics requires the creation of ultra-fine solder joints. Semiconductor manufacturing, flip chip, package on package (PoP), system in package (SiP), and miniature components like 0201M (008004 Imperial) may require printing through stencil apertures of 50-100 µm (2-4 mils) in size. Creating these miniature solder joints requires solder pastes optimized for use with IPC Type 6 (5-15 µm) or smaller solder powder sizes.

Type 6 solder powder size has a much higher surface area per Kg than Type 3, 4, and 5 solder powder sizes. The high surface area of Type 6 solder powder affects the performance of the solder paste including: shelf life, stencil life, printability, reflow performance, voiding, and reactivity or stability. Testing was conducted to measure solder paste performance for both water soluble and no clean solder pastes with Type 6 SAC305 solder powder. The performance of older generation solder pastes was compared to newly optimized solder pastes. The solder paste data was compared, and recommendations made for successful print and reflow in these miniaturized soldering applications.

Key words: Pb-free solder paste, ultra-fine feature, solder powder size, reflow in air, stencil aperture size, semiconductor manufacturing, flip chip, package on package (PoP), system in package (SiP), solder paste performance.

INTRODUCTION
The trend of miniaturization in electronics continues to challenge solder pastes. As solder joints become smaller, it becomes necessary to use smaller solder powder sizes which allow the solder paste to print and reflow successfully. Decreasing solder powder size carries the challenge of increased surface area of the solder powder. This higher surface area requires the solder paste flux to do more chemical "work" to remove metal oxides and prevent further oxidation during air exposure and reflow of the solder paste. The surface area of the solder powder increases dramatically from IPC Type 3 through Type 6 solder powder sizes (Table 1).

Table 1. Surface Area by Size for 1Kg of Solder Powder.

Solder Powder Size (IPC Type)	**Size Range of > 80% (µm)**	**Middle Surface Area of 1Kg (m^2)**	**Amount of Surface Area Over T3**
Type 3	25 - 45	22.9	**-**
Type 4	20 - 38	27.7	**1.2x**
Type 5	15 - 25	40.2	**1.7x**
Type 6	5 - 15	80.3	**3.5x**

For the same mass of solder powder, IPC Type 4 solder powder has 1.2 times the surface area of Type 3. IPC Type 5 solder powder has 1.7 times the surface area of Type 3. IPC Type 6 solder powder has 3.5 times the surface area of Type 3. Most modern solder paste fluxes are formulated to work well with Type 3 and 4 solder powders. Some fluxes can also accommodate Type 5 solder powder. The considerably higher surface area of Type 6 solder powder requires changes to the solder paste formulation. An increase in activity level and oxidation protection, as well as rheological modifications are required for solder pastes with Type 6 solder powder.

Cost of the solder powder is an important consideration when deciding to switch to a smaller solder powder size. The relative solder powder costs associated with Types 3 to 6 solder powders is shown below (Table 2).

Table 2. Solder Powder Size and Relative Cost

Type	**Relative Powder Cost**
3	1
4	1
5	1.1
6	4

Type 3 and 4 solder powders have similar cost while Type 5 costs roughly 10% more. Type 6 solder powder includes a significantly higher cost that is 4 times that of Type 3 and 4 solder powders. This cost increase translates directly to an increased cost of the solder paste.

The main reason for switching to a smaller solder powder size is to improve printability of the solder paste through small stencil apertures. One way to select a solder powder size for the aperture size is called the "5-ball rule" [1]. This rule suggests that a minimum of 5 particles of solder powder ("balls") must fit across the narrowest dimension of a stencil aperture (Figure 1).

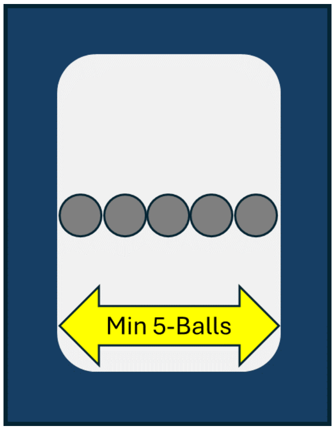


Figure 1. Stencil Aperture Size and the "5-Ball" Rule

The "5-ball" rule minimum and recommended minimum aperture sizes for each solder powder size is shown below (Table 3).

Table 3. Solder Powder Size and the Smallest Aperture Size Recommended.

Type	Size (µm)	Size (mils)	Smallest Aperture 5-Ball Rule (mils)	Smallest Aperture Recommended (mils)
2	45 - 75	1.8 - 3.0	15.0	16 - 17
3	25 - 45	1.0 - 1.8	9.0	10 - 11
4	20 - 38	0.8 - 1.5	7.5	9 - 10
5	15 - 25	0.6 - 1.0	5.0	6 - 7
6	5 - 15	0.2 - 0.6	3.0	4 - 5
7	2 - 11	0.1 - 0.4	2.0	3 - 4

Type 6 solder powder can theoretically allow a solder paste to print through a 3.0 mil wide stencil aperture, although 4-5 mil aperture sizes are recommended for adequate printability. The "5-ball" rule does not take into consideration the flux portion of the solder paste. Different solder pastes perform differently in printing applications due to variations in flux chemistry and rheology. The metal content of the solder paste also affects rheology and printability of the solder paste. When optimizing a solder paste to print through smaller stencil apertures, the solder powder size, metal concentration, and solder paste rheology need to be balanced. The flux chemistry also needs to be optimized with respect to oxide removal and protection of the solder powder.

It is the intent of this work to detail testing and progress in the optimization of solder pastes for use with Type 6 and smaller solder powder sizes. Older technology solder pastes will be compared to newer technology solder pastes. Recommendations will be made for successful print and reflow in these miniaturized soldering applications.

PRIOR WORK

T. Lentz [2] studied the effects of solder powder size on solder paste performance with SAC305 Types 3, 4, 5, and 6 solder powder size. Two solder pastes were tested with each powder size, which were water-soluble and no-clean formulations. Testing included: slump, solder balling, printing through small stencil apertures, print and pause, reflow, voiding, and stability. These solder pastes were not formulated for use with Type 6 solder powder size, and therefore the overall performance was worse for Type 6 than for the larger solder powder sizes.

E. Nauss [3] studied sealed versus exposed atmosphere printing for Type 6 solder pastes. Two solder pastes were tested with Type 6 solder powder in a challenging print application. One solder paste performed better than the other. The sealed chamber increased the stencil life and the print consistency over time.

T. O'Neill, et. al. [4] studied the impact of Type 4, 5, and 6 SAC305 solder pastes on solder paste print performance. Stencil design and print parameters were optimized. Square apertures with radiused corners provided the highest solder paste volume and lowest variability as compared to circular and square apertures, especially after long pauses in printing. Reducing solder powder size had a modestly adverse effect on print and pause performance over time, but also provided a modest benefit in printed volume for apertures below 0.66 area ratio (AR).

C. Ashmore [5] studied solder paste printing for the Metric M0201 assembly process. Type 5 and 6 solder pastes were used. The pad sizes were 125 x 115 µm and 100 x 115 µm with 0.50 and 0.45 aperture area ratios respectively. The Type 6 solder paste provided a fuller print (higher volume) but created more defects than the Type 5 solder paste. The defects were mainly related to high volume and included bridging, and shift/skew of the components.

S. Pei-Lim, et. al. [6] studied challenges in fine feature solder paste printing for SiP applications. Type 6 solder pastes were used with different stencil designs and printing parameters for 01005 Imperial (M0402) and 008004 Imperial (M0201) components. Two water soluble and two no clean solder pastes were used with Type 6 solder powder. Printing down to an area ratio of 0.60 was possible using the correct solder paste rheology. Metal content of the solder pastes also had a significant effect on printability.

S. Joshi [7] reported on Pb-free solder paste development for ultra fine-pitch printing and reflow of M03015 and M0201 metric components. SAC305 with a size range of 5 – 20 µm was used, which is slightly larger than IPC Type 6 (5 – 15 µm). A newly optimized solder paste gave less bridging and better response to pause in printing as compared to older technology. Thixotropy of the new solder paste was optimized for smaller solder powder sizes. Nitrogen was required to achieve acceptable reflow with the solder pastes evaluated.

S. Harter, et. al. [8] studied printing processes for M03015 metric component sizes. Stencil designs, materials, and nano-coatings were varied. SAC305 Type 5.5 (5 – 20 µm) and Type 6 (5 – 15 µm) solder pastes were used. The stencil aperture sizes varied from 120 x 139 µm to 190 x 219 µm. The main effects of the tests showed the following. Type 6 solder paste gave lower printed volume than Type 5.5. 80 µm stencil thickness gave lower printed volume than 60 µm. Bridging on smaller pad spacings was reduced with: thinner stencil, nano-coating, and Type 6 solder paste.

E. Griffith [9] reported on the evolution and application of fine feature solder paste printing for heterogenous application. System in package (SiP) applications typically use 008004 Imperial components, Type 6 and 7 solder pastes, and have small gaps (50 µm) between the pads. Print testing was conducted with three solder paste fluxes mixed with 3 quality levels of Type 6 solder powder, and pad sizes of 6 and 7 mils. Different combinations of flux and solder powder style gave different printing and slump results. This work demonstrated the need to optimize flux, solder powder size, and solder powder quality for SiP applications.

N. Lee [10] studied no clean solder pastes for SiP and 01005 Imperial assembly. This paper summarizes miniaturization of electronics, the limits of the solder paste print process, and the adequacy of flux capacity for smaller solder powder sizes. For a defect rate of less than 0.1%, the solder powder size shall not exceed 1/7 of the aperture width. Type 6 solder powder size is preferred for 0.2 mm pitch components. Type 7 solder powder would be required for 0.1 mm pitch components. Flux burn off was compared for paste flux without solder powder, and solder paste. With a small deposit size, solder paste retains more residue than paste flux due to the "flux shell" phenomenon. The flux workload required for Type 6 solder powder is approximately 2.3 times of that required for Type 3 powder size. Other challenges that solder paste must overcome are poor powder quality, oxides from parts, and oxidation at reflow.

EXPERIMENTAL METHODOLOGY

Testing was conducted to measure the strengths and weaknesses of five solder pastes each made with SAC305 Type 6 solder powder (5-15 µm). The testing detailed below is challenging and was designed to measure the failure limits of the solder pastes. The data was used to compare the strengths and weaknesses of the solder pastes to each other.

The solder paste technologies used to make the solder pastes are no-clean and water-soluble, of older and newer technology. The older technology solder pastes were designed for Type 3 (25-45 µm), 4 (20-38 µm), and 5 (15-25 µm) solder powder sizes. The newer solder pastes were designed to be capable with smaller solder powder sizes including Type 6. Two new no-clean solder pastes, and one new water-soluble solder paste were evaluated against older generations of no-clean and water-soluble solder pastes. The solder pastes were made with the following metal concentrations (Table 4).

Table 4. Solder Paste, Flux Class and SAC305 Type 6 Metal Content.

Solder Paste	Flux Class (J-STD-004)	Metal Content (% wt)
NC New	ROL0	80.6
NC New 2	ROL0	81.7
NC Old	ROL0	85.0
WS New	ORH1	80.0
WS Old	ORH1	85.0

The metal concentrations were chosen to optimize the print and reflow performance of each solder paste. The older solder pastes were not intended for use with Type 6 solder powder size and are being included for comparison to the newer technology solder pastes.

The PR test board V3 was chosen to measure print and reflow performance (Figure 2).

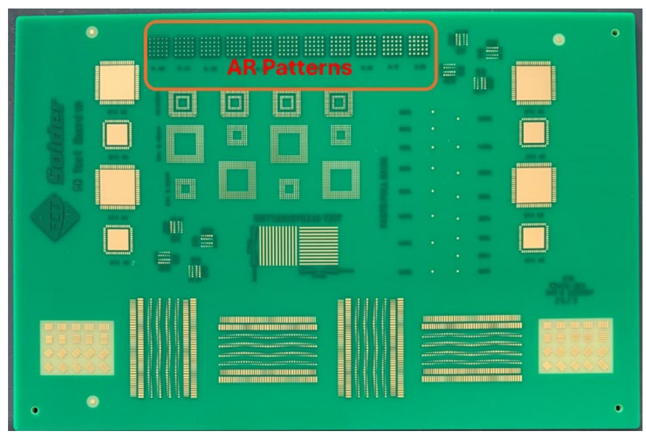


Figure 2. PR (Print and Reflow) Test Board V3.

The area ratio (AR) test patterns near the top edge of the printed circuit board (PCB) were used to measure printed solder paste volumes. These AR patterns have a 5x5 grid of 25 solder mask defined pads for each AR. The stencil apertures are designed with a range of 0.30 to 0.80 area ratios which increase by increments of 0.05 AR.

The stencil was laser cut 75 micron (3 mil) thick fine grain (FG) stainless steel. The stencil design details for the AR patterns are in Table 5 below. The apertures were rounded squares with 25-micron (1 mil) radius corners.

Table 5. Stencil Design Details for the Area Ratio Patterns.

Area Ratio*	Aperture Size (mils)	Theoretical Vol (mils^3)	# Type 6 "Balls"	Aspect Ratio*
0.30	3.40	32.1	5.7	1.13
0.35	3.96	44.5	6.6	1.32
0.40	4.54	59.3	7.6	1.51
0.45	5.12	76.0	8.5	1.71
0.50	5.70	94.9	9.5	1.90
0.55	6.29	116.1	10.5	2.10
0.60	6.88	139.4	11.5	2.29
0.65	7.47	164.8	12.5	2.49
0.70	8.06	192.3	13.4	2.69
0.75	8.65	221.9	14.4	2.88
0.80	9.25	254.1	15.4	3.08

*Values highlighted in **red** violate IPC stencil design guidelines [1].

The area ratios patterns are intended to challenge solder paste printing performance. Many of the area ratios fall below the IPC guideline of 0.60 minimum [1]. Two of the aspect ratios fall below the IPC guideline of 1.50 minimum [1]. The "5-ball" rule is met for each of these aperture designs when calculated using the maximum solder powder size of the main range for Type 6 which is 15 micron (0.6 mils).

Reflow performance was measured using wetting, solder balling and graping patterns (Figure 3).

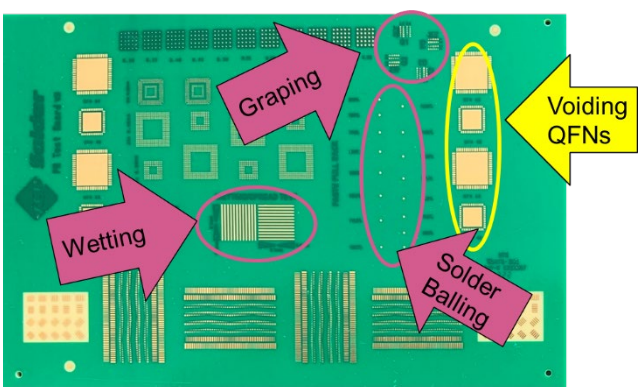


Figure 3. PR Test Board Wetting, Solder Balling, Graping Patterns, and Voiding QFNs.

Voiding was measured using X-ray inspection of the thermal pad solder joints of MLF68 quad-flat no-lead components (QFN). The stencil design in the QFN thermal pads was a standard 9 window pane design with 65% area of coverage of solder paste. 20 void area % measurements were taken for each solder paste.

Printing was done with a commercially available printer and the following print settings (Table 6).

Table 6. Printing Process Parameters.

Print Parameter	Value
Print speed (mm/sec)	30 mm/sec
Blade length (mm)	300 mm
Print pressure (kg)	5.0 – 8.0 Kg
Separation speed (mm/sec)	3 mm/sec
Separation distance (mm)	2 mm

The print pressure was set to 5.0 Kg for most of the solder pastes, except for the NC New and NC New 2 solder pastes which required a higher pressure of 8.0 Kg. Underside stencil cleaning was not performed during this experiment.

Convection reflow was performed in a commercially available 7-zone oven in an air atmosphere. The recorded reflow profiles are detailed below (Table 7).

Table 7. Measured Reflow Profile Parameters.

Reflow Parameter	SAC305 Ramp to Spike (RTS)	SAC305 Long Time Above Liquid (LTAL)
Soak Time (150-200°C)	76 to 78 sec	70 to 78 sec
Time Above Liquidus (>220°C)	57 to 59 sec	134 to 138 sec
Peak Temperature	241 to 244°C	247 to 250°C
Time from 25°C to Peak	4.4 to 4.6 min	5.6 to 5.8 min

A 24-hour print and pause test was used to challenge the solder pastes. The environmental conditions during this test were 22–23°C and 28-32% RH. The print and pause test is one way to determine the usable stencil life of the solder pastes.

The basic process used to test the solder pastes is shown below.

1. Insert the stencil into the printer and load it with approximately 275-325 grams of solder paste.
2. Print PCBs #1-5 and measure printed solder paste volumes in the AR patterns (Time = 0).
3. Place 4 QFN68 components on each PCB and reflow PCBs #1-5.
4. Measure reflow performance using the patterns on PCBs #3 and 4, and measure voiding in the QFN thermal pads on PCBs #1-5.
5. Allow the solder paste to sit idle on the printer for 1 hour. Print PCBs #6 and 7 and measure solder paste volumes (Time = 1 hr).
6. Place PCBs #6 and 7 on a benchtop and reflow the next day, with 24 hours of air exposure after print.
7. Allow the solder paste to sit idle on the printer for 1 hour. Print PCBs #8 and 9 and measure solder paste volumes (Time = 2 hrs).

8. Allow the solder paste to sit idle on the printer for 2 hours. Print PCBs #10 and 11 and measure solder paste volumes (Time = 4 hrs).
9. Allow the solder paste to sit idle on the printer for 4 hours. Print PCBs #12 and 13 and measure solder paste volumes (Time = 8 hrs).
10. Allow the solder paste to sit idle on the printer for 16 hours. Print PCBs #14 and 15 and measure solder paste volumes (Time = 24 hrs).

During this print and pause test, it is normal for the volume of the printed solder paste to decrease over time, especially for the smallest apertures (smallest area ratios). As the test progresses, the solder paste eventually clogs progressively larger apertures. Ideal solder pastes consistently print throughout this test without a decrease in solder paste volumes. Solder pastes with higher reactivity, and that are less environmentally tolerant tend to "dry" more quickly and clog the stencil apertures. Solder pastes are compared by measuring the rate of decrease of printed solder paste volumes over time.

The reflow performance of the solder paste is measured freshly printed and after 24 hours of the printed PCBs being exposed to the air. The intent is to gage the air reactivity / stability of the solder paste between print and reflow. Reflow was conducted with the SAC305 RTS profile for most testing. Reflow performance was also measured using the SAC305 LTAL profile for comparison.

Below is a list of other tests that were run on the solder pastes including several standard methods from IPC J-STD-005 [11] and JIS-Z-3284 [12].

- Tack force of freshly printed solder paste.
- Tack force of printed solder paste stored at 21-22°C (70-72°F) and 48-54% RH, for 24, 48, and 72 hours.
- Viscosity with T-bar spindle and Spiral viscometer.
- Reflow after printed PCBAs were exposed to air for 24 hours.

Solder pastes were "heat aged" in a dry oven at 34-36°C (93-97°F) for 3 days to simulate shipping delays in warmer conditions. The solder paste jars were sealed during heat aging. After heat aging, tack force and viscosity of these solder pastes were measured and compared to the values for fresh solder paste.

RESULTS AND DISCUSSION

Print Data at Time = 0

Initial (time 0) transfer efficiency (TE%) data for each solder paste was compared, broken out by aperture size below (Figure 4).

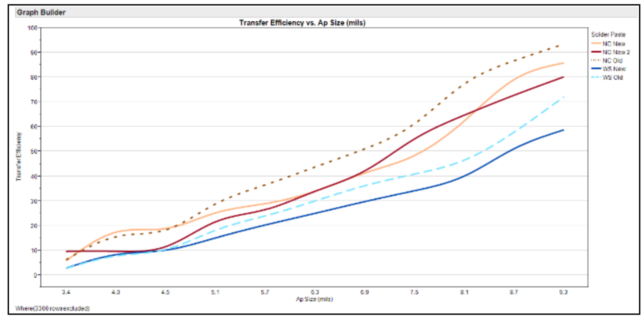


Figure 4. Initial TE% by Solder Paste for Each Aperture Size.

A typical passing minimum TE% of 50% is used in solder paste inspection (SPI) equipment. Using this criterion, each solder paste can be printed through the minimum aperture sizes shown below with a 75 micron (3 mil) thick stencil (Table 8).

Table 8. Minimum Aperture Sizes and Area Ratios for Each Solder Paste with a Min TE% of 50%

Solder Paste	Min Aperture Size (mils)	Min Area Ratio
NC New	7.5	0.65
NC New 2	6.9	0.60
NC Old	6.9	0.60
WS New	8.7	0.75
WS Old	8.1	0.70

Some solder paste volume was printed below these area ratios down to an aperture size of 4.5 mils (0.40 AR). The transfer efficiency decreased as aperture size decreased. These solder pastes may be used for apertures below the sizes in Table 8 depending upon the application.

Print and Pause Data

The 24-hour print and pause test showed some differences in the performance of the solder pastes (Figure 5). The transfer efficiency (TE%) data for all aperture sizes with area ratios greater than 0.35 are combined into each box plot.

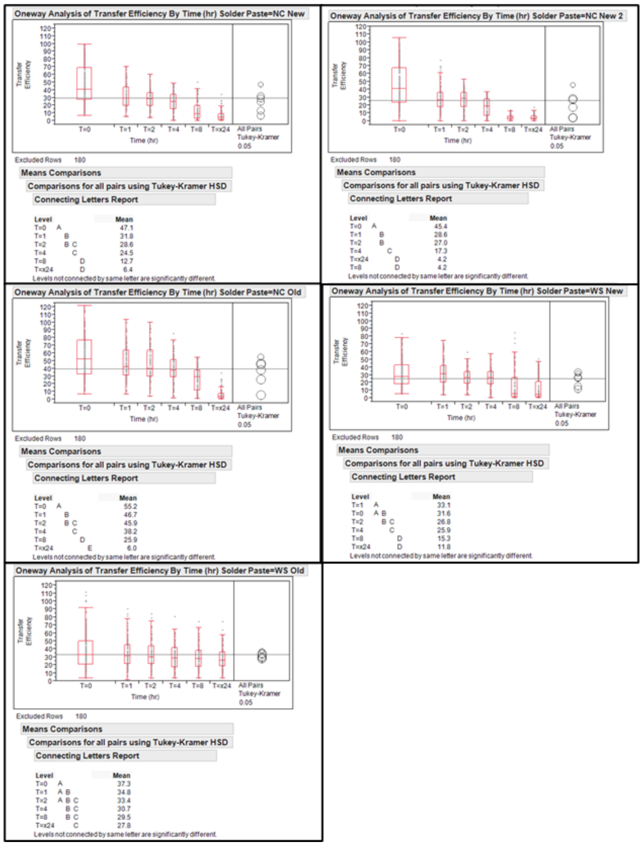


Figure 5. 24-Hour Print & Pause with TE% for Each Print Time. Includes all AR's > 0.35.

The NC New, NC New 2, NC Old, and WS New solder pastes all showed significant TE% decrease over time. The WS Old solder paste, while not formulated for Type 6 solder powder size, showed very stable print performance over time.

The mean TE% for each solder paste was plotted against print time. Linear trendlines were plotted to calculate the rate of TE% decrease (Figure 6).

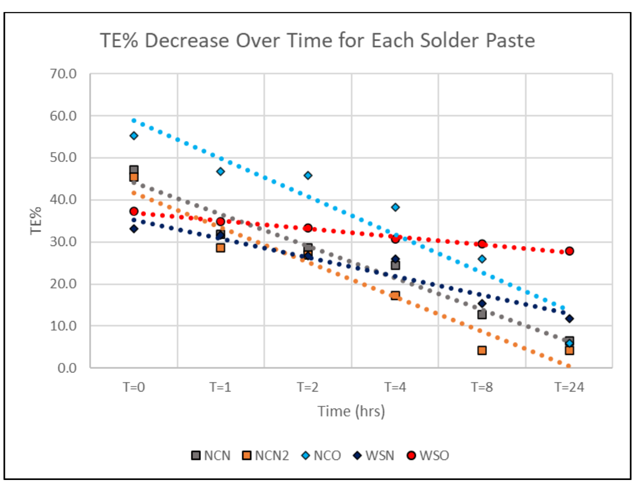


Figure 6. Rate of TE% Decrease for Each Solder Paste Over 24 hours, Inlcuding all AR's > 0.35.

The slopes of the linear trendlines for each solder paste were used to calculate the normalized rates of TE% decrease. The new and old solder pastes of each were compared to each other.

- The NC New solder paste showed a slower 0.8x TE% decrease as compared to the NC Old baseline.
- The NC New 2 solder paste showed a slower 0.9x TE% decrease as compared to the NC Old baseline.
- The WS New solder paste gave a faster 2.4x TE% decrease as compared to the WS Old baseline.

The new technology solder pastes were formulated with a balance of print and reflow properties for smaller solder powder sizes. The ability of the new no-clean solder pastes to protect the solder powder from oxidation, and to maintain printability was improved over the older technology. The new water-soluble solder paste gave a faster decrease in printed TE% as compared to the older technology water-soluble solder paste. This is due to the higher activity required to remove the oxides from Type 6 solder powder, which can lead to shorter life on the stencil.

Each of these solder pastes with Type 6 SAC305 solder powder show greater than a 4-hour stencil life. In normal operation, solder paste is added to the stencil on a regular basis, which extends the stencil life.

Reflow Data Using the SAC305 RTS Profile

Reflow testing was conducted using the PR Test Board which includes wetting, graping and solder balling patterns. Performance was ranked on a 0 to 100% scale, with 0% representing the worst possible performance and 100% representing the best possible performance. The reflow data for the solder pastes in the RTS profile is shown below (Figure 7).

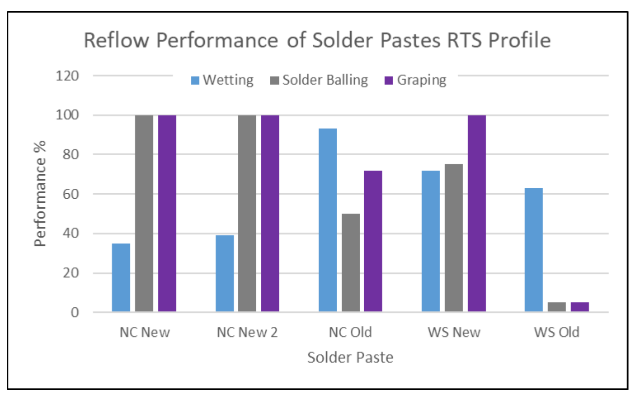


Figure 7. Reflow Performance for Each Solder Paste using the RTS Profile.

The NC New and NC New 2 solder pastes showed the lowest wetting performance, but the best possible solder balling and graping performance of the solder pastes tested. Type 6 solder powder is susceptible to random solder balling and graping due to the small solder powder size and heavy oxide as compared to larger powder sizes. The intent of the NC New solder pastes was to mitigate these issues.

The NC Old solder paste had the best wetting performance of the solder pastes tested, and moderate solder balling and graping performance. This is surprisingly good performance considering this solder paste was not intended for use with Type 6 solder powder size.

The WS New solder paste had above average wetting and solder balling performance, and the best possible graping performance like the NC New solder paste. The WS New solder paste was formulated to give above average performance in these reflow metrics.

The WS Old solder paste showed moderate wetting performance, and the lowest possible solder balling and graping performance. This solder paste was not formulated for use with Type 6 solder powder size, so this poor performance was expected.

Reflow Data After 24 Hours of Air Exposure Using the SAC305 RTS Profile

Reflow of each solder paste was conducted after 24 hours open to the air. The reflow performance is shown below (Figure 8).

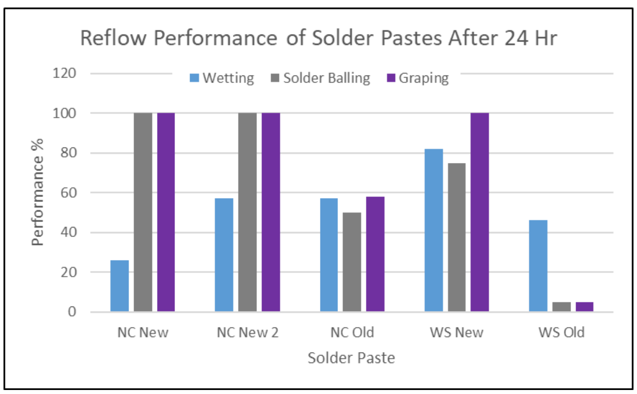


Figure 8. Reflow Performance for Each Solder Paste After 24 Hours of Air Exposure.

The NC New solder paste performed similarly after 24 hours of air exposure as when freshly printed and reflowed. This indicates good protection from oxidation by this solder paste.

The NC New 2 solder paste performance improved after 24 hours of air exposure as when freshly printed and reflowed. The wetting performance increased from 40 to 60%, and solder balling and graping performance were ideal at 100%. This indicates good protection from oxidation by this solder paste.

The NC Old showed worse performance after 24 hours of air exposure than when reflowed after being freshly printed. The oxidation protection of this solder paste is not as capable as the NC New solder pastes.

The WS New solder paste performed similarly after 24 hours of air exposure as when freshly printed. This indicates good protection from oxidation by this solder paste.

The WS Old solder paste showed worse performance than when reflowed after being freshly printed. The oxidation protection of this solder paste is not as capable as the WS New solder paste.

Reflow Data Using the LTAL Profile

The solder pastes were reflowed through an alternate profile with a Long Time Above Liquidus (LTAL). The reflow performance is shown below (Figure 9).

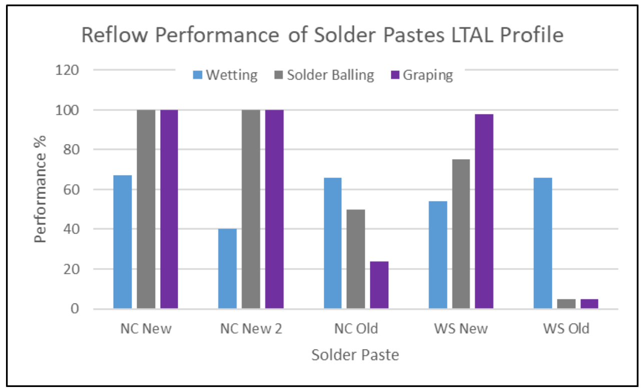


Figure 9. Reflow Performance for Each Solder Paste in the LTAL Profile.

The NC New solder paste showed above average wetting and optimal solder balling and graping performance in the LTAL profile. This was improved performance over the standard SAC305 RTS profile, especially with respect to wetting.

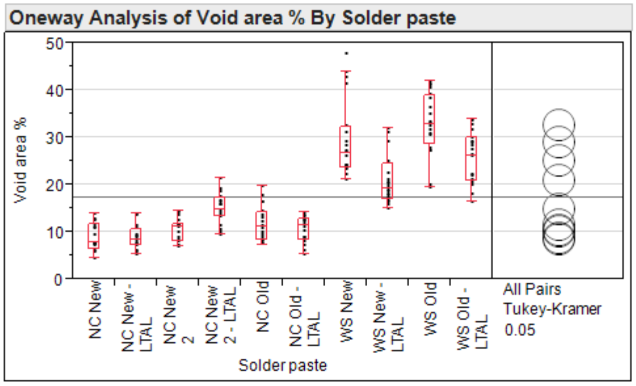
The NC New 2 solder paste showed average wetting and optimal solder balling and graping performance in the LTAL profile. This was nearly identical performance as the standard SAC305 RTS profile.

The NC Old solder paste showed significantly worse wetting and graping performance than when reflowed in the standard RTS profile. Solder balling performance was similar in the two reflow profiles.

The WS New solder paste showed worse wetting performance, but similar solder balling and graping performance as when reflowed in the RTS profile. The WS Old solder paste showed nearly identical poor reflow performance in the LTAL and RTS profiles.

Voiding Data Using the RTS and LTAL Reflow Profiles

Void area % was measured for the QFN68 thermal pads. This was done for both the RTS and LTAL reflow profiles. The data is shown below (Figure 10). The LTAL data is marked with “-LTAL” in the figure to distinguish it from the RTS data.



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level					Mean
WS Old	A				32.9
WS New	A	B			29.3
WS Old - LTAL		B	C		25.3
WS New - LTAL			C		21.1
NC New 2 - LTAL				D	15.0
NC Old				D E	11.7
NC Old - LTAL				D E	10.6
NC New 2				D E	10.4
NC New				E	8.9
NC New - LTAL				E	8.7

Levels not connected by same letter are significantly different.

Figure 10. Voiding Performance for Each Solder Paste in the RTS and LTAL Reflow Profiles.

The WS Old solder paste showed the highest voiding of all the solder pastes, but voiding was lower with the LTAL profile than the RTS profile. The WS New solder paste showed the 2nd highest voiding with the RTS profile, but voiding was lower with the LTAL profile. The NC New 2 voiding was mid-level with the LTAL profile and tied for lowest in the RTS profile. The NC Old solder paste showed mid-level voiding which was similar in both reflow profiles. The NC New voiding was the lowest overall of these solder pastes for both reflow profiles. In general, the LTAL profile gave lower voiding than the RTS profile for these solder pastes, except for the NC New and NC New 2 solder pastes.

Tack Force Over Time

The tack force was measured initially and after 1, 2, and 3 days of hold time at 21-22°C (70-72°F) and 48-54% RH. Ideal performance is a stable tack force over time. The tack force data is in Figure 11.

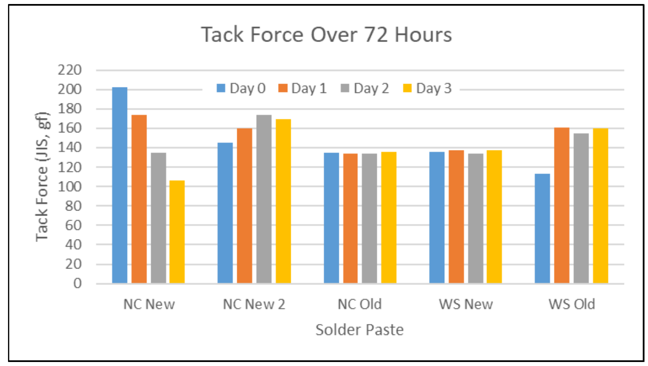


Figure 11. Tack Force Over 3 Days of Hold Time.

The NC New tack force was the highest overall initially and decreased significantly over 3 days. The NC New 2 tack force increased slightly over days 1 and 2 and held tack force into day 3. The NC Old and WS New tack force was consistent over 3 days, which shows good tack stability. The WS old tack force increased from the initial value to after 1 day, and then was stable over 3 days. It is common for tack force to increase slightly during the 1st day, and stabilize over days 2 and 3, as was shown by NC New 2 and WS Old. It is not common for tack force to drop during this test, which indicates instability as shown by NC New.

Heat Aged Solder Paste Testing

After heat aging at 34-36°C (93-97°F) for 3 days, the solder pastes were tested for viscosity and tack force. A significant increase of viscosity indicates instability in this test. The viscosity data (T-bar spindle) of fresh vs. heat aged solder paste is shown below (Table 9).

Table 9. Viscosity of Solder Pastes Before and After Heat Aging.

Solder Paste	Viscosity Initial (Kcps)	Viscosity After Heat Aging (Kcps)	Viscosity Increase (%)
NC New	1030	Not measurable	NM
NC New 2	640	1001	56%
NC Old	430	487	13%
WS New	120	154	28%
WS Old	390	510	31%

The NC New solder paste had the highest viscosity of all the solder pastes initially. Heat aging caused the viscosity to increase beyond the measurement capability of the instrument. This indicates a potential instability in the solder paste which may be a predictor of a short shelf life. The NC New 2 solder paste also increased significantly in viscosity due to heat aging. The other solder pastes increased in viscosity slightly with heat aging, but within normally expected ranges. The WS solder pastes increased in viscosity more than the NC Old solder paste. This is due to the overall higher reactivity of the WS solder pastes.

The tack force was measured for the solder pastes before and after heat aging. A significant decrease in tack force indicates instability in this test. The data is in Table 10 below.

Table 10. Tack Force of Fresh Solder Pastes and After Heat Aging.

Solder Paste	Tack Force (gf)	Tack Force After Heat Aging (gf)	Tack Force Change (%)
NC New	202	104	48% decrease
NC New 2	145	173	19% increase
NC Old	135	134	1% decrease
WS New	136	132	3% decrease
WS Old	113	138	22% increase

The tack force for the NC New solder paste dropped to nearly ½ of original with heat aging. This was also true for the tack force of this solder paste over the 72-hour hold time. This indicates a lack of stability that may lead to a short stencil and working life.

The tack force of the NC New 2 solder paste increased with heat aging, and with 72 hour hold time (Figure 11). It is normal for some solder paste formulas to show an increase in tack force from initial to 24 hours hold time open to the air, and with heat aging. This increase in tack force is not of concern because the tack force is within expected values.

The tack force of the NC Old and WS New solder pastes was unaffected by heat aging. This indicates good stability in this test.

The tack force of the WS Old solder paste increased due to heat aging and with the 72-hour hold time (Figure 11). Again this is due to normally expected reactions within the solder paste. This increase in tack force is not of concern because the tack force is within expected values.

CONCLUSIONS

There are many challenges for solder paste to overcome when using Type 6 or smaller solder powder sizes. The five solder pastes tested with SAC305 Type 6 solder powder showed performance differences. Here is a summary of the results.

- The NC New 2 and NC Old solder pastes were able to print with acceptable TE% through 0.60 AR apertures.
- In print and pause testing, each of the solder pastes showed a decrease in TE% over time, except for the WS Old solder paste, which is particularly stable over time on the stencil.
- The NC New and NC New 2 solder pastes showed a slower rate of TE% decrease than the NC Old solder paste.
- The NC New and NC New 2 solder pastes showed acceptable wetting, and the best possible solder balling and graping performance. They both outperformed the NC Old solder paste in reflow.
- The WS New solder paste showed good wetting and solder balling performance, and the best possible graping performance. This solder paste outperformed the WS Old solder paste in reflow.
- 24 hours of air exposure of the printed solder paste improved the reflow performance of the NC New and NC New 2 solder pastes. The NC Old solder paste showed worse reflow performance after 24 hours of air exposure.
- The WS New solder paste gave similar reflow performance with 24 hours of air exposure, as opposed to the WS Old solder paste which declined in reflow performance.
- Voiding performance was optimal for the NC New solder paste, with the NC New 2 performing 2nd best. The NC Old showed mid-range voiding performance. The WS New solder paste outperformed the WS Old solder paste in terms of voiding. Reflow profiling can be used to minimize voiding for each of these solder pastes.
- The NC New solder paste showed a significant decrease in tack force over 3 days, which indicates instability in this test. The NC New 2 and WS Old solder pastes gave a small increase in tack force over time, which is not unusual. The NC Old and WS New solder pastes were stable in tack force over time.
- Heat aging showed instability in the NC New solder paste, but NC Old solder paste showed stable viscosity and tack force. The NC New 2 solder paste showed an increase in viscosity and tack with heat aging. The WS New solder paste showed a slight increase in viscosity but stable tack force with heat aging. The WS Old solder paste showed an increase in both viscosity and tack force with heat aging.

Overall, the NC New 2 and WS New solder pastes outperformed their older technology counterparts with SAC305 Type 6 solder powder. These solder pastes may be acceptable for use with ultra fine feature printing and reflow for the creation of miniature solder joints.

REFERENCES

[1] Stencil Design Task Group (5-21e), “Stencil Design Guidelines”, IPC-7525C, November 2021.
[2] T. Lentz, “Size Matters - The Effects of Solder Powder Size on Solder Paste Performance”, Proceedings of IPC Apex Expo, 2019.
[3] E. Nauss, “Sealed Versus Exposed Atmosphere Solder Printing Comparison for Type-6 Powder Solder Paste”, Proceedings of IPC Apex Expo, 2024.
[4] T. O’Neill, C. Tafoya, G. Ramirez, “The Impact of Reduced Solder Alloy Powder Size on Solder Paste Print Performance”, Proceedings of IPC Apex Expo, 2016.
[5] C. Ashmore, “Investigating the Metric 0201 Assembly Process”, Proceedings of IPC Apex Expo, 2019.

[6] S. Pei-Lim, K. Thum, A. Mackie, “Challenges in Fine Feature Solder Paste Printing for SiP Applications”, Proceedings of IMAPS International Symposium on Microelectronics 2016.
[7] S. Joshi, “Lead-free Solder Paste Development for Ultra Fine-pitch Printing and Reflow of 03015 and 0201 Metric Chip Components”, Proceedings of SMTA International, 2016.
[8] S. Harter, J. Franke, C. Lantzsch, “Evaluation of the Stencil Printing for Highly Miniaturized SMT Components with 03015MM in Size”, Proceedings of SMTA International, 2015.
[9] E. Griffith, “Evolution and Applications of Fine Feature Solder Paste Printing for Heterogeneous Integration”, Proceedings of SMTA International, 2021.
[10] N. Lee, “Robust SMT No-Clean Solder Paste for SIP and 01005 Assembly”, Proceedings of SMTA International, 2018.
[11] Solder Paste Task Group (5-24b), “Requirements for Solder Pastes”, IPC J-STD-005B, March 2024.
[12] Japanese Standards Association, “Solder paste – Part 1: Kinds and quality classification”, JIS Z 3284-1:2014