IMPACT OF STENCIL QUALITY & TECHNOLGY ON SOLDER PASTE PRINTING PERFORMANCE

Jeffrey Len Yung Kwuan, Leon Rao, Evan Yip, Wisdom Qu, Jonas Sjoberg
Indium Corporation of Asia Pacific
Singapore
jsjoberg@indium.com

ABSTRACT

The growth of the Internet of Things (IoT) has greatly increased miniaturization development in packaging and board level assembly. As the industry is moving to smaller and finer pitches such as 008004, 0.3mm CSP, and BGA, screen printing becomes one of the critical processes to produce a good quality surface mount assembly. It has been widely accepted that 50–70% of SMT defects come from printing applications. There are many variables that will affect the quality of printing such as machine set up, solder paste handling and storage, stencil quality, stencil aperture design, printing parameters, and others. In this paper, we will evaluate the impact of stencil quality statistically through MiniTab software by comparing the printing performance of 0.35mm pitch and 01005 pads from different stencil suppliers.

Key words: Internet of Things (IoT), miniaturization, printing performance, 0.35mm pitch, 01005 pad

INTRODUCTION

In the era of the Internet of Things, where finer pitch components are used in applications such as mobile or system-in-package devices, process control of stencil printing is important as process windows have become tighter with little to no margin for error in the process. In the past, when the process window was more "forgiving" with large aperture printing, a good area ratio of ≥0.66 and the "5 balls rule" stencil design (Figure 1 & 3) was easily achievable and sufficient for quality printing performance. That is no longer the case, as when apertures get down to finer pitches of 01005 and 008004, other factors become critical to ensure good transfer efficiency.

Area Ratio ≥ 0.66
Minimum number of solder particles spanning an aperture should be at least 4.5

Figure 1: Stencil design guidelines

Good transfer efficiency is important to provide quality printing performance. Transfer efficiency equals the percentage of actual paste volume over theoretical paste volume on a desired pad. In order to have good transfer efficiency, solder has to be deposited onto the desired area at the right volume and correct solder height. Figure 2 shows the various factors that could affect the transfer efficiency of solder paste for a typical printing application.

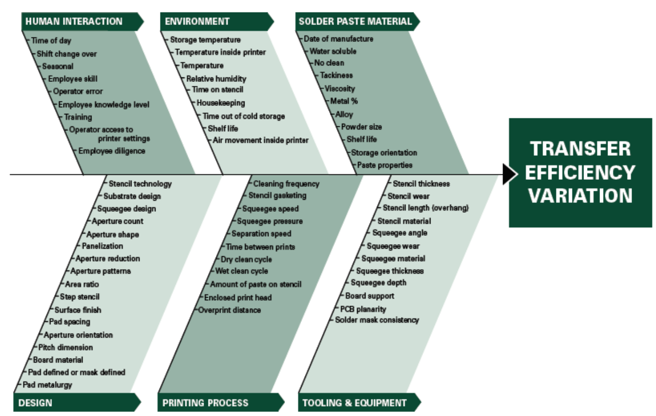


Figure 2. Cause and Effect diagram for transfer efficiency

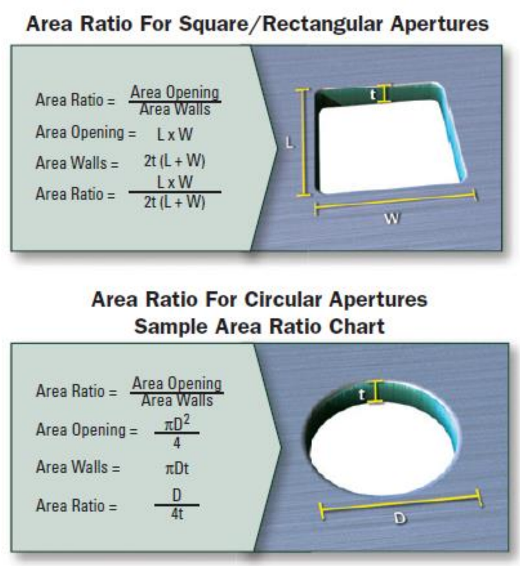


Figure 3. Area ratios for square and circular apertures

It is widely known that solder paste selection, printing parameters, stencil aperture design, and printer setup are common factors that will affect printing performance, but it is still unknown as to whether the quality of stencils from different suppliers affects the solder paste transfer efficiency. Each supplier might use different laser cut equipment with varying accuracy, nano-coating material, and fabrication process. In Figure 3, the SEM images show the difference in quality produced between laser cut-polished stencils 1 and 2. In this paper, several stencil suppliers have been selected to submit two best-effort stencil types on laser cut + eletropolished (EP stencil) and laser cut + eletropolished + nano-coated (nano-coated stencil). 1 electro-foam (EF) stencil was selected as benchmark. Data collected will be analyzed through Minitab software.

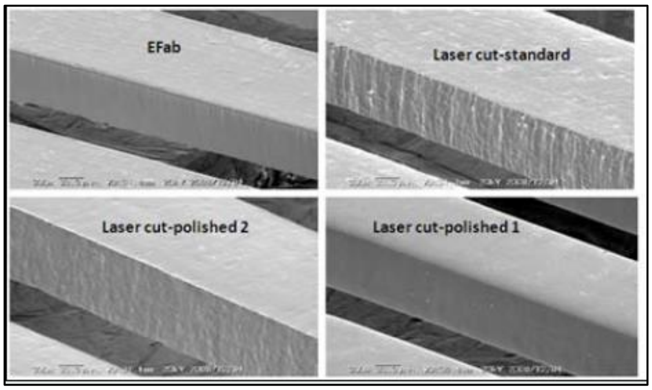


Figure 4. SEM photos of different stencil types

EXPERIMENTAL DESIGN

The focus of this experiment is to assess the impact of stencil quality on the paste's transfer efficiency of stencils, especially on a 01005 and 0.35mm pitch BGA pad. All stencils supplied were on a best-effort basis and outgoing inspection performed per the supplier's standard outgoing QC test. It was not within the scope of this study to verify the incoming QC test results from each supplier.

Solder paste

A no-clean, halogen-free SAC305 solder paste with a powder size particle from 15–25 microns was selected for this experiment. It is a proven solder paste within the industry with a robust printing process, and has a good transfer efficiency and response-to-pause.

Test vehicle

The test vehicles (Sample size – 6 boards) used in this experiment consisted of 0.35mm pitch (0.22 circles), a 01005 pad (0.20mm square), and various pads from 0.18mm–0.24mm in circular and square shapes. For the purpose of this study, we will focus on the data analysis of pads C0.22mm and SQ0.20mm.

Stencil suppliers

The six stencil suppliers selected are common stencil suppliers among our customers in different regions. Two types of stencils were selected: laser-cut eletropolished (EP stencil) and laser-cut nano-coated material (nano-coated stencil). Stencil thickness was fixed at 80 microns using SUS304 stencil material.

Table 1. Summary of stencil types and suppliers

Supplier	Country	EP	Nano	E-Fab
A	China	×	√	×
B	Malaysia	√	√	×
C	China	√	√	×
D	Europe	√	√	×
E	China	√	√	×
F	Malaysia	√	√	×
G	China	×	×	√

Stencil design and area ratio

Each stencil aperture was chosen to simulate the typical pad size for 0.35mm pitch BGA and a 01005 passive component pad.

Figure 5. Stencil Aperture Sizes

Table 2. Area ratio table

Shape	Dimension (mm)	Area Ratio	Remarks
Circle	0.22	0.72	0.35mm BGA pitch
Square	0.20 x 0.20	0.66	01005

Printing Process

Printing parameter optimization was performed prior to the experiment, and only one printing parameter was fixed to provide a better comparison of the printing performance of each stencil. A vacuum support block and foil-less clamp were used in this experiment. Under wipe cleaning was performed on every print and an inspection was done on the board support for every conversion to ensure proper printer setup. Below is the optimized printing parameter:

Print speed: 50mm/s
Print pressure: 7kg
Print gap: 0mm
Separation speed: 0.5mm/s
Separation distance: 3mm

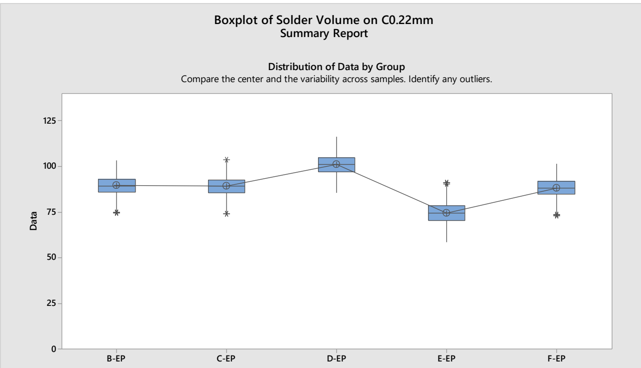
Equipment

- DEK Horizon printer
- Koh Young SPI machine
- Vacuum support

RESULTS AND DISCUSSION

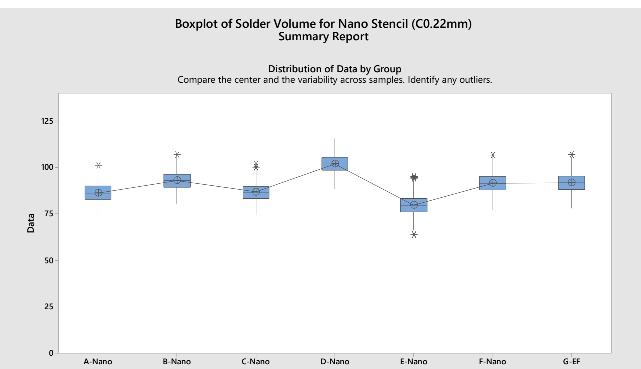
Box plot of EP and Nano-coated stencil on a C0.22mm pad

Printing SPI data was collected and analyzed through a box plot to reveal the mean and STD of solder volume. Results in Figures 6 and 7 shows that stencil D had the highest mean value for both the EP and nano-coated stencil at 101.00% (EP) and 101.89% (nano-coated stencil). Stencil F had the lowest volume variation of EP stencils with a standard deviation of 5.1937, while stencil C had the lowest volume variation of nano-coated stencils at 4.6344.



Statistics	B-EP	C-EP	D-EP	E-EP	F-EP
N	1320	1320	1320	1320	1320
Mean	89.512	89.164	101.00	74.521	88.268
StDev	5.2418	5.4699	5.5953	5.7943	5.1937
Minimum	74.331	74.171	85.665	58.675	72.953
Maximum	103.40	103.85	116.42	91.295	101.60

Figure 6. Box plot of volume on a C0.22mm pad (EP Stencils)

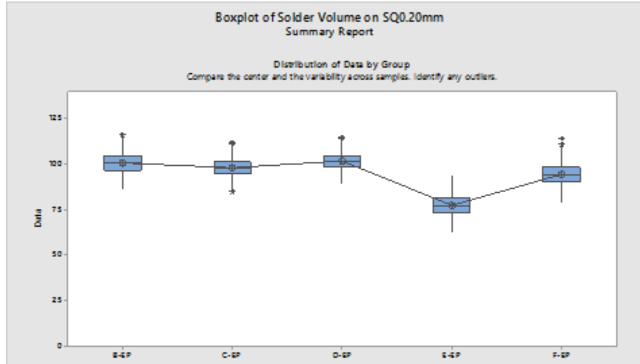


Statistics	A-Nano	B-Nano	C-Nano	D-Nano	E-Nano	F-Nano	G-EF
N	1320	1320	1320	1320	1320	1320	1320
Mean	86.189	92.985	86.756	101.89	79.741	91.473	91.697
StDev	5.0592	5.0587	4.6344	4.8702	5.0088	5.1336	5.3283
Minimum	72.276	80.059	74.285	88.374	63.684	77.1	78.07
Maximum	100.85	106.65	101.79	115.52	94.917	106.61	106.78

Figure 7. Box plot of solder volume on a C0.22mm Pad (Nano-coated stencil)

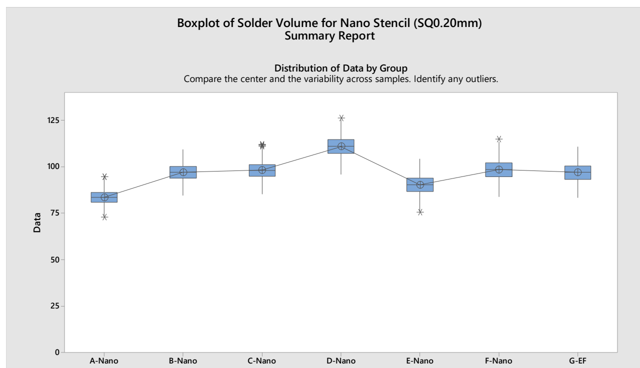
Box plot of EP and Nano-coated stencil on a SQ0.20mm pad

A similar trend was observed in the SQ0.20mm box plot result, where stencil D had the highest mean value for both the EP and nano-coated stencil at 101.76% (EP) and 110.78% (nano-coated stencil). EP stencils C and D had the lowest solder volume variation with a comparable standard deviation while nano-coated stencil A had the lowest volume variation with a standard deviation of 3.8574.



Statistics	B-EP	C-EP	D-EP	E-EP	F-EP
N	1200	1200	1200	1200	1200
Mean	100.69	98.269	101.76	77.379	94.427
StDev	5.7156	4.7370	4.7876	5.6779	5.9378
Minimum	86.027	85.111	89.092	62.051	78.465
Maximum	116.83	112.13	114.82	93.608	114.37

Figure 8. Box plot of solder volume on a SQ0.20mm pad (EP Stencil)



Statistics	A-Nano	B-Nano	C-Nano	D-Nano	E-Nano	F-Nano	G-EF
N	1200	1200	1200	1200	1200	1200	1200
Mean	83.486	96.959	98.134	110.78	90.209	98.374	96.888
StDev	3.8574	4.7469	4.9175	5.4355	5.2741	5.5253	5.2666
Minimum	72.704	84.367	85.099	95.822	75.509	83.692	83.144
Maximum	94.568	109.40	111.78	125.99	104.20	114.60	110.82

Figure 9. Box Plot of solder volume on a SQ0.20mm pad (Nano-coated stencil)

Process capabilities analysis

Further analysis was performed to measure the Ppk and Pp of each stencil. The specification limit was set at a default of 60 for LCL and 150% for UCL to give a better comparison of Ppk and Pp between different stencils. Ppk is used to define the accuracy and consistency of the paste transfer efficiency. In the case where the process is not centered but still within the upper and lower spec, Pp value is used to define the process consistency.

Based on results shown in Table 3, stencil D had the highest Ppk value on a C0.20mm pad for both the EP stencil and nano-coated stencil. It showed that stencil D was able to achieve consistent solder volume with a mean closest to the target value. Out of the stencils available, EP stencil E performed poorly on transfer efficiency where a number of pads achieved volume below the lower spec limit of 60%. There are various factors that potentially contributed to the poor transfer, which are not the focus in this study. Despite differences in the Ppk value, nano-coated stencil improved consistency of transfer efficiency as reflected in Pp value.

Table 3. Capability analysis of stencils on C0.22mm

Suppliers	Ppk			Pp		
	EP	Nano	E-Fab	EP	Nano	E-Fab
A	-	1.726	-		2.965	-
B	1.877	2.173	-	2.862	2.960	-
C	1.777	2.155	-	2.742	3.237	-
D	2.903	2.867	-	3.187	3.080	-
E	0.825	1.314	-	2.589	2.990	-
F	1.814	2.044	-	2.888	2.922	-
G	-	-	1.983	-	-	2.815

For the SQ0.20mm pad, stencil D achieved the highest Ppk on EP, but nano-coated stencil F had the highest Ppk value. One of the possible reasons for this is that the data distribution of stencil D is not centered, which can be reflected within the box plot analysis where stencil D achieved a mean solder paste volume of 110.78%. Most stencils except for stencil E achieved comparable Ppk value with electro-foam stencil G.

Table 4. Capability analysis of stencils on SQ0.20mm

Suppliers	Ppk			Pp		
	EP	Nano	E-Fab	EP	Nano	E-Fab
A	-	2.029	-		3.889	-
B	2.373	2.595	-	2.624	3.160	-
C	2.693	2.585	-	3.167	3.889	-
D	2.908	2.405	-	3.133	2.760	-
E	1.020	1.909	-	2.642	2.840	-
F	1.933	2.315	-	2.520	2.715	-
G	-	-	2.335	-	-	2.848

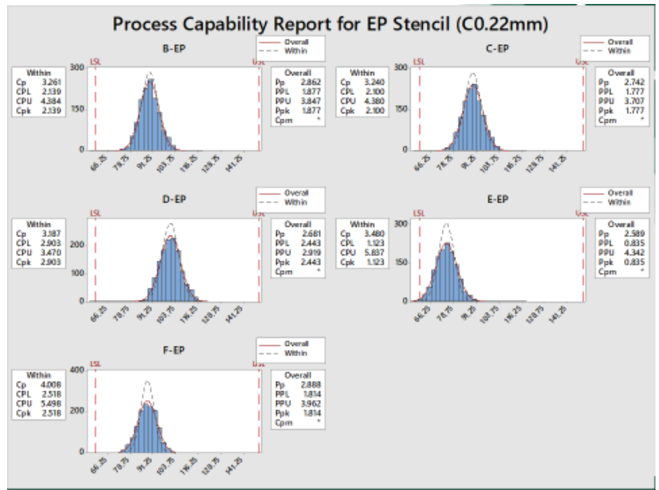


Figure 10. Cpk report of EP stencils on C0.22mm pad

One-Way ANOVA analysis

In order to assess the mean value differences between stencils statistically among suppliers, one-way ANOVA analysis was performed on both C0.22mm and SQ0.22mm data:

Null hypothesis, H_0: All means are equal
Alternative hypothesis, H_1: At least one mean is different

C0.22mm pad

The results of both EP and nano-coated stencils show that p-value < 0.05 indicate that the data provides sufficient evidence to reject the null hypothesis that at least one mean is different among EP and nano-coated stencils. Further analysis performed using Tukey pairwise comparison shows that all EP stencils have significant mean differences except for EP stencils B and C. As for nano-coated stencils, all nano-coated stencils are significant different with each other except for stencil F with stencil G and stencil A with C.

Factor Information

Factor	Levels	Values
Factor	7	A-Nano, B-Nano, C-Nano, D-Nano, E-Nano, F-Nano, G-EF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	376939	62823.1	2495.59	0.000
Error	9233	232428	25.2		
Total	9239	609367			

Figure 11. Example of One-Way ANOVA analysis result (nano-coated stencils)

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
D-Nano	1320	101.891	A
B-Nano	1320	92.985	B
G-EF	1320	91.697	C
F-Nano	1320	91.473	C
C-Nano	1320	86.756	D
A-Nano	1320	86.189	D
E-Nano	1320	79.741	E

Means that do not share a letter are significantly different.

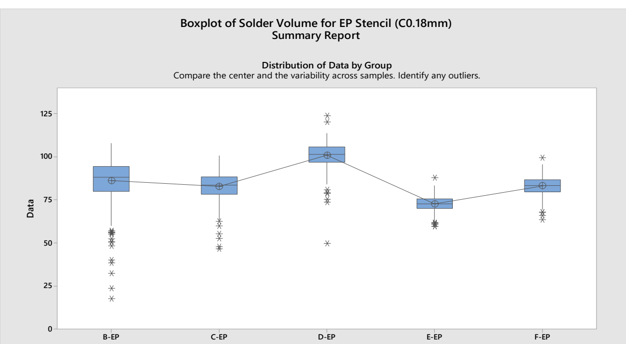
Figure 12. Example of Tukey pairwise comparison result (nano-coated stencils)

SQ0.20mm pad

The results of both EP and nano-coated stencils show that p-value <0.05 indicate that there is sufficient data evidence to reject the null hypothesis and at least one mean is different among EP and nano-coated stencils. Similarly, further analysis performed using Tukey Pairwise comparison shows all EP stencils are significantly different from one another. All nano-coated stencils are significant different with each other except for stencil C with stencil F and stencil B and G.

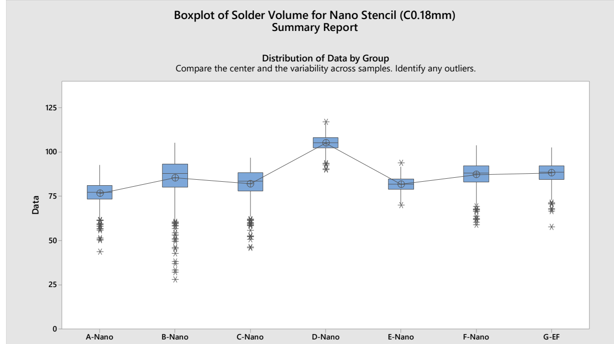
Impact of stencil quality on low area ratio aperture printing (AR: 0.59)

While it is not the scope of this study to analyze the printing performance on C0.18mm and SQ0.18mm pad size, box plot analysis was performed in order to understand the impact of stencil quality on printing performance of each stencil when the area ratio is reduced to 0.59. The box plot results indicate the differences in transfer efficiency and variation was observed among different stencil suppliers. In a similar pad size, square-shaped pads have a lesser volume variation and better paste release compared to circle pads. Insufficient solder was observed at a greater degree at stencil A, B and C mainly on circle 0.18mm pad. However further data collection and detailed analysis needed to confirm the observation.



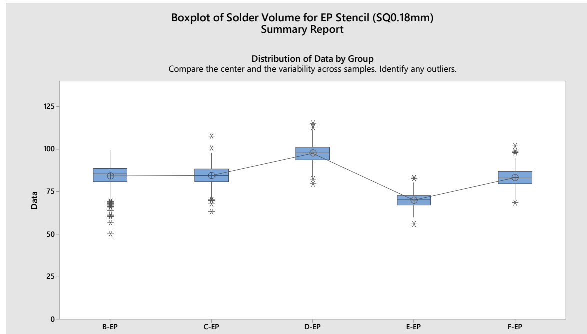
Statistics	B-EP	C-EP	D-EP	E-EP	F-EP
N	528	528	528	528	528
Mean	86.046	82.760	100.80	72.562	83.029
StDev	12.171	7.5584	6.8786	4.1631	5.3741
Minimum	17.7	46.391	49.583	59.553	63.387
Maximum	107.85	100.49	123.68	87.791	99.218

Figure 13. Box plot of solder volume for C0.18mm on EP stencils



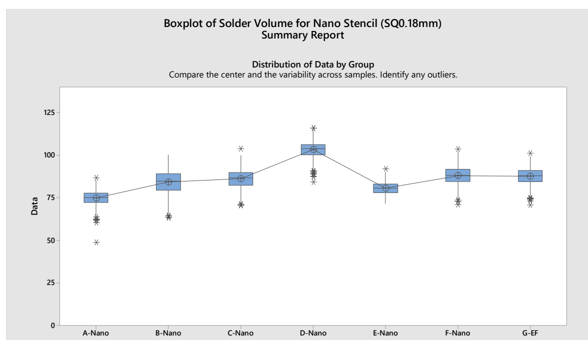
Statistics	A-Nano	B-Nano	C-Nano	D-Nano	E-Nano	F-Nano	G-EF
N	528	528	528	528	528	528	528
Mean	76.513	85.321	82.012	105.02	81.716	87.161	88.091
StDev	6.7105	11.601	8.4984	4.1945	4.0972	7.0127	6.0999
Minimum	43.55	28.039	45.9	89.782	69.839	58.896	57.571
Maximum	92.535	105.15	96.641	116.94	93.7	103.84	102.58

Figure 14. Box plot of solder volume for C0.18mm on nano-coated stencils



Statistics	B-EP	C-EP	D-EP	E-EP	F-EP
N	528	528	528	528	528
Mean	84.123	84.444	97.560	69.934	83.205
StDev	6.6670	5.6248	5.4494	3.9319	5.1426
Minimum	50.113	63.014	79.558	55.968	68.515
Maximum	99.511	107.50	114.94	82.79	101.67

Figure 15. Box plot of solder volume SQ0.18mm on EP stencil



Statistics	A-Nano	B-Nano	C-Nano	D-Nano	E-Nano	F-Nano	G-EF
N	528	528	528	528	528	528	528
Mean	74.791	84.146	86.039	103.16	80.540	87.867	87.529
StDev	4.2548	6.9331	5.2956	4.8043	3.4220	5.3463	4.9815
Minimum	48.727	63.23	70.368	84.085	71.415	70.761	70.721
Maximum	86.409	100.16	103.73	115.63	91.74	103.44	100.88

Figure 16. Box plot of solder volume SQ0.18mm on Nano-coated stencil

Impact of nano-coated stencil on printing transfer efficiency performance

Several published papers show different opinions on the impact of nano-coated stencils regarding the impact on printing transfer efficiency. Based on the results of this study, most nano-coated stencils provided less volume variation compare to EP stencils, as shown in the box plot and capabilities analysis. Varied results obtained in different published papers could be a result of various factors such as type nanomaterials used, and methods that nanomaterial was applied to the stencils. A new and ageing stencil with same nano-coating material may also give vary as the effect of nano-coating material deteriorate over time.

CONCLUSION

The following is the summary from this study:

- All EP and nano-coated stencils, except for stencil E, were able to perform good printing performance with Ppk >1.67 on SQ0.20mm and C0.22mm pad.
- With a C0.22mm pad, stencil D achieved high transfer efficiency on the EP and nano-coated stencil. One-way ANOVA analysis showed that there was a significant mean difference on EP stencils, except for stencils B and C while all nano-coated stencils had significant differences with each other except for stencil B with stencil G and stencil A with stencil C.
- With the SQ0.20mm pad, stencil D achieved high transfer efficiency on the EP stencil and stencil F on nano-coated stencil. One-way ANOVA analysis showed that all EP stencils were significantly different from one another. All nano-coated stencils are significant different with each other except for stencil C with F and stencil B with G.
- Impact of stencil quality on printing is greater as area ratio reduced to 0.59
- Nano-coated stencils provided lesser volume variation compare to EP stencil.

Based on this study, we can conclude that different stencils will provide different printing performances. There are a few possibilities that could contribute to the differences, such as the accuracy of laser cutting aperture dimensions, consistency of foil thickness, smoothness of the aperture side wall, nanomaterial, and the method by which the nano-coating material is applied. Verification of the factors is beyond the scope of this study, and will be part of the consideration for future work.

FUTURE WORK

We are following up this study with an assessment study on factors that contribute to the differences between stencils, and the impact that stencil foil materials such as fine grain, semi-fine grain, and standard stainless steel SUS304 have on printing performance.

REFERENCES

- Kenneth Thum, Jonas Sjoberg, Sze Pei Lim, “Printing Capability Study of 008004 (0201m) Components for SiP Applications,” SMTA SEA 2014
- Rita Mohanty Ph.d.,S.Manian Ramkumar Ph.d,CEMA, Chris Anglin, Toshitake Oda, “Effect of Nano-coat Stencil on 01005 Printing,” APEX 2011
- Whittier, R. and Shea, C., “Evaluation of Stencil Materials, Suppliers and Coatings,” Proceedings of SMTA International Conference, September 2011
- Farrell, R. and Shea, C., “Stencil and Solder Paste Inspection Evaluation for Miniaturized Components” Proceedings of SMTA International Conference, September 2014.