The Effects of Surface Finish on Solder Paste Performance - The Sequel

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ABSTRACT
This is a second study on how solderable surface finish affects solder paste performance in the surface mount process (SMT). The first study was presented at SMTA International 2018 [1] and included print, reflow and voiding data on 6 different surface finishes run with 4 different solder pastes. The performance of the surface finish - solder paste combinations were scored and ranked and recommendations given for optimal pairings.

This work explores some of the surface finish - solder paste combinations in more detail with an expanded set of SMT parameters. Three surface finishes were studied including electroless nickel immersion gold (ENIG), organic solderability preservative (OSP), and immersion silver (ISilver). Two lead-free solder pastes were used including a no clean SAC305 solder paste and a water soluble SAC305 solder paste. Three different reflow conditions were tested including a ramp-to-spike (RTS) profile, a ramp-soak-spike (RSS) profile, and reflowing two times through a RTS profile to simulate double-sided surface mount work. Print speeds were varied at 25, 50, and 100 mm/second and printed solder paste volumes measured. Reflow performance was measured including wetting, solder balling, and graping. Quad flat no lead (QFN) components were placed and voiding was measured.

All of the test results were summarized. Discussion of the strengths and weaknesses of each combination of surface finish and solder paste were given with respect to the various SMT parameters. Recommendations were made for optimal combinations of surface finish and solder paste.

Key words: surface finish, solder paste, print speed, reflow profile, wetting, solder balling, graping, voiding

INTRODUCTION
A variety of solderable surface finishes are used on printed circuit boards (Figure 1).

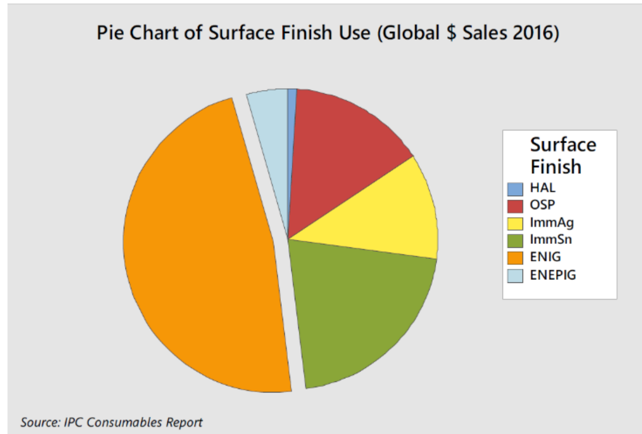

Figure 1. Surface Finishes Used by Sales ($) in 2016 [2]

Surface finishes are used to protect the underlying copper pads from oxidation. Surface finishes provide an easy to wet solderable surface that has a much longer shelf life than bare copper. Solderable surface finishes may also enhance the reliability of the finished solder joints.

Organic solderability preservative (OSP) is a popular finish due to its low-cost relative to the other surface finishes. OSP is typically composed of an imidazole type mixture [3] over the copper pad. OSP is planar which promotes good solder paste printing. OSP is known to show issues with multiple lead-free soldering cycles and is mainly used for cost sensitive applications that require a limited number of soldering cycles.

Electroless nickel immersion gold (ENIG) is a very popular surface finish, but it one of the costlier finishes. ENIG is susceptible to the issue of hyper-corrosion of the nickel which is known commonly as “black pad”, but ENIG processes have been improved over time to minimize the risk of “black pad”. ENIG is a planar finish which promotes good solder paste printing. ENIG is solderable through multiple cycles and has a long shelf life.

Immersion silver is a finish comprised of silver metal plated over the copper pads. Immersion silver is flat and solders well initially but can be tarnished through air exposure and by the heat applied for soldering. Tarnished immersion silver [3] is very difficult to wet with solder. Immersion silver is susceptible to handling damage because it is relatively thin, and must be protected from air and sulfur exposure. Immersion silver is a cost-effective finish.

When choosing a surface finish, there are characteristics to consider besides print and reflow performance. Here is a list of important characteristics of surface finishes [4].

- Solder joint reliability:
  - Surface mount solder joint reliability
  - Ball grid array & bottom terminated component solder joint reliability
  - Plated through hole reliability
- Solderability:
  - Shelf life
  - Solderability after multiple reflow cycles
  - Plated through hole fill after reflow soldering
- Coating characteristics:
  - Complexity of the coating process
  - Flatness of the finish
  - Conductivity for pin probe testing
  - Creep corrosion risk
  - Tin whisker risk

In this work a variety of solder pastes were tested with various surface finishes. Print and reflow characteristics were quantified for each combination of surface finish and solder paste. These results were used to give recommendations for the optimal combinations of solder paste and surface finish.

EXPERIMENTAL METHODOLOGY

The surface finishes used in this work are as follows: OSP, ENIG, and immersion silver. The coating thicknesses were measured and are shown below (Table 1).

Table 1. Surface Finish Thicknesses

Surface Finish	Thickness
OSP	< 2 µm
ENIG	3.05 - 6.10 µm nickel 0.05 - 0.13 µm gold
ISilver	0.15 - 0.38 µm silver

These thicknesses are normal and fall within standard guidelines given by the finish suppliers. The solder pastes used for this testing are listed below (Table 2). The codes in the right-hand column will be used to refer to these solder pastes throughout the rest of this paper.

Table 2. Solder Pastes Tested

Flux	IPC Flux Classification	Solder Alloy	Code
Water-soluble	ORH1	SAC305	WS SAC
No-clean	ROL0	SAC305	NC SAC

The solder powder size used with each solder paste was IPC Type 4 (20-38 µm). The solder pastes chosen are commercially available products from one manufacturer.

The circuit board used for this testing is called the Print and Reflow (PR) test board and is shown below (Figure 2).

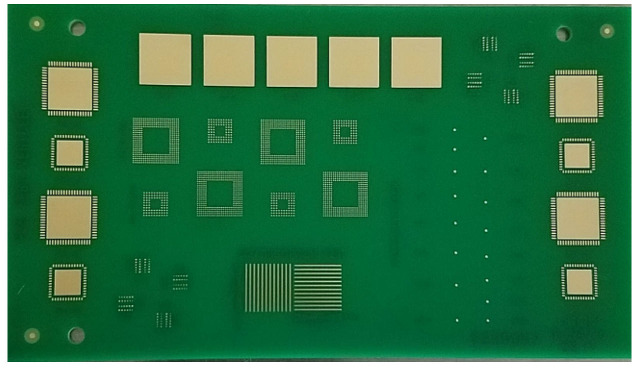

Figure 2. Print and Reflow (PR) Test Board

The PR test board has challenging patterns which allow for quantitative measurement of solder paste performance. These patterns have been used to measure solder paste performance in previous work [1, 5, 6, 7]. The patterns used for printed solder paste volume measurement are 0.4 mm pitch ball grid arrays (BGA). The stencil was 127 µm (5 mils) thick and the apertures were 254 µm (10 mil) squares with 51 µm (2 mil) radiused corners. These patterns had an area ratio (AR) of 0.50 which challenges the printability of solder pastes (Figure 3).

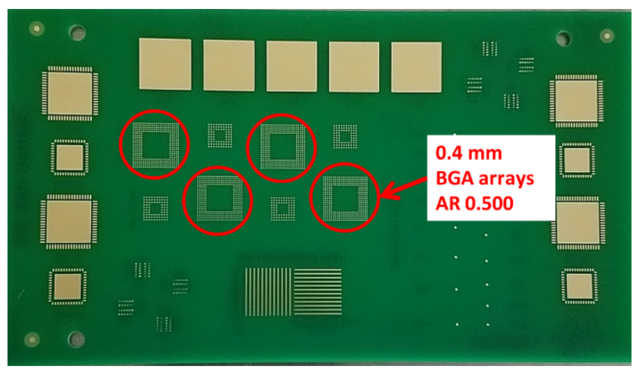

Figure 3. 0.4mm Pitch BGA Arrays Used for Solder Paste Volume Measurement

Additional solder paste printed volume data is gathered from area ratio limit patterns. The stencil apertures are rounded squares ranging in size from 254 µm (10 mil) down to 152 µm (6 mils) and have area ratios of 0.50 down to 0.30 AR (Figure 4).

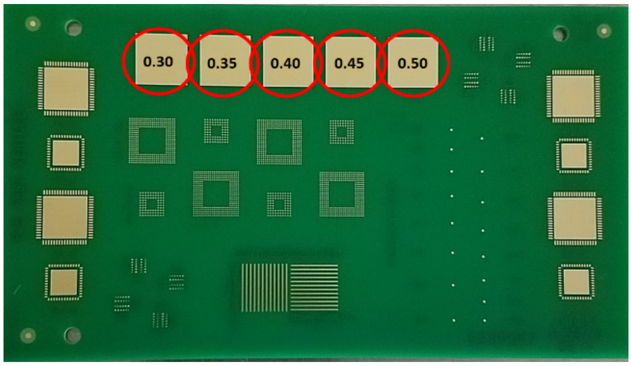

Figure 4. Area Ratio Limit Patterns Used for Solder Paste Volume Measurement

The area ratio limit patterns show the lower limit of printability for solder pastes. Many solder pastes will not print through the smallest patterns (0.30 and 0.35 AR).

A 10-print study was run for each combination of solder paste and surface finish. Printed solder paste volumes were measured and transfer efficiency percentages (TE%) were calculated. Statistical analysis was used to compare and contrast the data sets.

The standard solder paste print parameters used for this testing are shown below (Table 3).

Table 3. Standard Solder Paste Print Parameters

Printer	Dek Horizon 02
Print Speed	50 mm/sec (varies)
Blade Length	300 mm
Blade Pressure	See below
Separation Speed	3.0 mm/sec
Separation Distance	2.0 mm

The print speed was varied (25, 50, 100 mm/sec) to challenge printability of the solder pastes on each surface finish. The print pressure was modified based on the print speed for each solder paste in order to get a clean scrape of solder paste off of the top of the stencil. The modified print parameters are shown below (Table 4.).

Table 4. Modified Solder Paste Print Parameters

Parameter	**NC SAC**	**WS SAC**
Pressure for 25 mm/sec	5.0 kg (0.167 kg/cm)	8.0 kg (0.267 kg/cm)
Pressure for 50 mm/sec	5.0 kg (0.167 kg/cm)	8.0 kg (0.267 kg/cm)
Pressure for 100 mm/sec	8.0 kg (0.267 kg/cm)	15.0 kg (0.500 kg/cm)

The WS SAC solder paste did not scrape clean at 100 mm/sec even with a blade pressure of 15.0 kg. This caused issues with solder paste release from the stencil and the data was removed from this study.

There are several reflow patterns on the PR test board which allow for quantitative measurement of reflow performance. The characteristics which can be measured are wetting, solder balling, graping, and voiding.

The wetting patterns include 12 parallel lines in both the vertical and horizontal directions. Fifteen solder paste bricks of 0.4 mm width are printed down each line with varying pitch ranging from 0.4 mm at the edges to 0.1 mm in the center of each line (Figure 5).

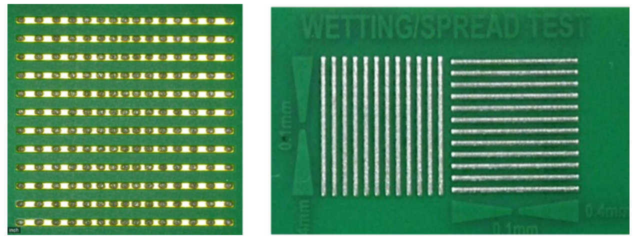

Figure 5. Wetting Reflow Patterns. Printed Solder Paste (Left) and Reflowed Solder (Right)

Ideal wetting is demonstrated by the solder completely covering the entire line. The wetting or spread percentage for each combination of surface finish and solder paste was tallied. The number of gaps that were not covered in solder were counted for each pattern on two circuit boards. The wetting percentage was calculated with the equation below:

$$\text{Wetting \%} = [(\text{Total \# gaps}) / 672] \times 100\%$$

Larger wetting percentages indicate better wetting performance. Ideal wetting is 100%.

Random solder balling was measured using overprint/pullback patterns (Figure 6).

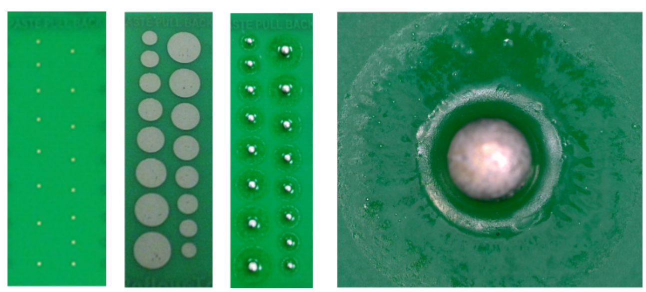

Figure 6. Random Solder Balling Reflow Patterns

The pad size on the circuit board is 0.51 mm (20 mils). The overprint of solder paste onto the pad and surrounding solder mask ranges from 500% to 1250% which equates to stencil aperture diameters of 2.55 mm (100 mils) to 6.35 mm (250 mils). During reflow the solder paste pulls back into one central sphere leaving random solder balls behind in the flux pool. Solder balling performance was measured on two circuit boards per surface finish/solder paste combination and was recorded in three categories as follows:

- The largest % overprint that has 0 solder balls
- The largest % overprint that has < 5 solder balls
- The largest % overprint that has < 10 solder balls

Higher overprint percentages in each category indicate better solder balling performance. Ideal performance is 1250% overprint in each category.

The solder balling performance often varied from one circuit board to another. A judgement call was made and average solder balling performance was recorded. Theoretically surface finish should have a minor effect on solder balling performance, because solder balling is created more by the pull-back of solder paste from the solder mask. The solder pastes used are the major contributors to solder balling.

Graping was measured using patterns which include solder mask defined (SMD) and non-solder mask defined (NSMD) round and square shaped pads of varying size. The area ratios of the stencil apertures range from 0.35 to 0.60 AR (Figure 7).

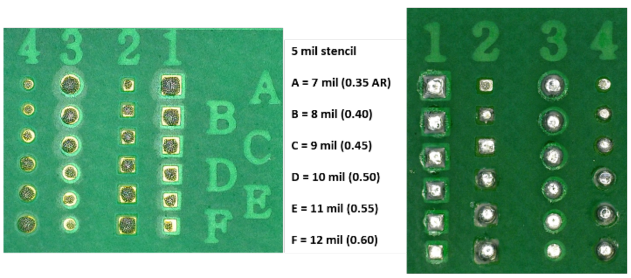

Figure 7. Graping Reflow Patterns. Printed Solder Paste (Left) and Reflowed Solder (Right)

These small solder paste deposits are designed to show graping after reflow. The total number of solder deposits which showed graping were tallied for four patterns on each of two circuit boards. A graping percentage was calculated using the equation below:

$$\text{Graping \%} = [(\text{Total \# graping}) / 192] \times 100\%$$

Lower graping percentages indicate better performance. Ideal performance is 0% graping.

Voiding was measured on the thermal pads of 10 mm body quad flat no lead (QFN68) components using a 2D X-ray system. This is similar to testing done in previous work [5, 6]. The solder paste print was broken up into a standard 9-pane cross hatch pattern with 0.51 mm (20 mil) web width and 65% area coverage of the thermal pads (Figure 8).

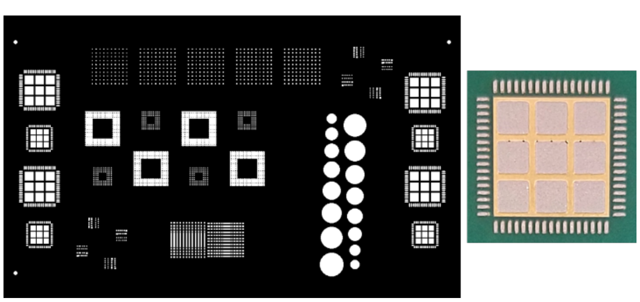

Figure 8. Stencil Design for the Voiding Patterns

Two QFNs were placed per circuit board over the course of a run of ten circuit boards for a total of 20 QFNs. Voiding was measured on the QFN thermal pads and void area % and the largest void % were recorded. Statistical analysis was performed on the voiding data to compare and contrast the data sets. Lower void area and lower void size indicates better performance. Ideal voiding performance is 0% void area.

The SAC305 reflow profiles used were a linear ramp-to-spike (RTS) profile and a ramp-soak-spike (RSS) profile. The RTS reflow profile is shown below (Figure 9).

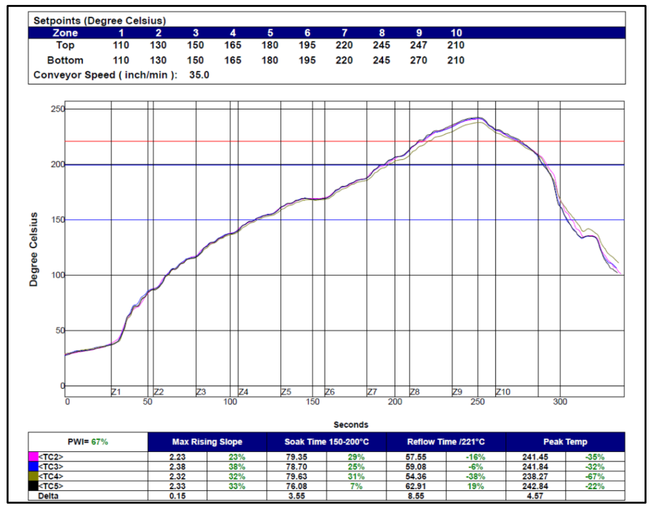

Figure 9. Linear Ramp-To-Spike Reflow Profile

The RSS reflow profile is shown below (Figure 10).

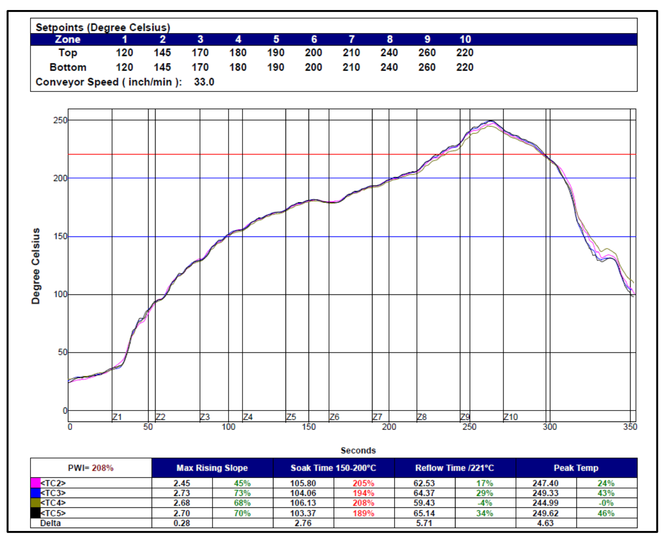

Figure 10. Ramp-Soak-Spike Reflow Profile

A summary of the measured parameters in each reflow profile is shown below (Table 5).

Table 5. Reflow Profile Parameters

Parameter	SAC305 Linear Profile (RTS)	SAC305 Soak Profile (RSS)
Max Rising Slope (20 sec window)	2.2 - 2.4 °C/sec	2.4 - 2.7 °C/sec
Soak Time (150 to 200 °C)	76 - 80 seconds	103 - 106 seconds
Reflow Time (> 220°C)	54 - 63 seconds	59 - 65 seconds
Peak Temperature	238 - 243°C	245 - 249°C
Time from 25°C to Peak	4.1 to 4.2 minutes	4.1 to 4.2 minutes

Print performance was measured at three print speeds: 25, 50, and 100 mm/sec. The 50 mm/sec print speed was used for all of the circuit boards that were run through reflow testing. The 25 and 100 mm/sec print speeds were run with each surface finish & solder paste combination and printed solder paste volumes were measured, but the circuit boards were not reflowed.

Here is a general overview of the reflow testing procedure:

1. Print solder paste at 50 mm/sec
2. Measure printed solder paste volumes
3. Place 2 QFN components per board
4. Reflow using the appropriate profile
5. Take pictures of the reflowed solder
6. Tally the wetting, solder balling and graping data
7. Measure voiding on the QFN thermal pads
8. Repeat this test procedure to make a total of 10 circuit boards for each combination of surface finish and solder paste

This procedure was modified in order to simulate and measure reflow performance on the 2nd side of a double-sided surface mount circuit board. The circuit boards were run one time through the RTS reflow profile before printing solder paste. Then the general reflow procedure above was followed.

Statistical analysis was done to compare the data sets for printed solder paste transfer efficiency and voiding. The data was displayed in box plot format and Tukey-Kramer honest significant difference (HSD) testing was used to compare the data sets. Tukey-Kramer HSD testing is similar to a Student's T test and is used to determine whether the data sets are significantly different. A 95% confidence level was used in the Tukey-Kramer HSD testing.

RESULTS AND DISCUSSION

Printing Overview

Here is the transfer efficiency for each solder paste and surface finish combination for the 50 mm/sec print speed (Figure 11).

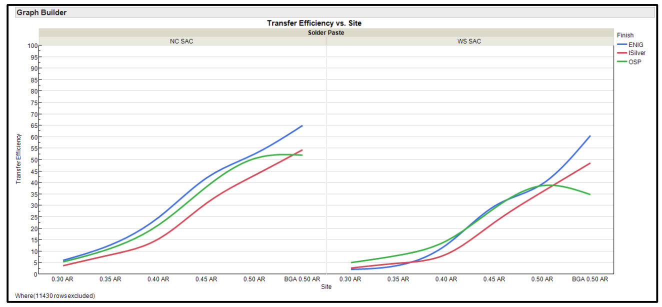

Figure 11. Transfer Efficiency by Area Ratio for Each Solder Paste and Surface Finish with a 50 mm/sec Print Speed

Generally speaking, the water-soluble solder paste gave lower overall transfer efficiencies than the no clean solder paste. Similar printing performance differences between solder pastes have been reported in the past [7]. Immersion silver gave lower overall transfer efficiencies than ENIG and OSP which showed similar print performance.

The effects of print speed on the performance of the no clean solder paste on each surface finish are shown below (Figure 12).

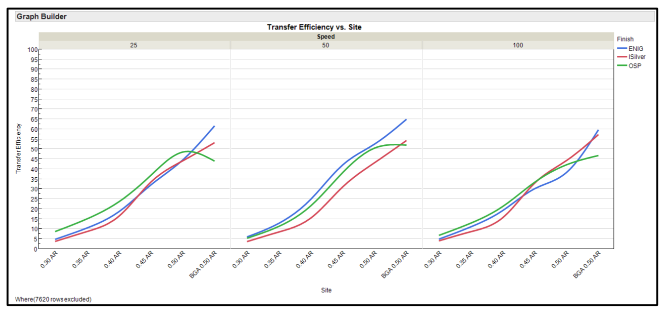

Figure 12. Transfer Efficiency by Area Ratio for the No Clean Solder Paste and Each Surface Finish Broken Out by Print Speed

The no clean solder paste printed equally well at each print speed. Immersion silver gave slightly lower transfer efficiencies than the other surface finishes.

The effects of print speed on the performance of the water-soluble solder paste on each surface finish are shown below (Figure 13).

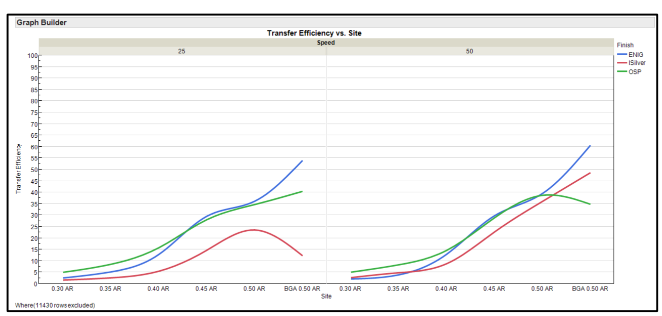

Figure 13. Transfer Efficiency by Area Ratio for the Water-Soluble Solder Paste and Each Surface Finish Broken Out by Print Speed

The water-soluble solder paste did not print well at 100 mm/sec and that data was removed. The water-soluble solder paste printed similarly at 25 and 50 mm/sec print speeds. The immersion silver finish gave the lowest overall transfer efficiency. ENIG gave higher transfer efficiencies than OSP in the BGA (0.50) AR array.

Coefficient of variation was calculated for the transfer efficiency of each solder paste and each surface finish in the 0.4 mm pitch BGA arrays using the 50 mm/sec print speed (Tables 6 and 7).

Table 6. Coefficient of Variation Analysis (TE) for the No Clean Solder Paste with Each Surface Finish, the 50 mm/sec Print Speed and the 0.4 mm Pitch BGA Arrays

Surface Finish	Mean TE%	Standard Deviation of TE%	CV (%)
ENIG	65.2	9.5	15%
ISilver	54.5	10.2	19%
OSP	52.2	11.0	21%

The overall mean transfer efficiency was highest for ENIG and immersion silver and OSP were statistically similar. The CV values were higher than 10% for all three surface finishes with OSP giving the overall highest CV. The high CV values indicate that this process could use some refinement in order to improve repeatability of print performance, especially with the immersion silver and OSP surface finishes.

Table 7. Coefficient of Variation Analysis (TE) for the Water-Soluble Solder Paste with Each Surface Finish, the 50 mm/sec Print Speed and the 0.4 mm Pitch BGA Arrays

Surface Finish	Mean TE%	Standard Deviation of TE%	CV (%)
ENIG	60.8	17.1	28%
ISilver	48.8	17.7	36%
OSP	34.9	22.2	64%

The overall mean transfer efficiency was highest for ENIG with immersion silver having the 2nd highest TE% and OSP giving the lowest TE%. The CV values were higher than 10% for all three surface finishes with OSP giving the overall highest CV. In general, the CV values for the water-soluble solder paste were higher than those for the no clean solder paste.

Reflow Performance - Wetting

Each surface finish, solder paste combination was reflowed in 3 different reflow profile conditions. RSS is a ramp-soak-spike profile, RTS is a ramp-to-spike profile, and RTSx2 is a ramp-to-spike profile run once before printing solder paste and once after print. Differences in wetting performance are charted below (Figure 14).

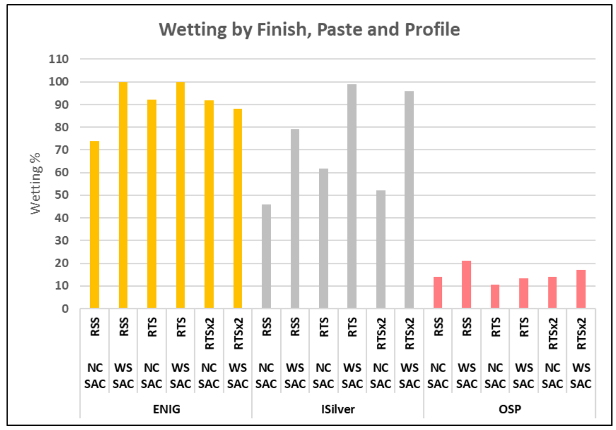

Figure 14. Wetting or Spread Broken Out by Surface Finish, Solder Paste and Reflow Profile

ENIG gave the overall highest wetting around 91% mean. Immersion silver wetting was a little worse than ENIG with a mean of 72%. OSP wetting was the worst overall with a mean of 15%. The WS SAC solder paste (68% mean) wetted better than the NC SAC paste (51% mean) on each of the surface finishes. The RTS profile gave the best overall wetting (63% mean) followed by the RTSx2 (60% mean) and the RSS profile (56% mean) for the ENIG and immersion silver finishes. The RSS profile gave the best wetting on the OSP surface finish followed by the RTSx2 profile and the RTS profile. Adding heat in the form of a soak profile or a profile run before printing the solder paste seems to improve wetting on OSP. Perhaps some of the OSP layer evaporates during reflow which enables the solder paste to flow and wet to the underlying copper a little more easily. Representative pictures of the wetting for the RSS profile are shown below (Figure 15).

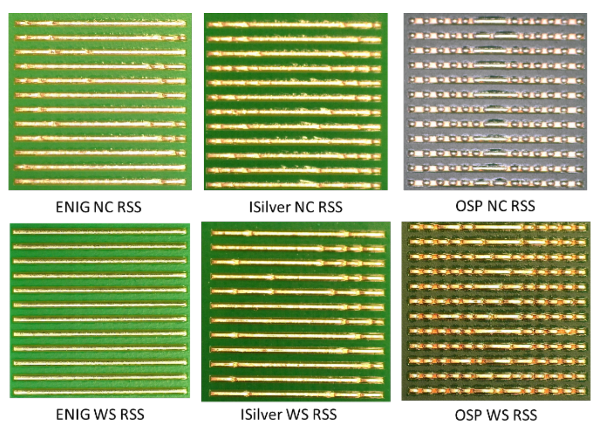

Figure 15. Wetting or Spread Broken Out by Surface Finish and Solder Paste with the RSS Reflow Profile

Reflow Performance - Solder Balling

Solder balling was measured and charted as the largest % overprint that showed less than 10 solder balls (Figure 16).

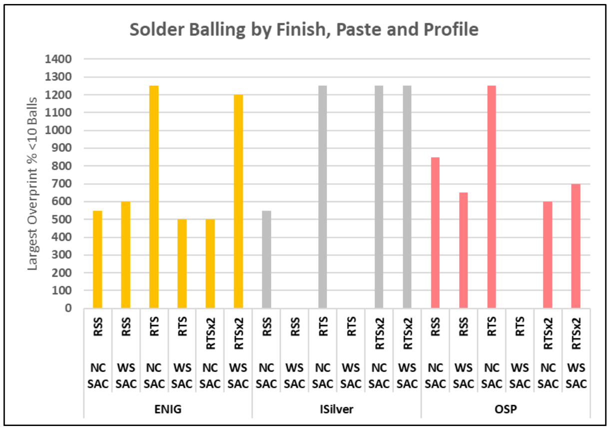

Figure 16. Solder Balling Broken Out by Surface Finish, Solder Paste and Reflow Profile

Higher % overprint ratings are better in this test. The worst solder balling performers show no bars (0%) which are two of the immersion silver combinations and one OSP combination. The best performance is shown by 3 immersion silver combinations, 2 ENIG combinations and 1 OSP combination. Generally speaking, the no clean solder paste performed better than the water-soluble paste, and the RTS profile performed better than the other profiles. RSS type profiles tend to increase the potential for random solder balling. Representative pictures of the solder balling are shown below (Figure 17).

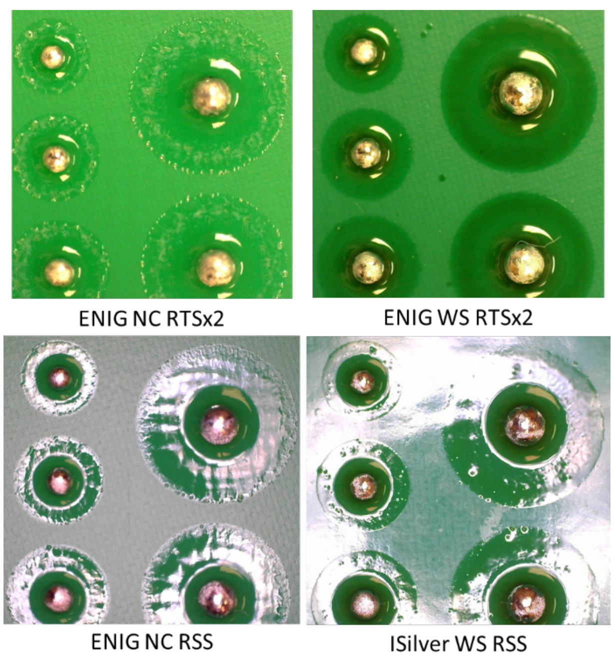

Figure 17. Solder Balling for Select Surface Finish, Solder Paste, and Reflow Profile Combinations

Reflow Performance - Graping

Graping broken out by surface finish, solder paste and reflow profile is shown below (Figure 18).

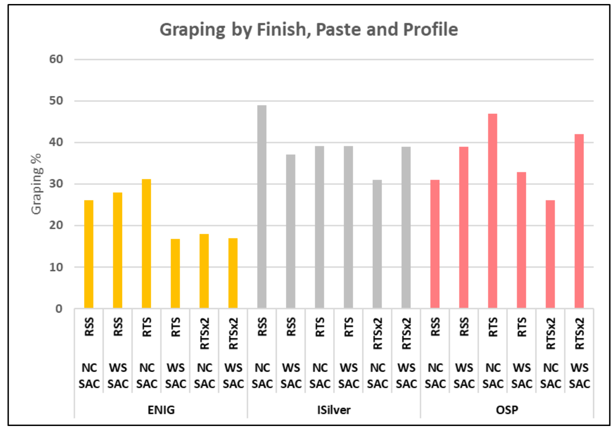

Figure 18. Graping Broken Out by Surface Finish, Solder Paste and Reflow Profile

Lower graping % are better in this test. ENIG showed the best graping performance (23% mean), while immersion silver (39% mean) and OSP (36% mean) showed similar worse performance. The highest graping was shown by the immersion silver / no clean / RSS and the OSP / no clean / RTS combinations. The lowest overall graping was shown by ENIG with the RTSx2 profiles.

Voiding Performance

Looking in general at voiding performance by surface finish, by solder paste, and by reflow profile gave the following results (Figure 19).

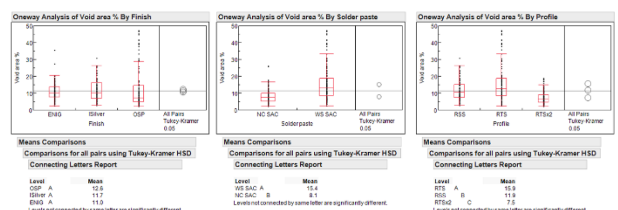

Figure 19. Voiding Performance by Surface Finish, Solder Paste and Reflow Profile with All Other Variables Included

Analyzing the voiding data by surface finish shows statistically equivalent performance. The water-soluble solder paste gave higher overall voiding than the no clean solder paste. The reflow profiles gave 3 different voiding levels: RTS was the highest, followed by the RSS profile, and lastly the RTSx2 profile gave the lowest overall voiding.

The RTSx2 profile was used to thermally stress the circuit board finishes by first running the bare boards (no solder paste) through the RTS profile, then printing solder paste, placing components, and finally reflowing the solder paste using the RTS profile. It was expected that the thermal stress of the surface finishes caused by the first RTS profile would limit wetting of the solder paste and lead to higher voiding area. This was not the case. This begs several questions which will require additional work to clarify.

The voiding levels for each solder paste broken out by surface finish are shown below (Figure 20). This data includes all of the reflow profiles.

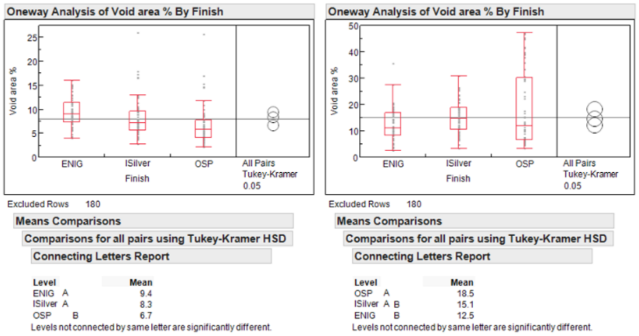

Figure 20. Voiding Performance for the No Clean Solder Paste (Left) and the Water-Soluble Solder Paste (Right) Broken out by Surface Finish

The voiding levels for the no clean solder paste were higher for both the ENIG and immersion silver finishes and lower for the OSP surface finish. The voiding levels for the water-soluble solder paste were higher for the OSP and immersion silver finishes and lower for the ENIG surface finish. It is clear that these surface finishes have an influence on voiding levels which is different for each solder paste.

The voiding levels for each solder paste broken out by reflow profile are shown below (Figure 21). This data includes all of the surface finishes.

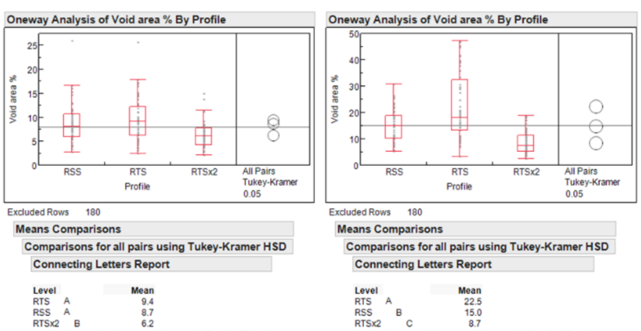

Figure 21. Voiding Performance for the No Clean Solder Paste (Left) and the Water-Soluble Solder Paste (Right) Broken out by Reflow Profile

Each solder paste follows the same general trend of higher voiding with the RTS profile, moderate voiding with the RSS profile, and low voiding with the RTSx2 profile. Again, thermal stress on the surface finishes seems to lower the voiding potential.

The voiding levels for the no clean solder paste broken out by reflow profile and surface finish are shown below (Figure 22).

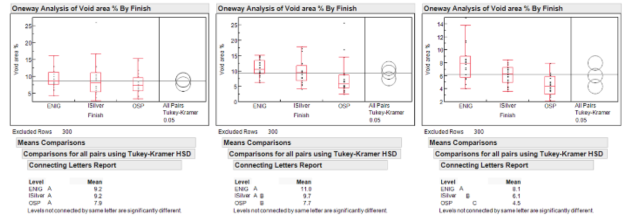

Figure 22. Voiding Performance for the No Clean Solder Paste and the RSS Profile (Left), RTS Profile (Center), RTSx2 Profile (Right) Broken out by Surface Finish

The no clean solder paste in the RSS profile showed equivalent voiding for each of the surface finishes. The no clean solder paste with the RTS profile showed higher voiding with the ENIG and immersion silver finishes but lower voiding with the OSP finish. The no clean solder paste with the RTSx2 profile showed higher voiding with ENIG, moderate voiding with immersion silver, and lower voiding with OSP. It is apparent that surface finish affects voiding in different ways based on the reflow profile used.

The voiding levels for the water-soluble solder paste broken out by reflow profile and surface finish are shown below (Figure 23).

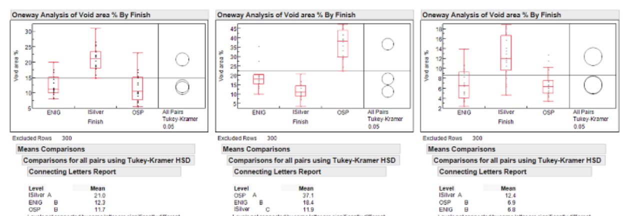

Figure 23. Voiding Performance for the Water-Soluble Solder Paste and the RSS Profile (Left), RTS Profile (Center), RTSx2 Profile (Right) Broken out by Surface Finish

The water-soluble solder paste with the RSS profile showed higher voiding with the immersion silver finish and lower voiding with both the ENIG and OSP finishes. The water-soluble solder paste with the RTS profile showed higher voiding with OSP, moderate voiding with ENIG, and the lowest voiding with the immersion silver finish. The water-soluble solder paste with the RTSx2 profile showed higher voiding with immersion silver and lower voiding with OSP and ENIG finishes. Again, the surface finish affects voiding in different ways depending on the reflow profile used.

The ENIG surface finish showed low voiding with the RSS profile and the water-soluble solder paste. With the RTS profile high voiding was observed with the no clean paste and moderate voiding was seen with the water-soluble paste. With the RTSx2 profile high voiding was seen with the no clean paste and low voiding was seen with the water-soluble paste.

The immersion silver finish showed high voiding with the RSS profile and the water-soluble solder paste. With the RTS profile, high voiding was seen with the no clean paste but low voiding was seen with the water-soluble solder paste. With the RTSx2 profile, moderate voiding was seen with the no clean solder paste and high voiding was seen with the water-soluble solder paste.

The OSP surface finish showed low voiding with the RSS profile and the water-soluble solder paste. With the RTS profile, low voiding was seen with the no clean paste but high voiding was seen with the water-soluble solder paste. With the RTSx2 profile, low voiding was seen with both solder pastes.

Scoring of Each Surface Finish Solder Paste Combination
A scoring system was used to rank the performance of each surface finish and solder paste combination. This scoring system was based upon a scale of 1 to 5. A score of 1 indicates the worst performance in that particular category. Scores of 2 to 4 indicate "middle of the pack" performance. A score of 5 indicates the best possible performance in that category. The raw data from each surface finish and solder paste combination was used and scores were assigned within each category and performance metric (Table 8).

Table 8. Scoring Scales for Each Category

	Print 0.4 mm BGA		Print 0.50 AR Pattern		Reflow			Voiding	
Score	TE%	CV%	TE%	CV%	Wetting %	Solder Balling	Graping %	Void Area %	Largest Void %
1	<50	>15	<40	>20	0-20	none	41-50	>25	>5.0
2	51-57	10-14	41-45	16-20	21-40	500-650	31-40	16-25	3.1-5.0
3	58-64	8-9	46-50	11-15	41-60	700-850	21-30	11-15	2.1-3.0
4	65-70	6-7	51-55	8-10	61-80	900-1050	11-20	6-10	1.1-2.0
5	>70	0-5	>55	<8	81-100	1100-1250	0-10	1-5	0-1.0

The raw data that was used for scoring is not included in this paper for brevity. The overall print scores were summarized for the print speeds, surface finishes and solder pastes used (Table 9).

Table 9. Overall Print Scores for Each Print Speed, Surface Finish, and Solder Paste Combination

Print Speed (mm/sec)	Surface Finish	Solder Paste	Total Print Score
50	ENIG	NC SAC	12
25	ENIG	NC SAC	10
50	OSP	NC SAC	10
100	ISilver	NC SAC	9
25	ISilver	NC SAC	7
25	OSP	NC SAC	7
25	OSP	WS SAC	7
50	ISilver	NC SAC	7
100	ENIG	NC SAC	7
100	OSP	NC SAC	7
50	ENIG	WS SAC	6
25	ENIG	WS SAC	5
50	ISilver	WS SAC	5
25	ISilver	WS SAC	4
50	OSP	WS SAC	4
100	ENIG	WS SAC	N/A
100	ISilver	WS SAC	N/A
100	OSP	WS SAC	N/A

Generally speaking, the 100 mm/sec print speed generated lower print scores than the 50 and 25 mm/sec print speeds. This is especially true for the WS SAC solder paste which did not scrape clean off the stencil at 100 mm/sec, and therefore could not be scored (N/A). The ENIG surface finish had the highest overall scores followed by OSP and then immersion silver. The best printing combinations were the 50 and 25 mm/sec print speeds with ENIG and NC SAC solder paste. The poorest printing combinations were the 25 mm/sec speed with immersion silver and WS SAC, and 50 mm/sec speed with OSP and WS SAC paste.

The overall reflow scores (wetting, solder balling, graping) are shown below (Table 10).

Table 10. Overall Reflow Scores for Each Surface Finish, Solder Paste, and Reflow Profile Combination

Surface Finish	Solder Paste	Reflow Profile	Total Reflow Score
ENIG	WS SAC	RTSx2	14
ISilver	WS SAC	RTSx2	12
ENIG	NC SAC	RTS	11
ENIG	WS SAC	RTS	11
ENIG	NC SAC	RTSx2	11
ENIG	WS SAC	RSS	10
ISilver	NC SAC	RTS	10
ENIG	NC SAC	RSS	9
ISilver	NC SAC	RTSx2	9
ISilver	WS SAC	RTS	8
ISilver	WS SAC	RSS	7
OSP	NC SAC	RTS	7
ISilver	NC SAC	RSS	6
OSP	NC SAC	RSS	6
OSP	WS SAC	RSS	6
OSP	NC SAC	RTSx2	6
OSP	WS SAC	RTS	4
OSP	WS SAC	RTSx2	4

The best surface finish reflow performance was shown by ENIG, followed by immersion silver, and OSP came in a distant third. Sorting this data by solder paste shows nearly identical performance for each solder paste. The RTSx2 reflow profile gave higher overall scores than the RTS profile and finally the RSS profile gave the lowest overall score. The best overall combinations in terms of reflow performance were ENIG and immersion silver with WS SAC and the RTSx2 profile. The worst overall combinations were OSP with WS SAC and the RTS and RTSx2 profiles. This shows that reflow performance is very dependent upon surface finish.

The overall voiding scores (void area, largest void) are shown below (Table 11).

Table 11. Overall Voiding Scores for Each Surface Finish, Solder Paste, and Reflow Profile Combination

Surface Finish	Solder Paste	Reflow Profile	Total Voiding Score
OSP	NC SAC	RTSx2	10
ENIG	NC SAC	RSS	8
ISilver	NC SAC	RSS	8
OSP	NC SAC	RSS	8
OSP	NC SAC	RTS	8
ENIG	NC SAC	RTSx2	8
ISilver	NC SAC	RTSx2	8
ENIG	WS SAC	RTSx2	8
OSP	WS SAC	RTSx2	8
ISilver	NC SAC	RTS	7
ENIG	WS SAC	RSS	7
ENIG	NC SAC	RTS	6
OSP	WS SAC	RSS	6
ISilver	WS SAC	RTS	6
ISilver	WS SAC	RTSx2	6
ENIG	WS SAC	RTS	5
ISilver	WS SAC	RSS	4
OSP	WS SAC	RTS	2

The best voiding performance by surface finish was displayed by ENIG and OSP, followed by immersion silver. The WS SAC solder paste showed worse voiding than the NC SAC solder paste. The RTSx2 profile gave the best voiding, followed by the RSS profile and finally the RTS profile gave the worst voiding. The best overall combination in terms of voiding performance was OSP with the NC SAC solder paste and the RTSx2 reflow profile. The worst overall combination was OSP with the WS SAC paste and the RTS profile. This shows that voiding performance can vary based on all three factors: surface finish, solder paste and reflow profile. All three must work together to optimize voiding performance.

The total overall scores for each surface finish and solder paste combination are shown below (Table 12).

Table 12. Total Overall Scores for Each Surface Finish & Solder Paste Combination

Surface Finish	Solder Paste	Total Score
ENIG	NC SAC	82
ISilver	NC SAC	71
OSP	NC SAC	69
ENIG	WS SAC	66
ISilver	WS SAC	52
OSP	WS SAC	41

ENIG surface finish outperformed immersion silver and both outperformed OSP in this study. NC SAC solder paste outperformed WS SAC solder paste in this study. The reader should be aware that multiple variables affect print, reflow and voiding performance. Performance is not dictated completely by surface finish and solder paste, although surface finish and solder paste certainly have a large influence on performance.

CONCLUSIONS

The best overall performance was found with ENIG surface finish and no clean SAC305 solder paste. Immersion silver gave moderate performance with both no clean and water-soluble SAC305 solder pastes. OSP gave the worst overall performance with both solder pastes. Despite the performance seen in this study, these solder paste and surface finish combinations are used to make high quality printed circuit board assemblies every day. While all of these combinations can be used, it is important to recognize the strengths and weaknesses of each of these combinations (Table 13).

Table 13. Strengths and Weaknesses of Each Surface Finish & Solder Paste Combination

Surface Finish - Solder Paste	Printing	Reflow	Voiding
ENIG - NC SAC	✓	✓	✓
ISilver - NC SAC	✓	✗	✓
OSP - NC SAC	✓	✗	✓
ENIG - WS SAC	✗	✓	✗
ISilver - WS SAC	✗	✓	✗
OSP - WS SAC	✗	✗	✗

The SMT process can be adjusted to minimize the impact of potential issues with these surface finish - solder paste combinations. It is recommended that the user run their own evaluation of surface finish and solder paste to determine the best fit for their application.

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