Optimization of Solder Paste Printing for Ultra-High-Density-Interconnect (UHDI) Applications

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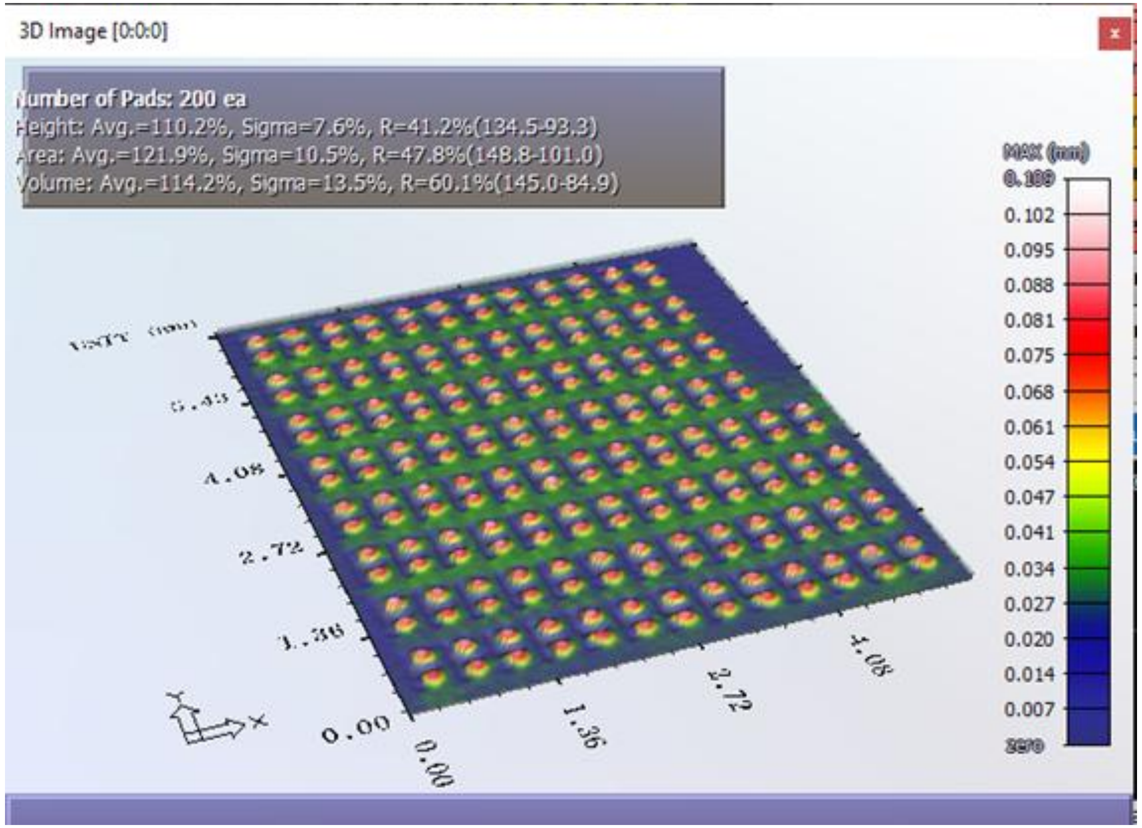
Agenda

- Introduction
  - UHDI and HDI
  - Solder Powder Size
- Experimental Methodology
  - Process, Materials, Equipment
- Results & Discussion
  - 0201M Printing
  - 0.3mm BGA Printing
  - Comparison – Same Aperture
- Conclusions & Recommendations
- Acknowledgments
- Q&A



3D Image [0:0:0]

Number of Pads: 200 ea
Height: Avg.=110.2%, Sigma=7.6%, R=41.2%(134.5-93.3)
Area: Avg.=121.9%, Sigma=10.5%, R=47.8%(148.8-101.0)
Volume: Avg.=114.2%, Sigma=13.5%, R=60.1%(145.0-84.9)

Introduction

UHDI & HDI Electronics

- Standard PCB technology limited to pad & spaces of 75 µm
- HDI – High-Density Interconnect
  - Pad, via & trace spacing specification reduced to 25 µm
  - Subtractive process (etching) 50 µm and/or mask defined pads 25 µm*
  - Up to 9X increase in density
  - Reduction in layer count and package size

  *Mask defined pads may have issues of positional repeatability & print alignment
- UHDI – Ultra High-Density Interconnect
  - Pad, via & trace spacing reduced to 12.5 µm
  - Additive process – adding conductors directly on the dielectric
  - Up to a 36X increase in density
  - Buried, stacked, staggered & blind via interconnects to reduce layer count

75 micron

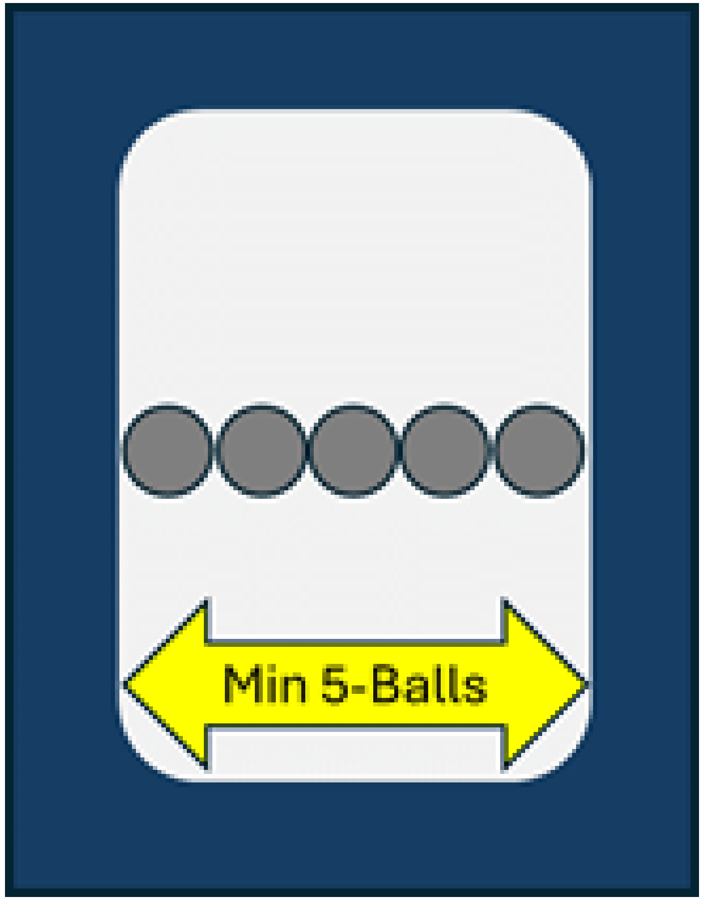
25 micron

12.5 micron

Solder Powder Size and UHDI

Solder Powder Size (IPC Type)	Size Range of > 80% (µm)	Middle Surface Area of 1Kg (m^2)	Amount of Surface Area Over T3	Relative Powder Cost
Type 3	25 - 45	22.9	-	1
Type 4	20 - 38	27.7	1.2x	1
Type 5	15 - 25	40.2	1.7x	1.1
Type 6	5 - 15	80.3	3.5x	4

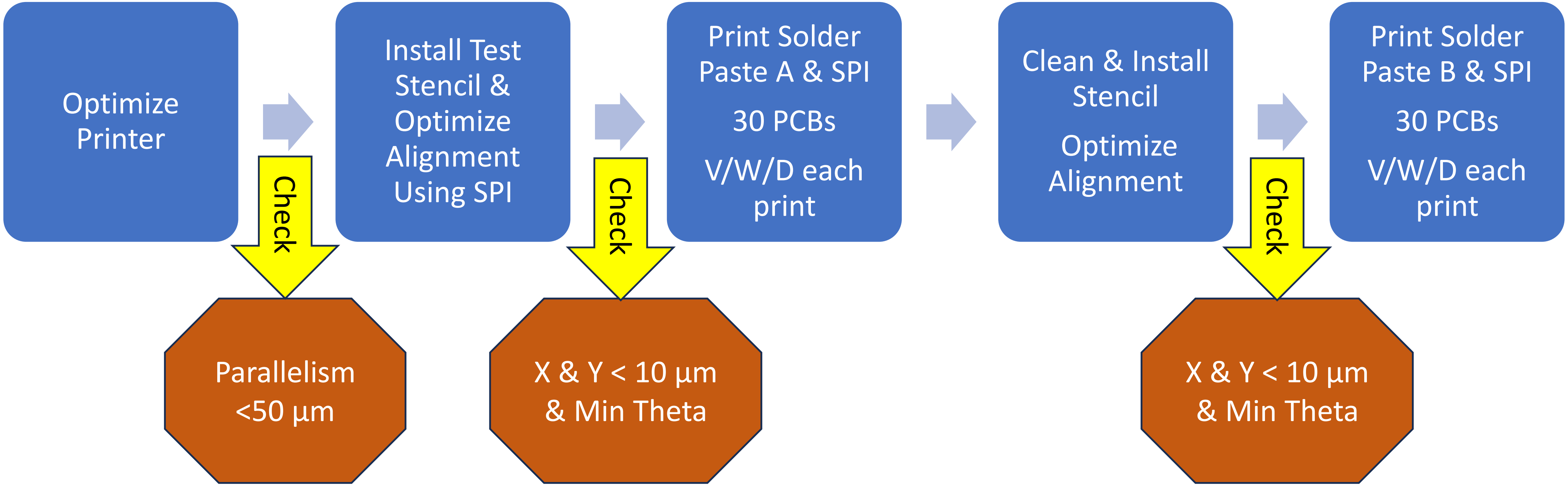
Solder Powder Size and UHDI



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

Experimental Methodology

Test Process



Optimize Printer

Install Test Stencil & Optimize Alignment Using SPI

Print Solder Paste A & SPI

30 PCBs

V/W/D each print

Clean & Install Stencil

Optimize Alignment

Print Solder Paste B & SPI

30 PCBs

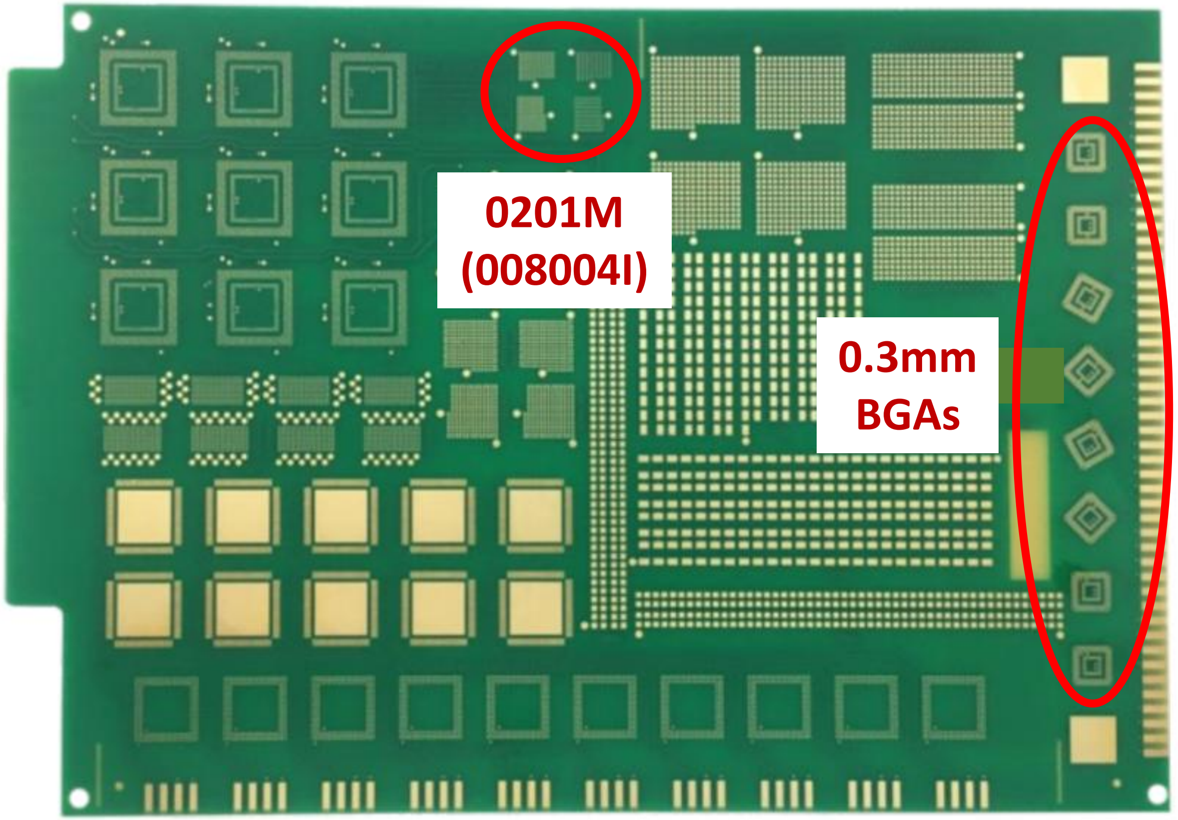
V/W/D each print

Parallelism <50 µm

X & Y < 10 µm & Min Theta

X & Y < 10 µm & Min Theta

Test PCB



Component	Pad Design	Pad Spacing
0201M (008004I) NE & SE	120 x 145 µm (4.7 x 5.7 mils) NSMD	120 µm (4.7 mils)
0201M (008004I) NW & SW	130 x 160 µm (5.1 x 6.3 mils) NSMD	120 µm (4.7 mils)
0.3 mm BGAs	152 µm (6.0 mils) round SMD	148 µm (5.8 mils)

Test Stencil

Component	Aperture Size	Area Ratio	Narrowest Space Between Apertures
0201M (008004I) NE	152 x 152 µm (6.0 x 6.0 mils) RSQ	0.75	147 µm (5.8 mils)
0201M (008004I) NW	180 µm wide x 150 µm tall (7.1 x 5.9 mils) radiused	0.81	120 µm (4.7 mils)
0201M (008004I) SE	160 µm wide x 130 µm tall (6.3 x 5.1 mils) radiused	0.70	170 µm (6.7 mils)
0201M (008004I) SW	150 µm wide x 180 µm tall (5.9 x 7.1 mils) radiused	0.81	120 µm (4.7 mils)
0.3 mm BGAs	152 x 152 µm (6.0 x 6.0 mils) RSQ	0.75	147 µm (5.8 mils)

Stencil: FG, 50 µm (2.0 mil), Ceramic Nano-Coating

Printer Equipment & Parameters

Specifications

- Wet print accuracy: 17 microns @ 6 sigma, CpK ≥ 2.0
- Alignment repeatability: ±11 microns @ 6 sigma, CpK ≥2.0
- Calibrated and verified
- Options: Edge PCB clamping, Paste height monitor
- Tooling: Block PCB support.
- Blades: 220 mm (8”) stainless steel blades with a 55-degree attack angle

Parameter	Value (Solder Paste A)	Value (Solder Paste B)
Squeegee force	6.8 kg	7.7 kg
Print speed	38.1 mm/sec	38.1 mm/sec
Blade gap	-2.0 mm	-2.0 mm
Post print lift height	12.5 mm	5.1 mm
Post print lift speed	80.0 mm/sec	80.0 mm/sec
Separation distance	2.54 mm	2.54 mm
Separation speed	1.27 mm/sec	1.27 mm/sec

SPI Equipment & Specifications

Specifications

- X – Y Resolution (µm): 7x7
- Height, Area, and Volume Repeatability
  - 3 Sigma < 1 µm, on a certified target
- Height Accuracy: 2 µm, on a certified target

Transfer Efficiency (TE%) & Coefficient of Variation (CV%)

TE% = 100% x [(Measured Volume) / (Aperture Volume)]

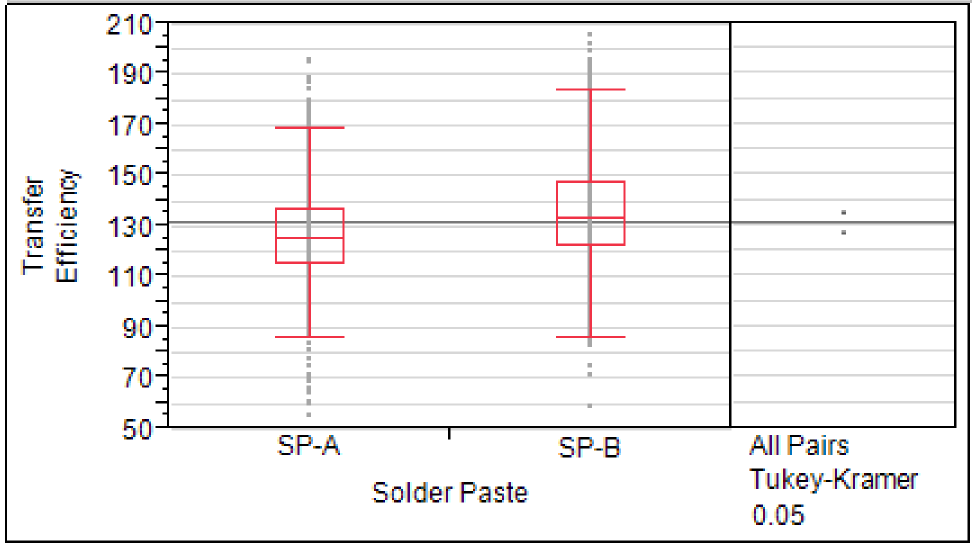
CV% = 100% x [(Standard Dev TE%) / (Mean TE%)]

CV < 10% Capable Process
CV 10-15% Marginal Process
CV > 15% Not-Capable Process

Results & Discussion

0201M Print Data by Solder Paste

Oneway Analysis of Transfer Efficiency By Solder Paste



Excluded Rows 2065

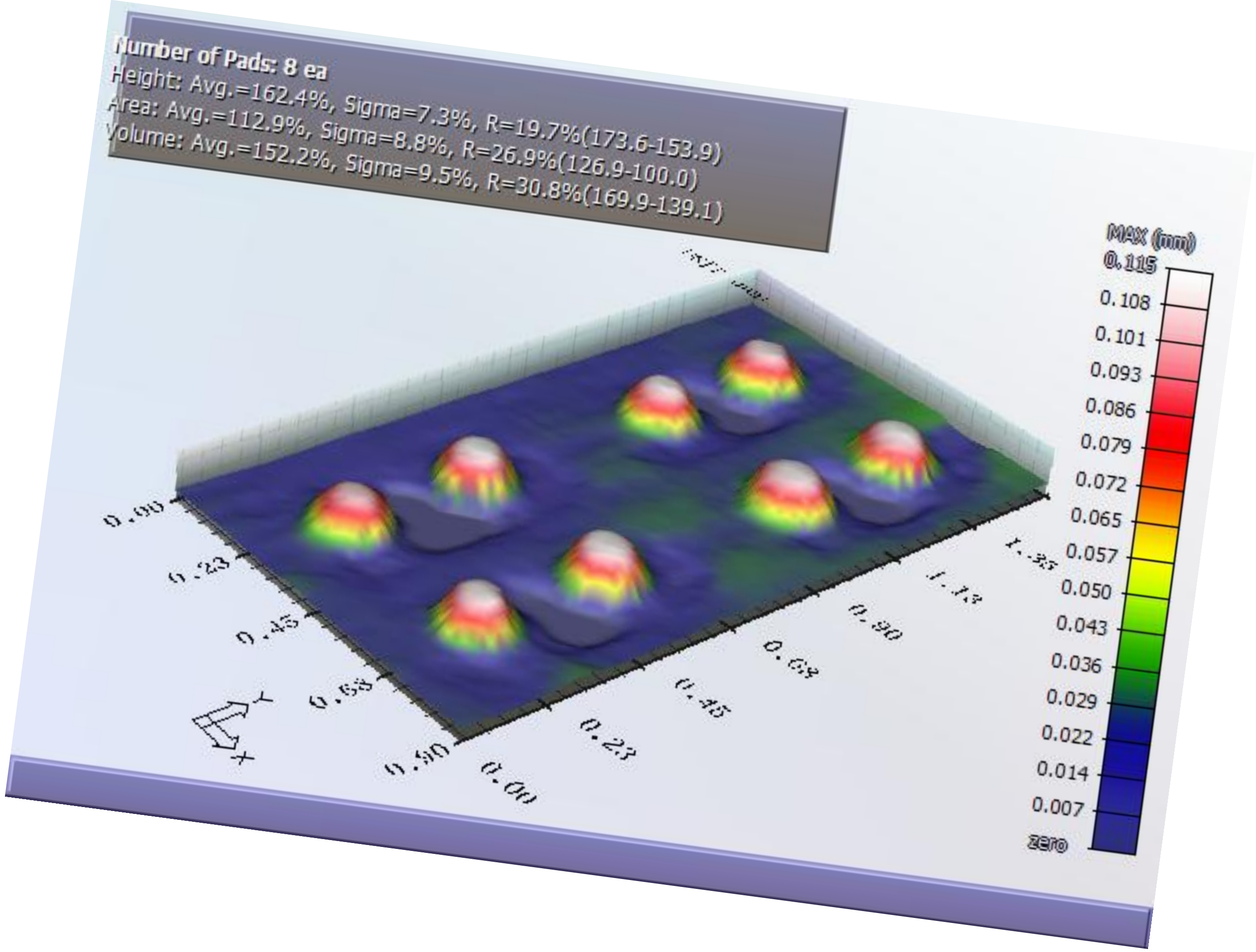
Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
SP-B	A		135.5
SP-A		B	127.5

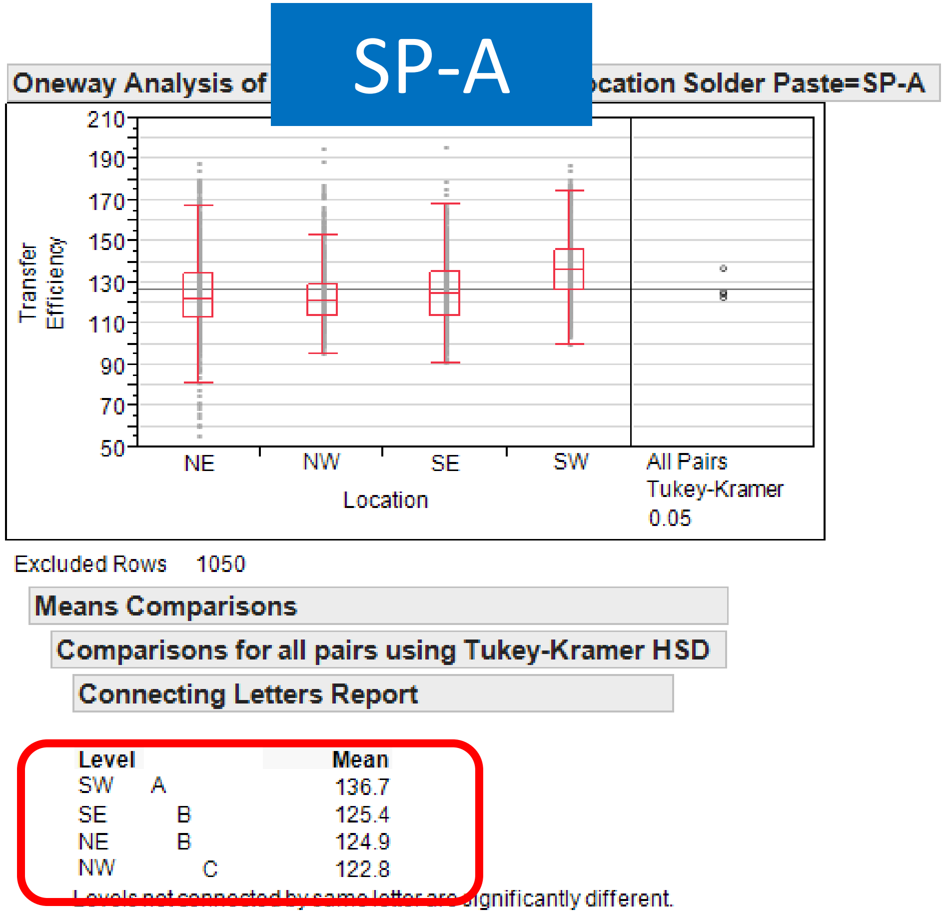
Levels not connected by same letter are significantly different.



Number of Pads: 8 ea
Height: Avg.=162.4%, Sigma=7.3%, R=19.7%(173.6-153.9)
Area: Avg.=112.9%, Sigma=8.8%, R=26.9%(126.9-100.0)
Volume: Avg.=152.2%, Sigma=9.5%, R=30.8%(169.9-139.1)

SP-B Printed with Higher TE%

0201M Print Data by Location



Oneway Analysis of … cation Solder Paste=SP-A

Excluded Rows 1050

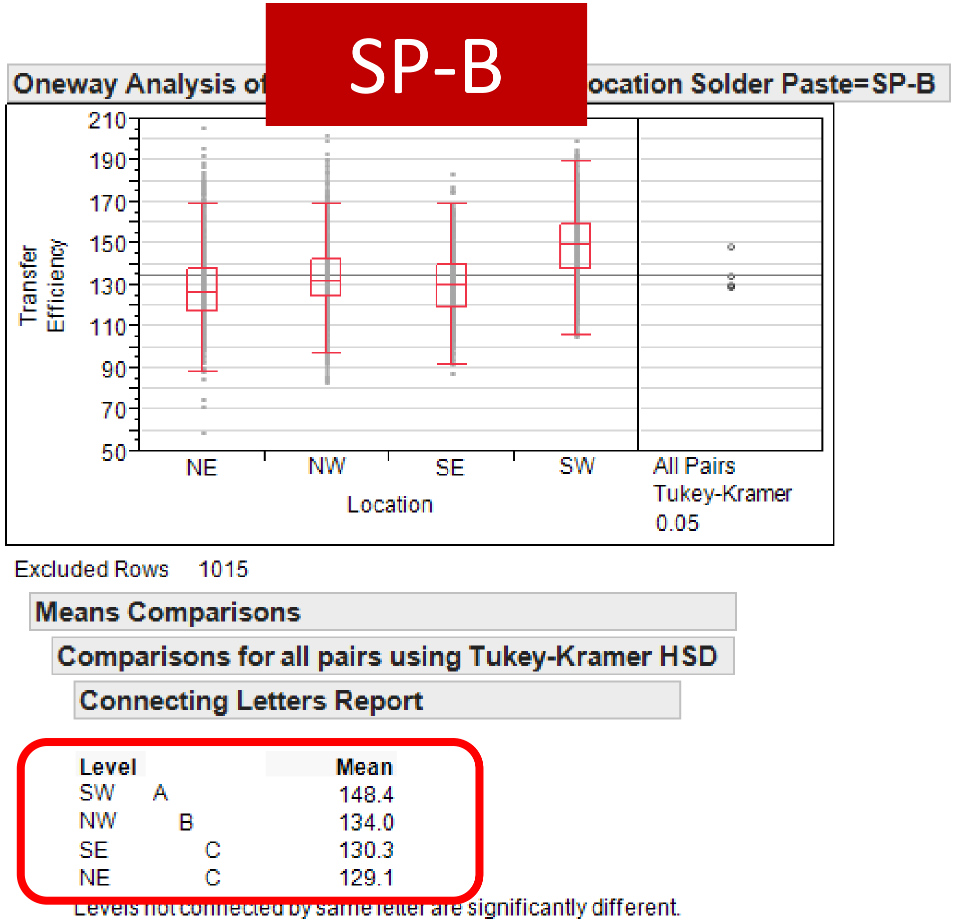
Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level				Mean
SW	A			136.7
SE		B		125.4
NE		B		124.9
NW			C	122.8

Levels not connected by same letter are significantly different.



Oneway Analysis of … ocation Solder Paste=SP-B

Excluded Rows 1015

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

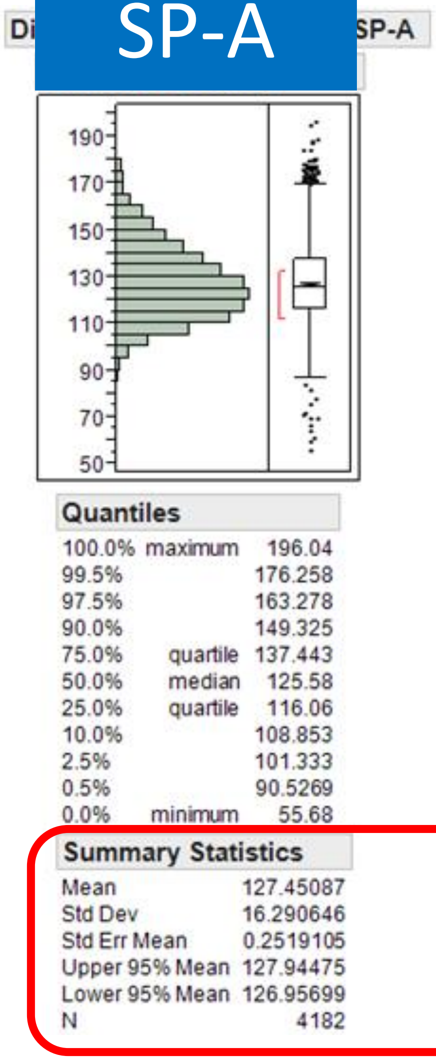
Level				Mean
SW	A			148.4
NW		B		134.0
SE			C	130.3
NE			C	129.1

Levels not connected by same letter are significantly different.

SW Location Printed with Higher TE%

0201M Distribution by Solder Paste

SP-A



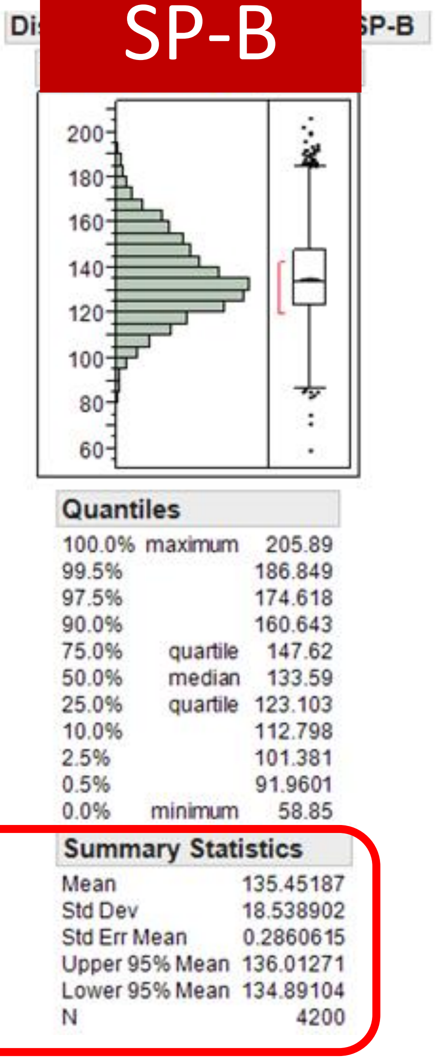
Quantiles

100.0%	maximum	196.04
99.5%		176.258
97.5%		163.278
90.0%		149.325
75.0%	quartile	137.443
50.0%	median	125.58
25.0%	quartile	116.06
10.0%		108.853
2.5%		101.333
0.5%		90.5269
0.0%	minimum	55.68

Summary Statistics

Mean	127.45087
Std Dev	16.290646
Std Err Mean	0.2519105
Upper 95% Mean	127.94475
Lower 95% Mean	126.95699
N	4182

SP-B

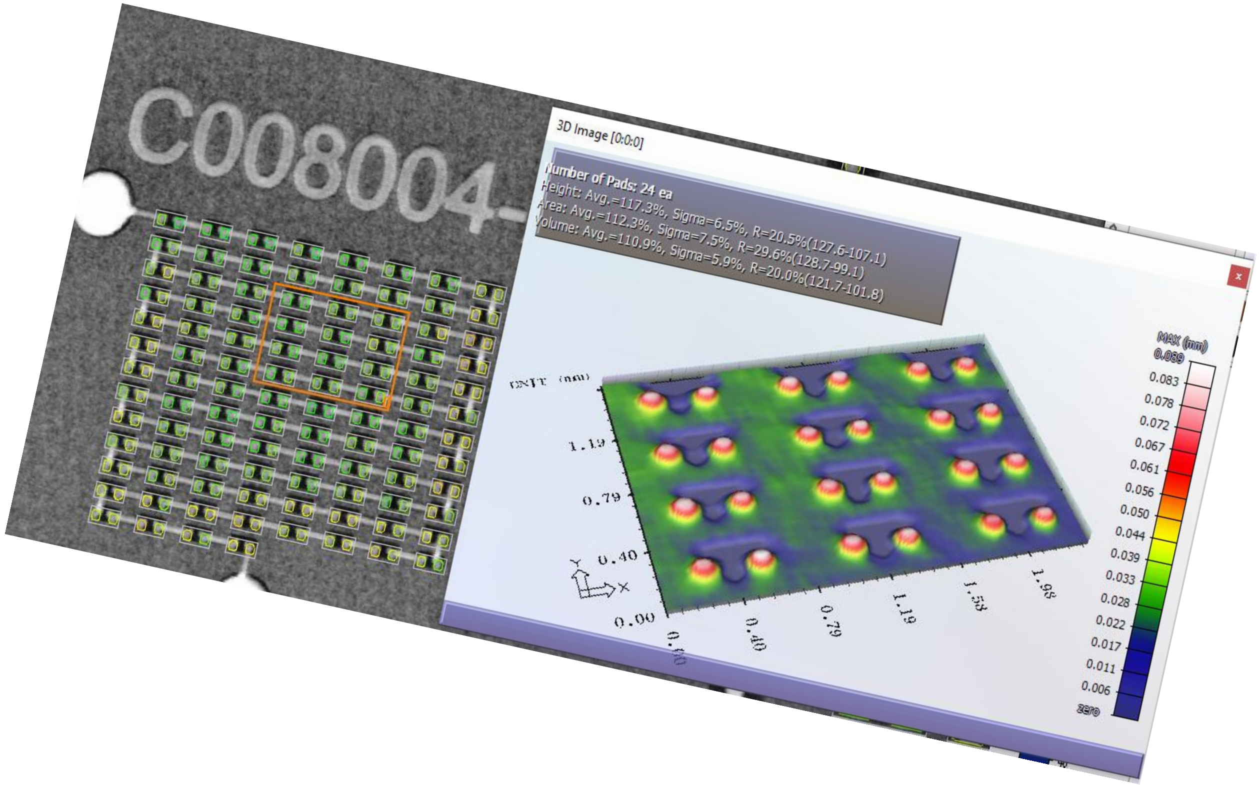


Quantiles

100.0%	maximum	205.89
99.5%		186.849
97.5%		174.618
90.0%		160.643
75.0%	quartile	147.62
50.0%	median	133.59
25.0%	quartile	123.103
10.0%		112.798
2.5%		101.381
0.5%		91.9601
0.0%	minimum	58.85

Summary Statistics

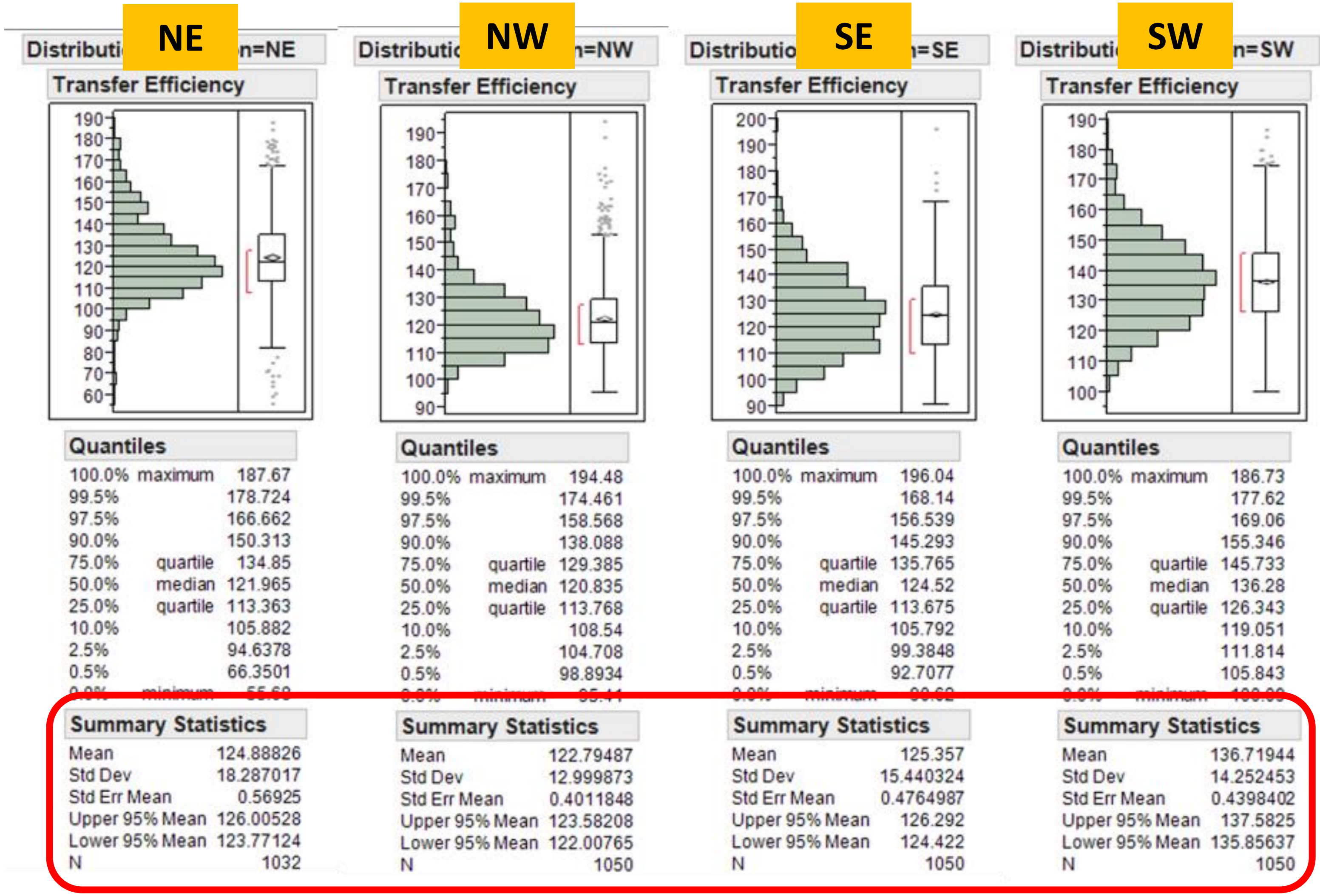
Mean	135.45187
Std Dev	18.538902
Std Err Mean	0.2860615
Upper 95% Mean	136.01271
Lower 95% Mean	134.89104
N	4200



Number of Pads: 24 ea
Height: Avg.=117.3%, Sigma=6.5%, R=20.5%(127.6-107.1)
Area: Avg.=112.3%, Sigma=7.5%, R=29.6%(128.7-99.1)
Volume: Avg.=110.9%, Sigma=5.9%, R=20.0%(121.7-101.8)

SP-A has Lowest Mean & STDev

0201M Distribution by Location: SP-A

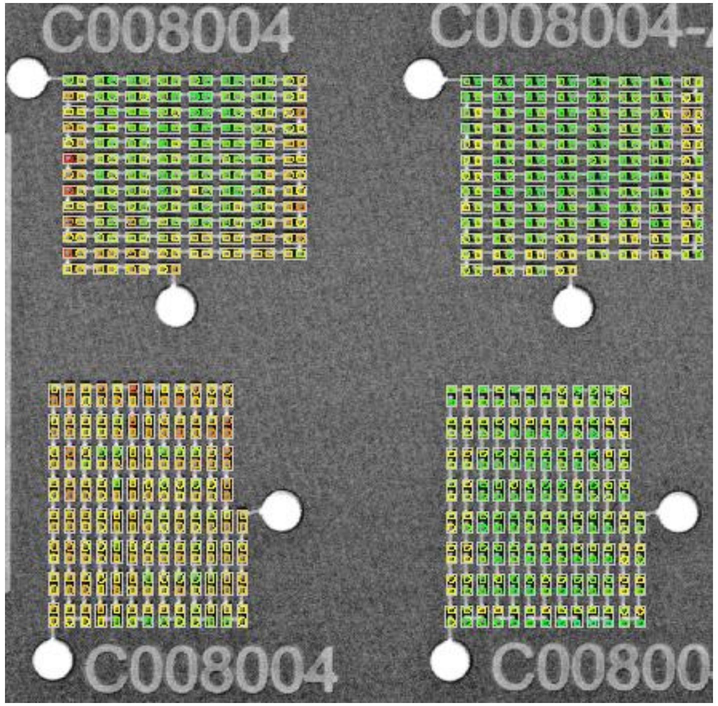


Quantiles

		NE	NW	SE	SW
100.0%	maximum	187.67	194.48	196.04	186.73
99.5%		178.724	174.461	168.14	177.62
97.5%		166.662	158.568	156.539	169.06
90.0%		150.313	138.088	145.293	155.346
75.0%	quartile	134.85	129.385	135.765	145.733
50.0%	median	121.965	120.835	124.52	136.28
25.0%	quartile	113.363	113.768	113.675	126.343
10.0%		105.882	108.54	105.792	119.051
2.5%		94.6378	104.708	99.3848	111.814
0.5%		66.3501	98.8934	92.7077	105.843

Summary Statistics

	NE	NW	SE	SW
Mean	124.88826	122.79487	125.357	136.71944
Std Dev	18.287017	12.999873	15.440324	14.252453
Std Err Mean	0.56925	0.4011848	0.4764987	0.4398402
Upper 95% Mean	126.00528	123.58208	126.292	137.5825
Lower 95% Mean	123.77124	122.00765	124.422	135.85637
N	1032	1050	1050	1050



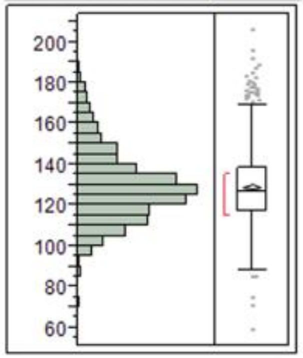
NW Location has Lowest Mean & STDev

0201M Distribution by Location: SP-B

NE

Distribut n=NE

Transfer Efficiency



Quantiles

100.0%	maximum	205.89
99.5%		186.286
97.5%		173.381
90.0%		153.515
75.0%	quartile	138.223
50.0%	median	126.86
25.0%	quartile	117.338
10.0%		108.321
2.5%		99.3638
0.5%		85.8097
0.0%	minimum	58.85

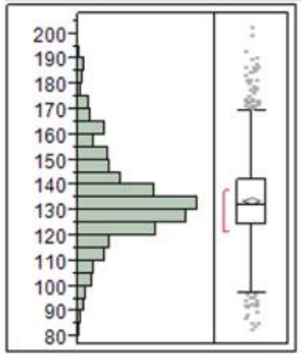
Summary Statistics

Mean	129.06428
Std Dev	18.061241
Std Err Mean	0.557382
Upper 95% Mean	130.15799
Lower 95% Mean	127.97057
N	1050

NW

Distributi n=NW

Transfer Efficiency



Quantiles

100.0%	maximum	202.23
99.5%		190.226
97.5%		177.351
90.0%		160.303
75.0%	quartile	142.42
50.0%	median	131.79
25.0%	quartile	124.303
10.0%		113.541
2.5%		98.3933
0.5%		87.2549
0.0%	minimum	82.08

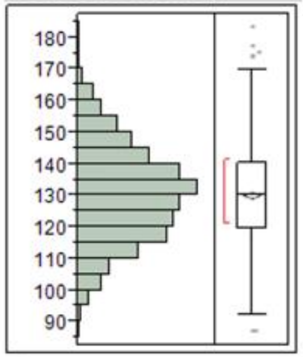
Summary Statistics

Mean	134.04547
Std Dev	18.130468
Std Err Mean	0.5595184
Upper 95% Mean	135.14337
Lower 95% Mean	132.94756
N	1050

SE

Distributi n=SE

Transfer Efficiency



Quantiles

100.0%	maximum	183.13
99.5%		172.833
97.5%		161.846
90.0%		150.285
75.0%	quartile	140.075
50.0%	median	130.33
25.0%	quartile	119.468
10.0%		110.963
2.5%		101.306
0.5%		93.854
0.0%	minimum	86.92

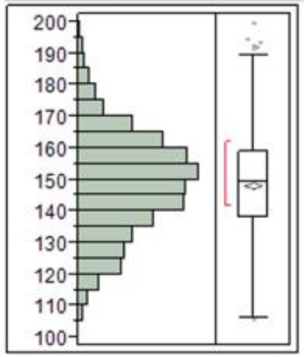
Summary Statistics

Mean	130.27986
Std Dev	15.184289
Std Err Mean	0.4685973
Upper 95% Mean	131.19935
Lower 95% Mean	129.36036
N	1050

SW

Distribut n=SW

Transfer Efficiency

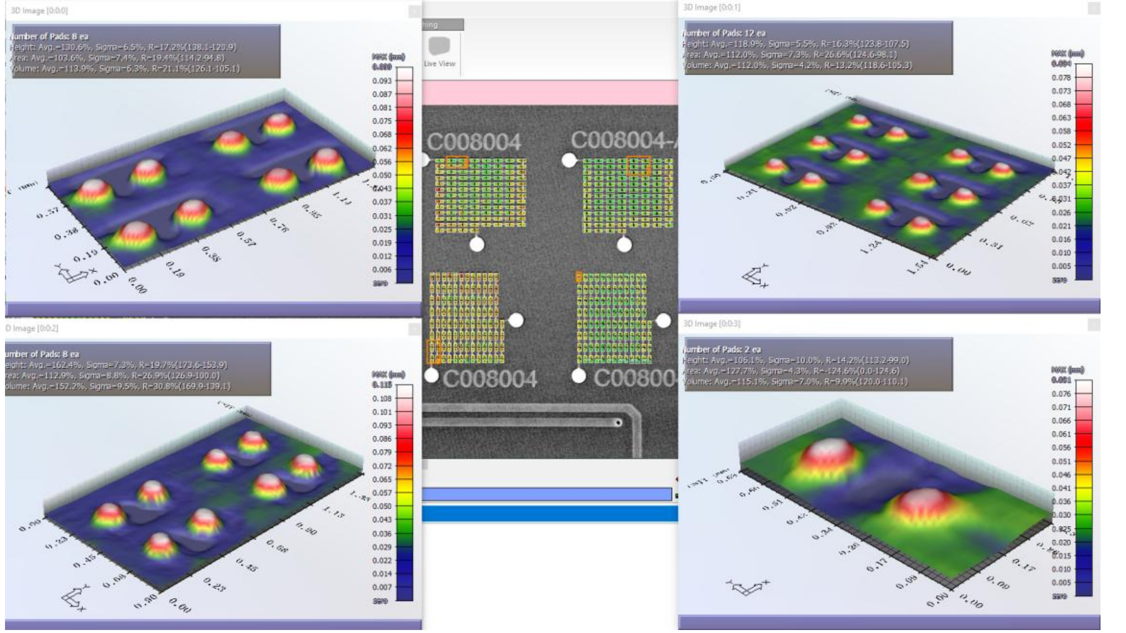


Quantiles

100.0%	maximum	199.45
99.5%		191.771
97.5%		179.765
90.0%		167.189
75.0%	quartile	159.1
50.0%	median	149.16
25.0%	quartile	137.955
10.0%		126.29
2.5%		117.464
0.5%		109.166
0.0%	minimum	105.45

Summary Statistics

Mean	148.4179
Std Dev	15.886729
Std Err Mean	0.4902751
Upper 95% Mean	149.37993
Lower 95% Mean	147.45586
N	1050



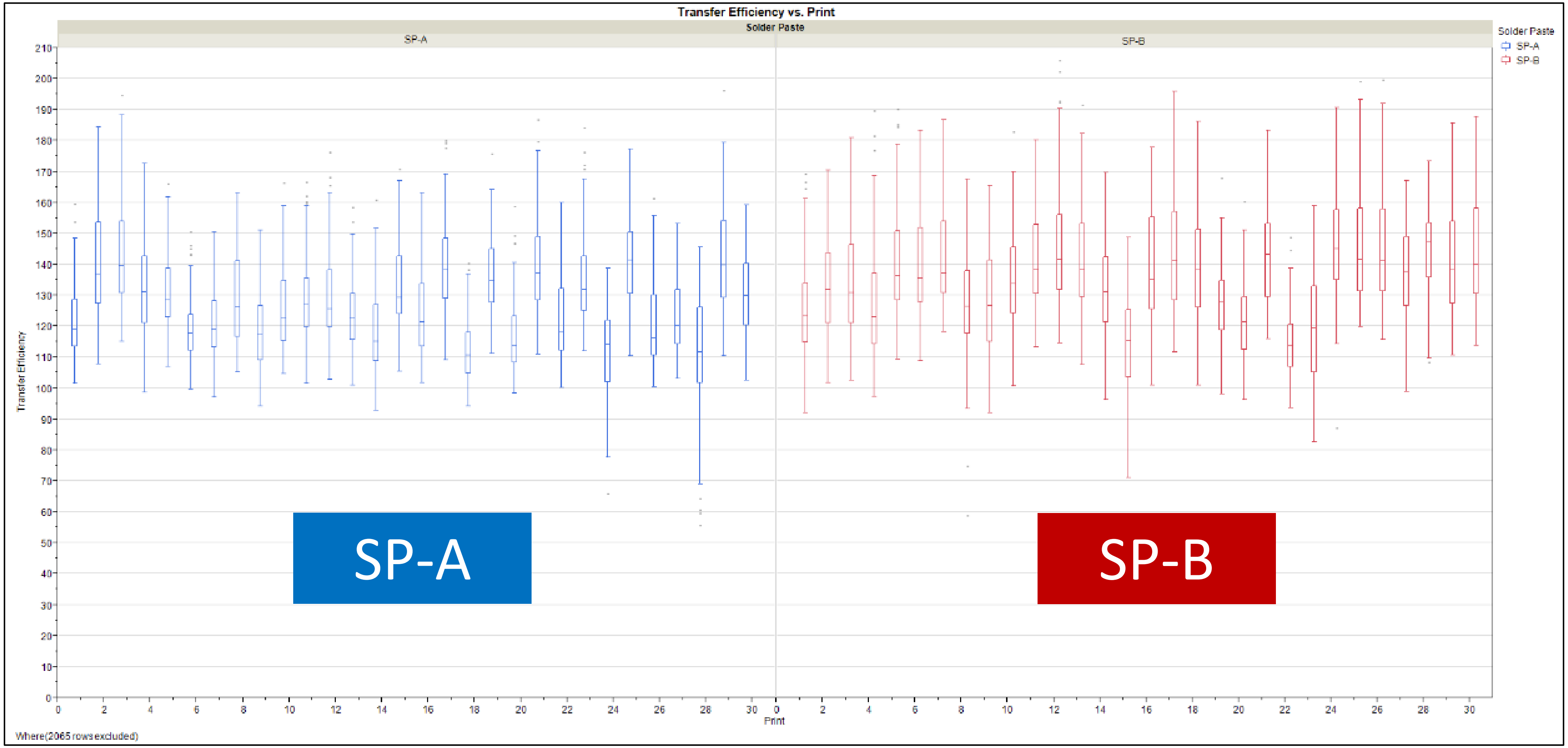
SE Location has Lowest STDev

0201M CV by Location

0201M Location	CV% for Solder Paste A	CV% for Solder Paste B
NE	14.6	14.0
NW	10.6	13.5
SE	12.3	11.6
SW	10.4	10.7

SW Location Gave Lowest CV%

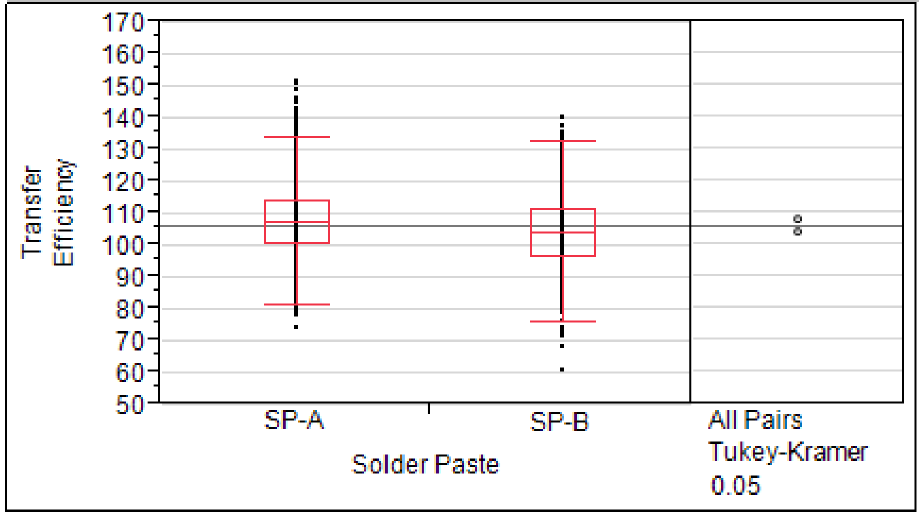
0201M TE% by Print



SP-A Less Variation from Print to Print

0.3mm BGA Print Data by Solder Paste

Oneway Analysis of Transfer Efficiency By Solder Paste



Excluded Rows 8382

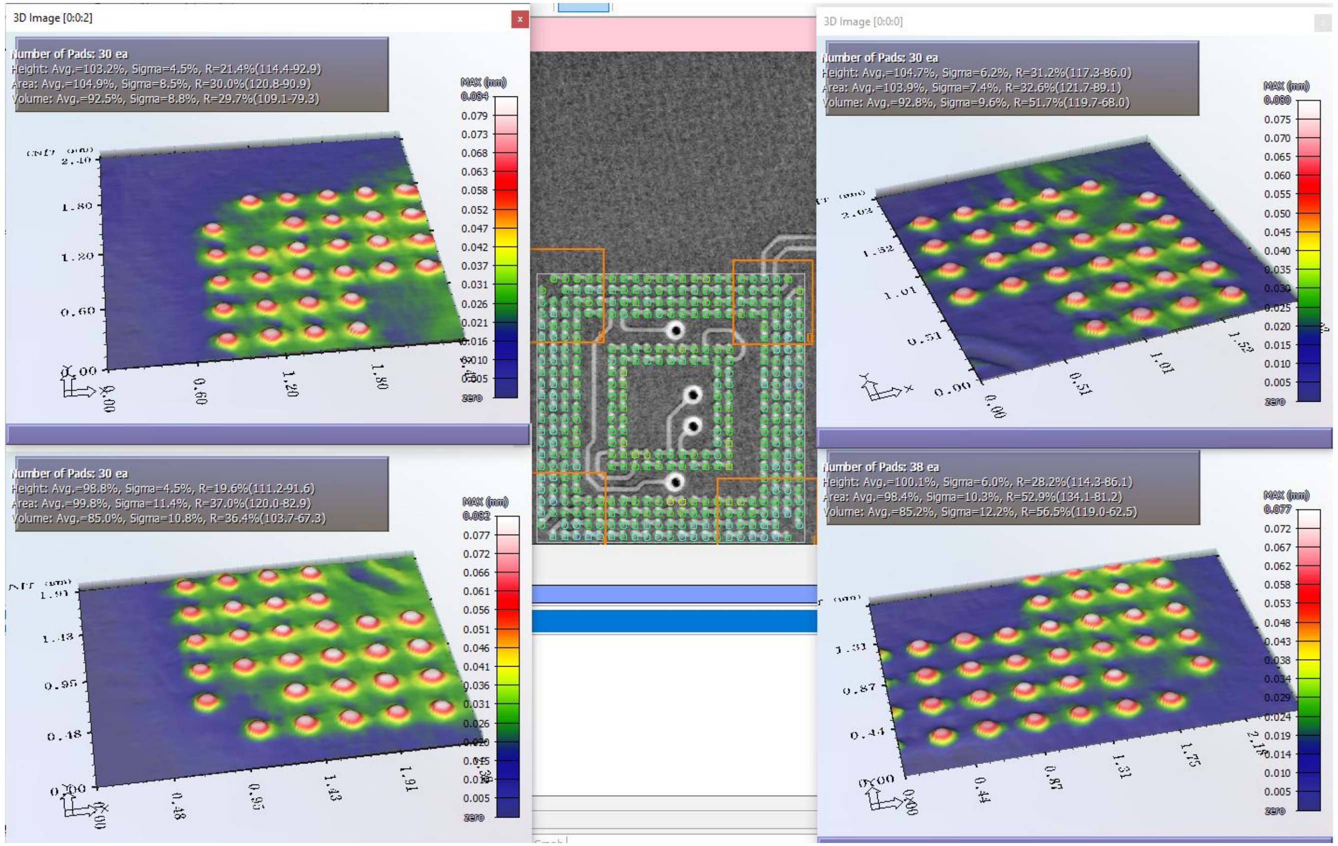
Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
SP-A	A		107.7
SP-B		B	104.1

Levels not connected by same letter are significantly different.



Number of Pads: 30 ea
Height: Avg.=103.2%, Sigma=4.5%, R=21.4%(114.4-92.9)
Area: Avg.=104.9%, Sigma=8.5%, R=30.0%(120.8-90.9)
Volume: Avg.=92.5%, Sigma=8.8%, R=29.7%(109.1-79.3)

Number of Pads: 30 ea
Height: Avg.=104.7%, Sigma=6.2%, R=31.2%(117.3-86.0)
Area: Avg.=103.9%, Sigma=7.4%, R=32.6%(121.7-89.1)
Volume: Avg.=92.8%, Sigma=9.6%, R=51.7%(119.7-68.0)

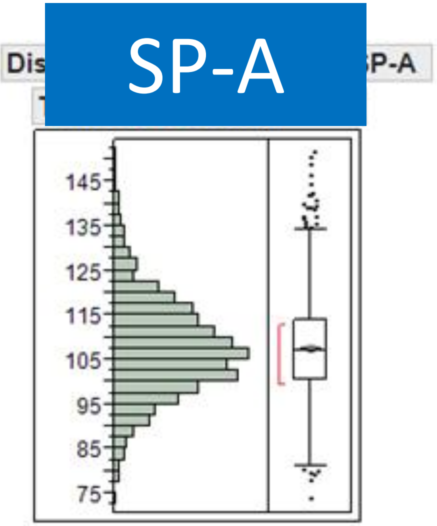
Number of Pads: 30 ea
Height: Avg.=98.8%, Sigma=4.5%, R=19.6%(111.2-91.6)
Area: Avg.=99.8%, Sigma=11.4%, R=37.0%(120.0-82.9)
Volume: Avg.=85.0%, Sigma=10.8%, R=36.4%(103.7-67.3)

Number of Pads: 38 ea
Height: Avg.=100.1%, Sigma=6.0%, R=28.2%(114.3-86.1)
Area: Avg.=98.4%, Sigma=10.3%, R=52.9%(134.1-81.2)
Volume: Avg.=85.2%, Sigma=12.2%, R=56.5%(119.0-62.5)

SP-A Printed with Higher TE%

0.3mm BGA Distribution by Solder Paste

SP-A



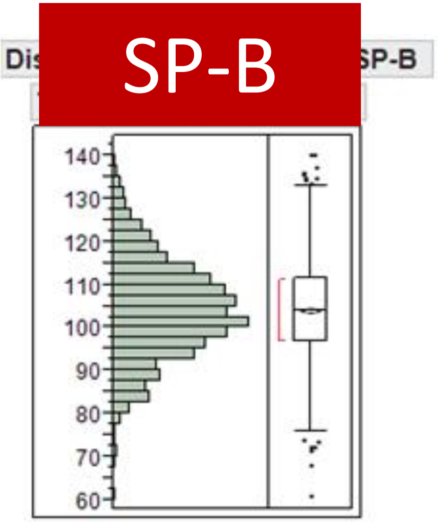
Quantiles

100.0%	maximum	151.65
99.5%		143.888
97.5%		133.6
90.0%		121.446
75.0%	quartile	114.075
50.0%	median	107.01
25.0%	quartile	100.543
10.0%		94.397
2.5%		86.535
0.5%		79.7971
0.0%	minimum	73.84

Summary Statistics

Mean	107.71895
Std Dev	11.077485
Std Err Mean	0.3418586
Upper 95% Mean	108.38976
Lower 95% Mean	107.04815
N	1050

SP-B



Quantiles

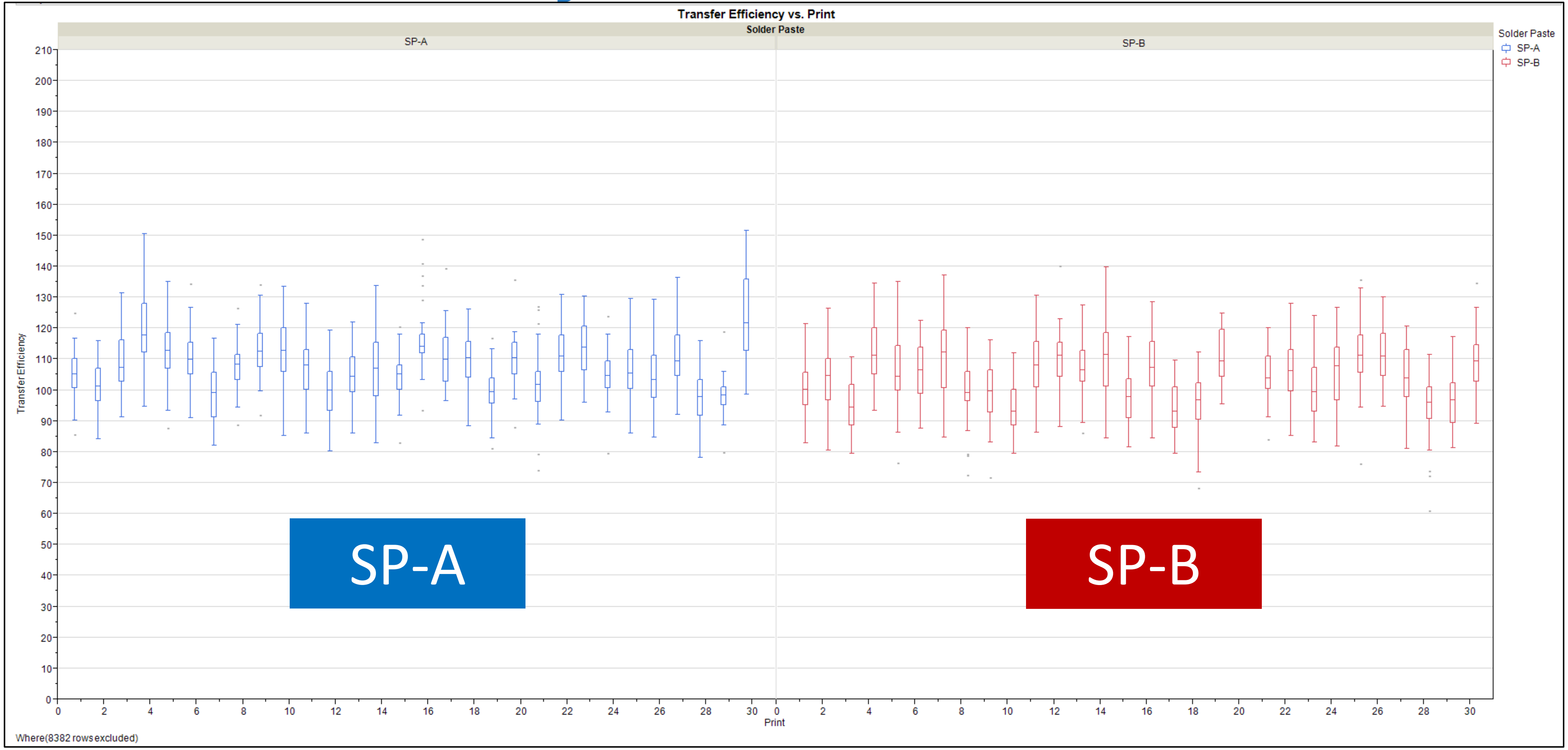
100.0%	maximum	139.87
99.5%		135.06
97.5%		128.336
90.0%		119.24
75.0%	quartile	111.36
50.0%	median	104.09
25.0%	quartile	96.84
10.0%		89.27
2.5%		81.608
0.5%		72.448
0.0%	minimum	60.84

Summary Statistics

Mean	104.13631
Std Dev	11.555264
Std Err Mean	0.3626994
Upper 95% Mean	104.84803
Lower 95% Mean	103.42458
N	1015

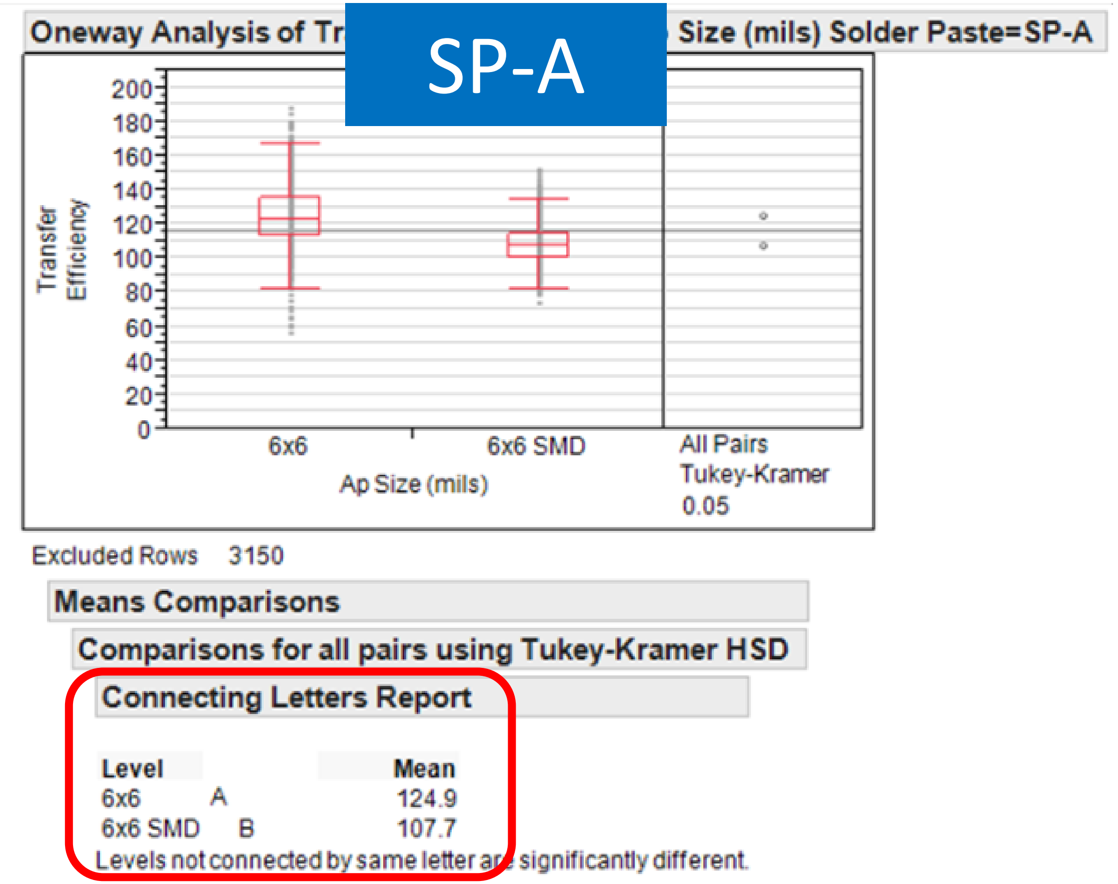
SP-A has Higher Mean & Lower STDev

0.3mm BGA TE% by Print



0.3mm BGA Less Variation Print to Print than 0201M

0201M NE & 0.3mm BGA Print Data – (6x6 mil Ap.) Cu vs Solder Mask Defined Pads



Oneway Analysis of Tr **Size (mils) Solder Paste=SP-A**

Excluded Rows 3150

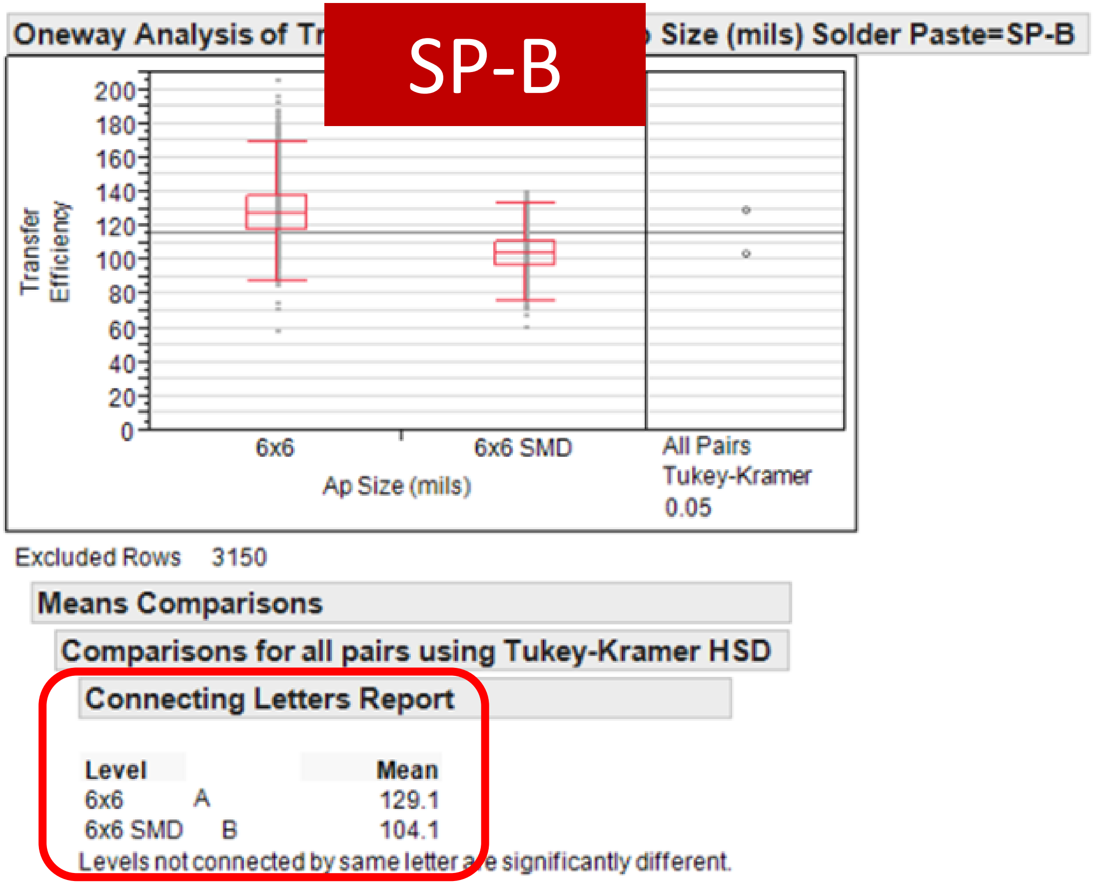
Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level		Mean
6x6	A	124.9
6x6 SMD	B	107.7

Levels not connected by same letter are significantly different.



Oneway Analysis of Tr **Size (mils) Solder Paste=SP-B**

Excluded Rows 3150

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level		Mean
6x6	A	129.1
6x6 SMD	B	104.1

Levels not connected by same letter are significantly different.

Both Pastes Showed Higher TE% in the Cu Defined Pads

0201M NE & 0.3mm BGA Print Data – (6x6 mil Ap.) Cu vs Solder Mask Defined Pads

Location	Mean TE% for Solder Paste A	CV% for Solder Paste A	Mean TE% for Solder Paste B	CV% for Solder Paste B
0201M NE 120 x 145 µm (4.7 x 5.7 mils) Cu Defined	124.9	14.6	129.1	14.0
0.3mm BGA 152 µm (6.0 mils) Round SM Defined	107.7	10.3	104.1	11.1

Overall Similar Performance for Both Solder Pastes

Conclusions & Recommendations

Conclusions

0201M Printing

- Solder paste B TE% > solder paste A.
- Solder paste A CV < solder paste B, and both are moderately capable.
- SW location: highest TE% and lowest CVs for both solder pastes.
  - Rectangular aperture – long edge parallel to the print direction.
- NE location: lowest TE% and highest CVs for both solder pastes.
  - “Squircle” aperture
- 30 prints over 1 hour showed good print consistency & repeatability for both solder pastes.
- No bridging was observed.

Conclusions

0.3mm BGA Printing

- Solder paste A gave slightly higher TE% & lower CV than solder paste B.
  - Both CVs were at the low end of the marginal CV range.
- 30 print testing: less variation than the 0201Ms.
- No bridging was observed.

Comparing Both Components with the Same Stencil Design

- 0201M NE location TE% & CVs >> 0.3mm BGAs for both solder pastes.
- Copper defined 0201M rectangular pads gave higher TE% but less consistency than the solder mask defined 0.3mm BGA pads.

Recommendations for HDI & UHDI Printing

- Optimize the printer parallelism and stencil to PCB registration.
- Use a No-clean Pb-free solder paste that is designed for Type 6 or 7 printing.
- Use a fine-grain, laser cut stencil with ceramic nano-coating.
- Orient rectangular pads with the long edge parallel to the print direction.
- Use solder-mask defined pads (where possible) to reduce print variation.

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