THE DEVELOPMENT OF A 0.3mm PITCH CSP ASSEMBLY PROCESS PART 2: ASSEMBLY & RELIABILITY

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ABSTRACT

With shrinking component technology the stencil printing process is becoming increasingly challenged. Not only do long established design rules need to be broken to accommodate finer pitches, but print quality and consistency of print are becoming even more critical to maintain a high yield assembly process.

A major study has been undertaken looking at several different aspects of the stencil printing process and their impact upon the assembly and reliability of 0.3mm pitch CSP components.

Previously, in Part 1, stencil printing factors such as aperture design (circles, rotated squares), aperture size (140 microns thru 200 microns) and printing technology (standard squeegees, active squeegees) were investigated. Highlights of the experiments are summarised here (whilst full details can be found in the 2015 conference proceedings of SMTA South East Asia [1] and SMTA ICSR [2]).

Key learnings from Part 1 have subsequently been used for a series of assembly trials to determine the impact, (if any) of the stencil printing process on ultimate solder joint reliability of 0.3 mm pitch CSP assemblies.

Assembly yields in terms of electrical continuity and identification of shorted solder bumps are reported here, together with preliminary reliability data from ongoing thermal cycling of assemblies.

Key words: Printing, stencil, squeegee, aperture, area ratio, 0.3mm pitch, chip scale package, heterogeneous, fine pitch, transfer efficiency, miniaturization, assembly yield, reliability

INTRODUCTION

Miniaturization has been of “ongoing” concern in the electronic assembly industry for a number of years now. Driven predominately by the mobile communications market, components and electronic assemblies have been continually shrinking. From a stencil printing process perspective, printing for smaller components alone is not a major issue. By simply reducing stencil thickness, feature sizes down to 100 microns in size can be printed (Figure 1 refers). However, problems arise when trying to accommodate both small and large components within the same assembly (heterogeneous assembly). As a result, assembly houses are now exploring the use of stepped stencils and dual print process techniques which naturally further challenge the production process, and are far from ideal.

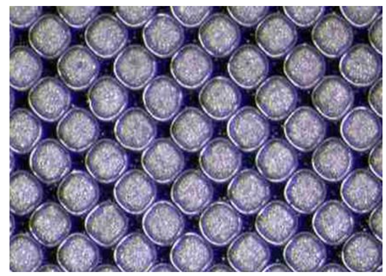

Figure 1. 110 micron solder paste deposits, 150 micron pitch, printed using a 50 micron thick stencil.

The underlying roadblock to achieving full heterogeneous assembly with existing, standard printing techniques (i.e. without stepped stencil technology) are todays stencil aperture area ratio capabilities. Stencil apertures with 0.5 area ratios are currently considered to represent the lower limit of the printing process.

Area Ratio & Transfer Efficiency

Stencil printing performance has historically been characterized by the well-known correlation between stencil aperture dimensions and the corresponding solder paste transfer that is predictable. The stability of this relationship has allowed the standardization of stencil design guidelines published by the IPC [3].

The definition of aperture Area Ratio (AR) is straight-forward – it is simply the ratio between the surface area of an aperture opening to the surface area of the aperture wall, represented by the following equation.

$$AR = \frac{\text{Aperture Open Area}}{\text{Aperture Wall Area}}$$

Whilst there are many facets which influence the stencil printing process, it is the stencil aperture area ratio which fundamentally dictates what can and what cannot be printed. If the surface area of the aperture wall exceeds that of the aperture opening then the solder paste will want to ‘stick’ to the aperture wall more than the pad, resulting in a contaminated aperture and an incomplete solder paste deposit. Conversely, if the aperture opening area is greater, then the solder paste will favor adhesion to the pad rather than the aperture wall leading to a more complete printed deposit. Figure 2 illustrates the concept of how area ratio influences solder paste transfer.

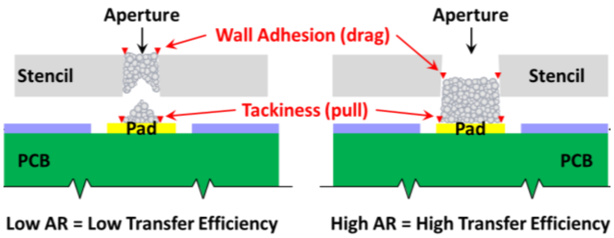

Figure 2. Area Ratio influence on solder paste transfer efficiency.

From this, it can be appreciated that as stencil aperture area ratio decreases then the chances of successful printing with full deposits becomes slimmer. A typical paste transfer efficiency curve representative of where the industry is today is shown in Figure 3 alongside a historical curve from some 20 years ago. The positive shift in transfer efficiency capabilities can be attributed to a number of factors including improvements in solder paste materials, stencil manufacturing techniques together with better understanding of equipment set up and process parameters [4,5,6,7,8].

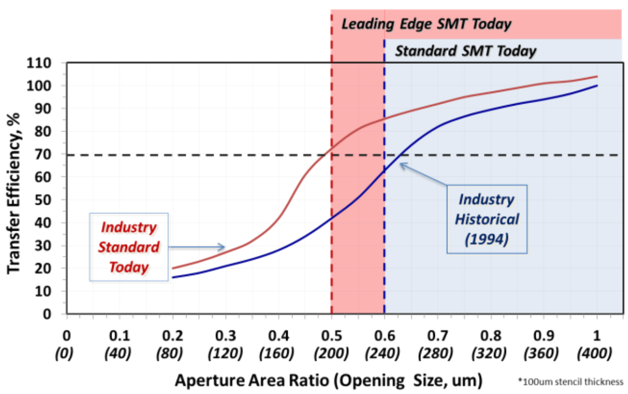

Figure 3. Today's leading edge solder paste transfer efficiency capabilities compared to 1994.

Future Requirements

The relentless appetite for new mobile communication devices virtually dictates that the manufacturing process becomes more challenging with each subsequent product launch. Next generation products are set to feature 0.3mm pitch Chip Scale Packages (CSP's) which will further challenge the stencil printing process. Such components will require printed features within the 160 micron to 200 micron range, which, if printed with current standard stencils of 100 micron thickness determines stencil apertures with area ratios of between 0.40 and 0.50.

Moving forward, it is clear that there is a very real requirement for print process capabilities down to aperture area ratios of 0.4 to address imminent roadmap challenges.

Whilst the industry continues to invest in various material improvements, the current authors have been investigating the benefits of "active" squeegees to fulfil this requirement. In this system, the squeegee assembly contains ultrasonic transducers within its body to assist the deposition process during a print stroke. Previous studies [9,10,11,12,13] indicate that the technique can enhance the print process with stencil aperture area ratios down to the 0.40 mark (Figure 4 refers). What has not been understood though is the impact (if any) of this improved print process upon ultimate assembly and reliability yields.

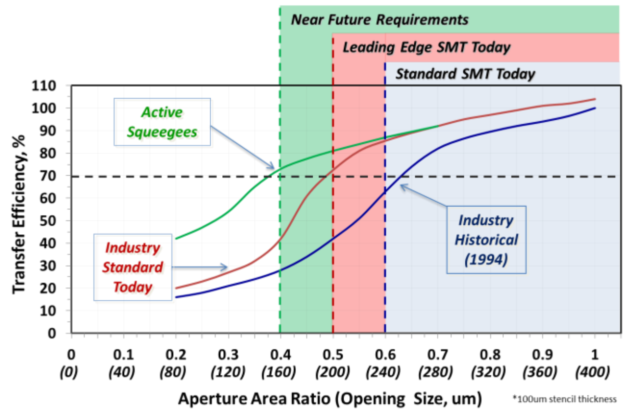

Figure 4. Near future solder paste transfer efficiency requirements.

EXPERIMENTAL

Objectives

To a) study the effect of print performance upon assembly yield and component reliability and b) to provide recommendations for a sub 0.5 area ratio print process suitable for the assembly of 0.3mm pitch CSP components using a 100 micron thick stencil suitable for heterogeneous assembly.

Test Vehicle & Components

The test vehicle used throughout this investigation consisted of fifteen, 0.3mm pitch CSP staggered arrays on a 1mm thick FR4 substrate measuring 132mm x 77mm (Figure 5). Each array contained 925 non solder mask defined pads. Fully functional 0.3mm pitch CSP components from an industry leading supplier were used for assembly.

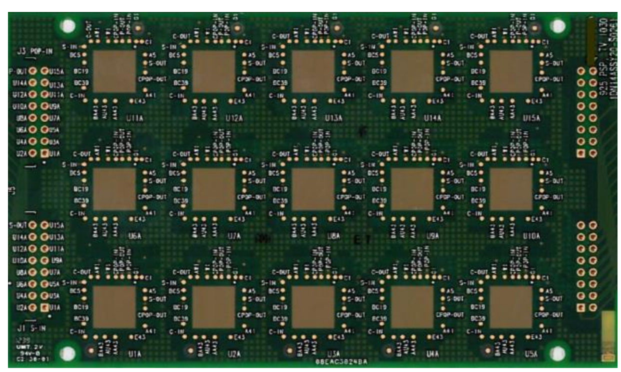

Figure 5. 15-up 0.3mm pitch CSP test vehicle.

Stencil Printing Investigation - Part 1, Highlights

Within part 1 of this study[1,2], print trials were conducted with a 100 micron thick laser cut metal stencil containing circular apertures with nominal dimensions of 160, 170, 180, 190 and 200 microns, (equating to area ratios of 0.40, 0.425, 0.45, 0.475 and 0.50). The objective was to determine the effect of stencil aperture size and squeegee type upon solder paste transfer efficiency ***and*** process capability.

The stencil contained three replicates of each aperture size and print tests consisting of 10 consecutive prints were conducted with and without squeegee activation to compare paste transfer efficiency capabilities.

The printed volume data collected with both the squeegee activation on and off is summarized in Figure 7. All statistical analysis was performed using a target of 80% paste transfer efficiency with lower/upper specification limits of 40% and 120% respectively.

The data showed that a robust print process could be achieved with 170, 180, 190 & 200 micron circular apertures when using activated squeegees. In contrast, it was only with the largest aperture size (200 microns) that a stable process could be obtained with a standard squeegee approach.

Assembly Testing – Logic Behind Test Strategy

From review of the preliminary stencil printing results it can be seen that with 170 thru 200 micron circular apertures (with both active and standard squeegees) a wide range of solder paste volumes and process capabilities can be achieved (Figure 7). As a consequence of this data it was considered to be of interest to run individual assembly trials under these eight conditions to monitor their impact upon assembly yield and reliability.

Assembly Test - Stencils

Four, 100 micron thick laser cut stainless steel stencils consisting of circular apertures with nominal dimensions of 170, 180, 190 and 200 microns, (equating to area ratios of 0.425, 0.45, 0.475 and 0.50) were manufactured and utilized specifically for the assembly trials. The design provided for 15 component replicates with each aperture size per printed substrate/assembly.

Assembly Test - Equipment & Materials

An ASM DEK Horizon 01iX automatic stencil printer fitted with an "active" squeegee assembly was used for all printing. Printed deposits were measured for volume, height, and area using a Koh Young Aspire 2 solder paste inspection (SPI) tool fitted with quad projection and 10 micron pixel resolution camera.

During the print cycle the test substrates were secured in place with a dedicated vacuum tooling plate. The same squeegee assembly together with 170mm long metal blades was used for all testing in both the standard and activated print mode. Prior to each test run the squeegees were automatically calibrated. An industry standard lead-free Type 4, no clean solder paste was used for all printing.

For assembly, components were placed using a GSM XS followed by reflow under nitrogen in a BTU Pyramax 100N 8 Zone oven. The reflow profile recommended by the solder paste vendor was closely adhered too (Figure 6).

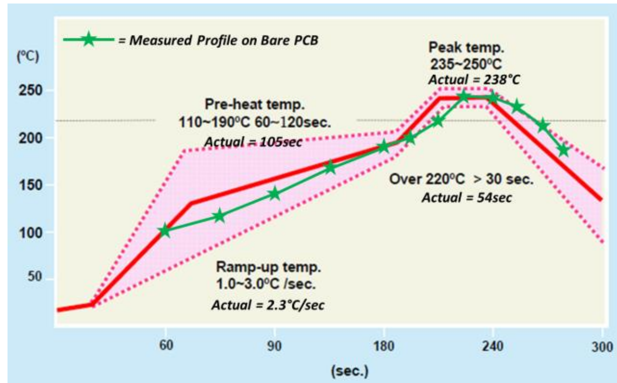

Figure 6. Reflow profile used for the assembly of all components.

Assembly Test - Procedure

For experimental integrity all tests were performed with the identical machine, operator, process parameters (Table 1), and material set (excluding stencil). For each test condition, eight consecutive prints without interruption were made. All printed substrates were inspected for solder paste deposit volume with the 7th & 8th prints being used for assembly immediately after inspection. For each stencil aperture size, two runs were conducted; with and without the squeegee system activated. This procedure produced 30 assembled components on two substrates for each test condition.

Following assembly, each component was individually tested for electrical continuity and inspected using a DAGE XD7600 X-Ray system to check for shorted solder joint defects.

Finally, all components were wired up for event detection and committed to thermal cycling within a Thermotron Model F-82-CLV-25-25 environmental chamber. All components were subjected to a -40/125°C regime with a 15 minute dwell and a total 74 minute duty cycle. The thermal cycling profile is shown in Figure 9. To date, components have been subjected to just over 1000 thermal cycles.

Table 1. Materials & Process Parameters

Solder paste comp/size	SAC305/Type 4
Tooling	Dedicated Vacuum Block
Squeegee blade length	170mm
Squeegee blade overhang	15mm
Squeegee angle	60 degree
Print Speed	50mm/s
Squeegee Force	5 kg
Separation Speed	20mm/s

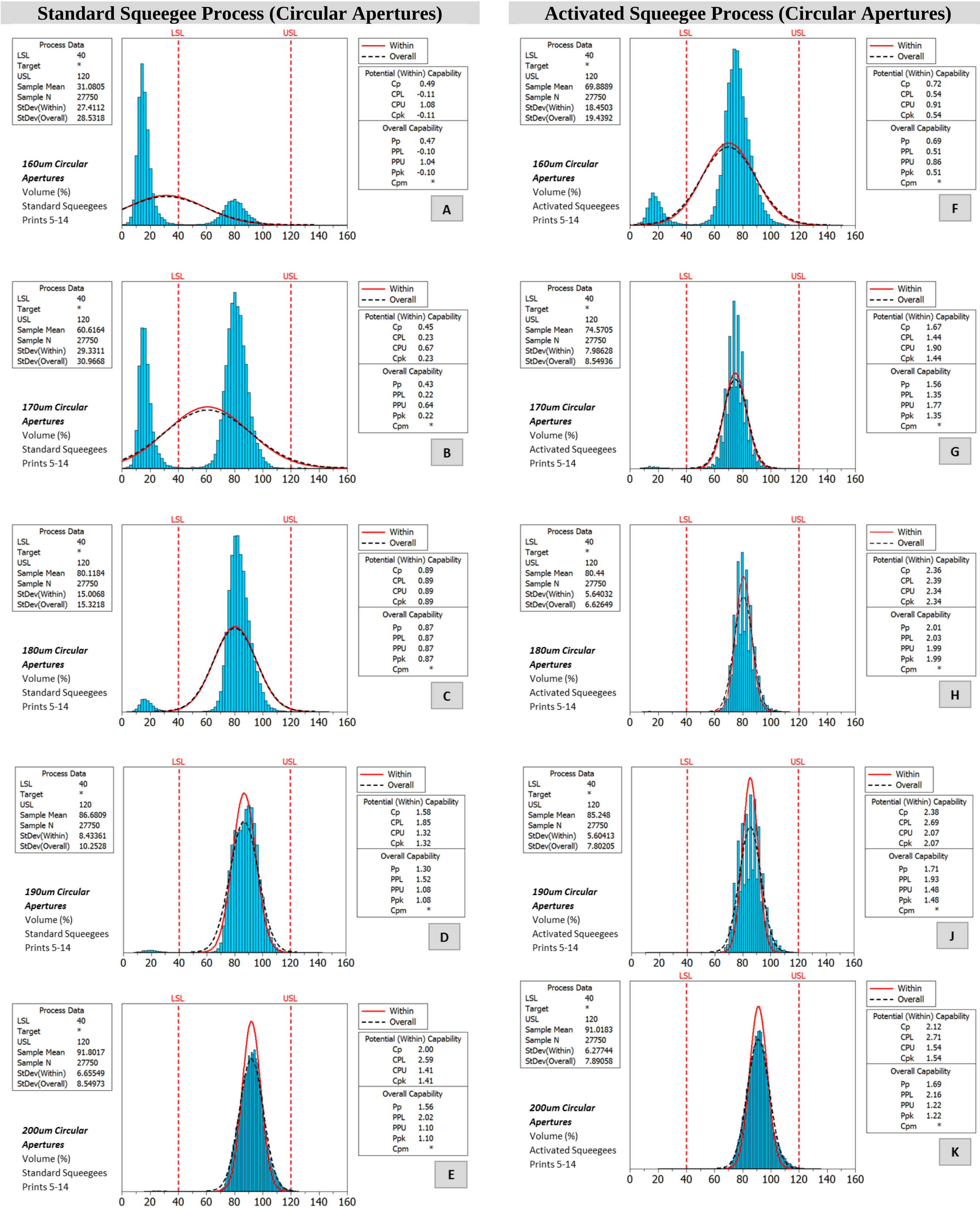

Figure 7. Standard squeegee process (A-E) compared to activated squeegee process (F-K), circular aperture sizes between 160-200 microns (data from Part 1).

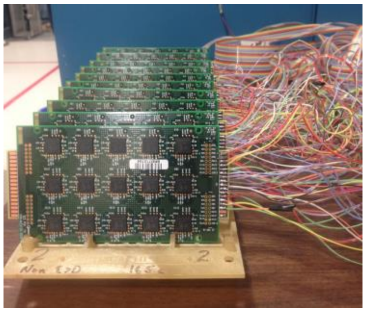

Figure 8. Assemblies wired for event detection prior to placement in thermal cycling chamber.

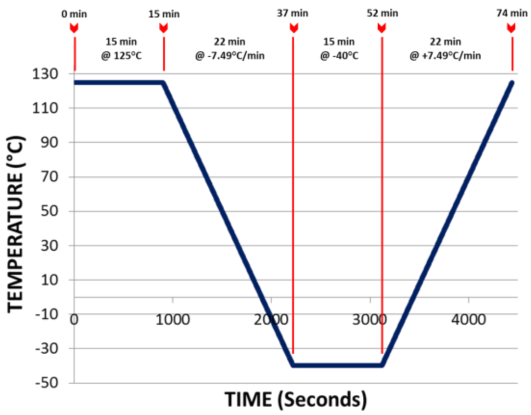

Figure 9. The accelerated thermal cycle profile used for the reliability testing of assemblies.

ASSEMBLY TEST - RESULTS & DISCUSSION

Assembly Test - Stencil Printing Process

The printed volume data collected from the four stencils with 170, 180, 190 and 200 micron circular apertures is shown in Figure 10, both for standard and activated squeegee process runs. Each chart contains all data points collected from prints 7 & 8 in each test run (30 components, 27,750 pads). These represent the boards which were ultimately assembled & reflowed with components.

All statistical analysis was performed using a target of 80% paste transfer efficiency with lower/upper specification limits of 40% and 120% respectively.

Compared to the preliminary stencil printing results from Part 1 (Figure 7), the distribution of the data sets produced with the printed substrates used for assembly (Figure 10) are not as tightly banded. There are several possible explanations for this. Firstly, the data sets for the preliminary tests are based on measurements from 3 components over 10 consecutive prints, whilst the data for the assembly trials is based on that from 15 components taken from the 7th and 8th prints in an eight board print run. Secondly, new stencils were manufactured for the assembly trials and probably provide the main reason for differences. When measured, the assembly test stencil apertures were within the specification of the stencil vendor but tended to be 2-4 microns undersize compared to the 2-4 microns oversized apertures with the stencil used in the preliminary testing. With sub 0.5 area ratio printing a sum total difference of up to 8 microns becomes significant! Nonetheless the trends within the data remained the same, with process capabilities improving with increasing aperture size, and active squeegees showing increased print performance over standard squeegees.

Assembly Yield & Reliability

Following assembly, all components were tested for electrical continuity. A number of failures, resulting in open joints (Figure 11) were recorded with components assembled using a standard squeegee process. Failures were randomly distributed within components. Of the 24 affected components, four suffered with open corner joints with the remainder of failures being within the main body of the arrays. In contrast, all of those assembled with an active squeegee approach exhibited 100% electrical continuity. Figure 12 charts the failures by stencil aperture size and assembly process.

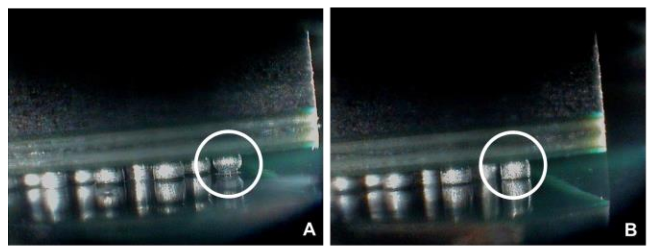

Figure 11. Failed, open corner joint (A) and "good" electrically complete corner joint (B).

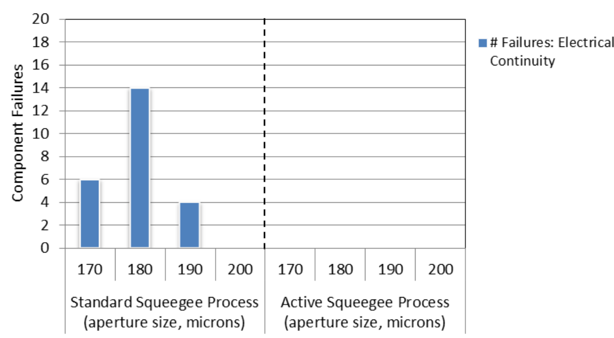

Figure 12. Number of components exhibiting failed electrical continuity (maximum possible is 30).

The trend seen should not be a surprise based on the stencil printing results in Figure 10. When using standard squeegees, process capability dropped steadily with decreasing aperture size and it is the resultant increase in number of "lighter" deposits which ultimately impacted electrical integrity.

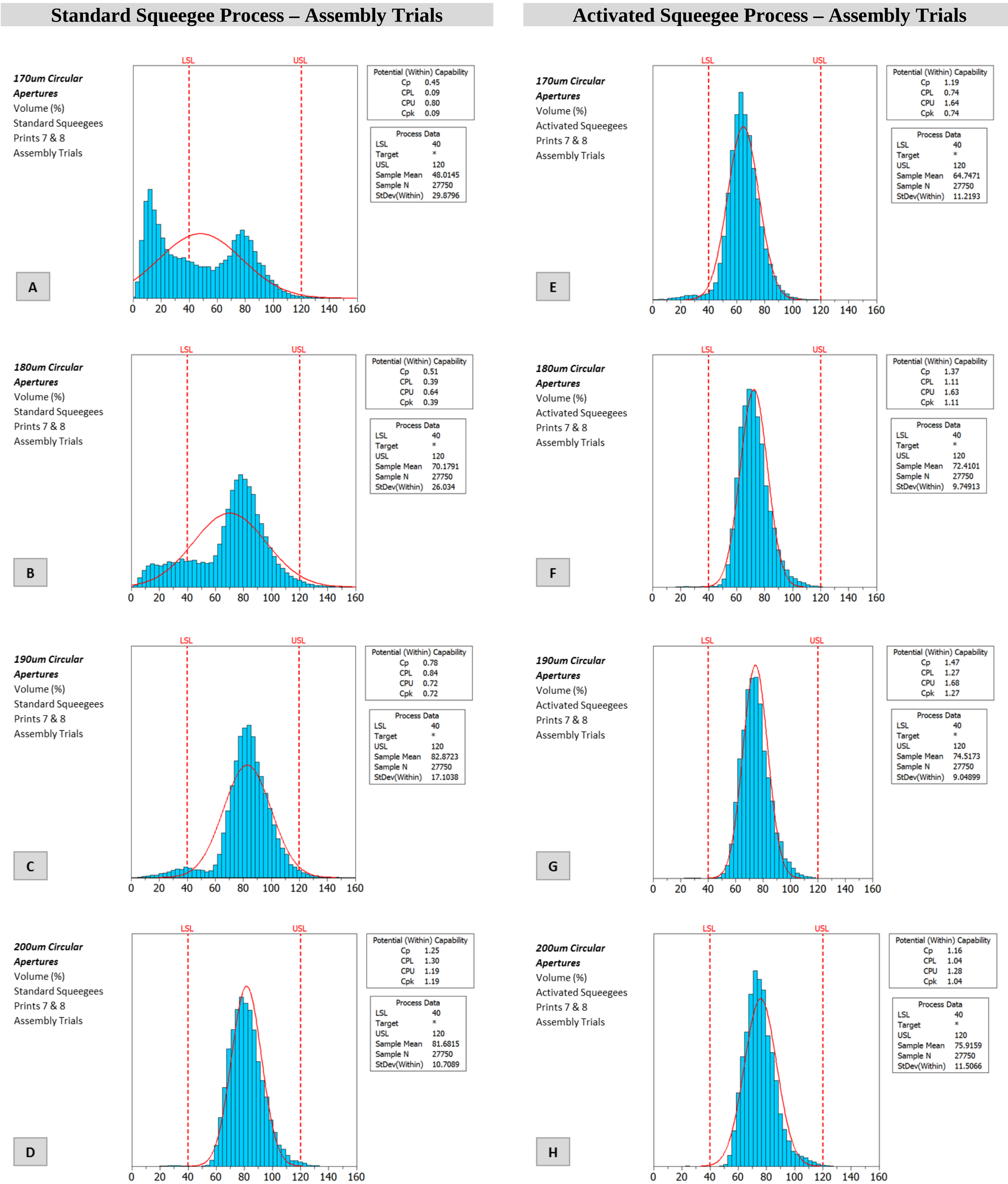

Figure 10. Standard squeegee process (A-D) compared to activated squeegee process (E-H), circular aperture sizes between 170-200 microns (data from boards used for assembly).

Figure 13A visually captures the typical variability of printed deposits across a single component when using a standard squeegee process with 170 micron circular stencil apertures. Based on this level of variability, the only surprise is that 24 of the 30 components assembled exhibited electrical integrity! Nonetheless the overall trend is clear; as print process capability drops, assembly yield is at risk. For components assembled using active squeegees, where a Cp >1 was maintained, assembly yield remained at 100%, even when using aperture sizes down to 170 microns (Figure 13B).

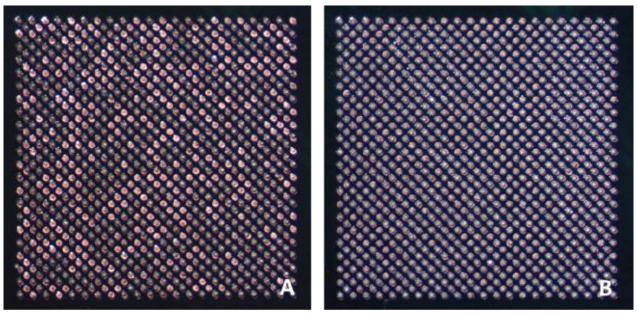

Figure 13. 0.3mm pitch CSP printed using 170 micron circular apertures with a standard squeegee print process (A) and an activated squeegee print process (B).

X-ray analysis of all components revealed another assembly failure mode – that of shorted solder bumps (Figure 14). Again, this type of defect was only associated with components assembled using a standard squeegee process. With the 30 components assembled using 190 micron apertures and standard squeegees, 44 shorted joints were observed within 14 components. With the 200 micron stencil aperture assemblies, 24 bridges were recorded, affecting 9 components. The sum total of all assembly defects are shown in Figure 15.

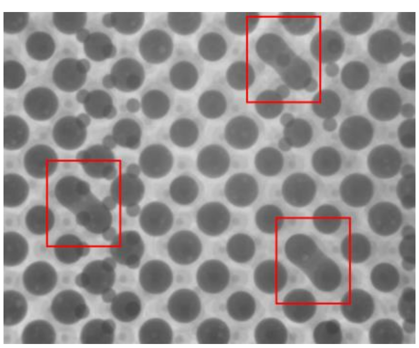

Figure 14. X-ray analysis: showing 3 shorted joints within a component.

This level of solder shorting is somewhat surprising bearing in mind that those assembled with an active squeegee approach maintained 100% yield. The histogram charts of printed volume for the 200 micron apertures (Figure 10D & H) are very similar in profile so the expectation was for the assembly yield to be the same.

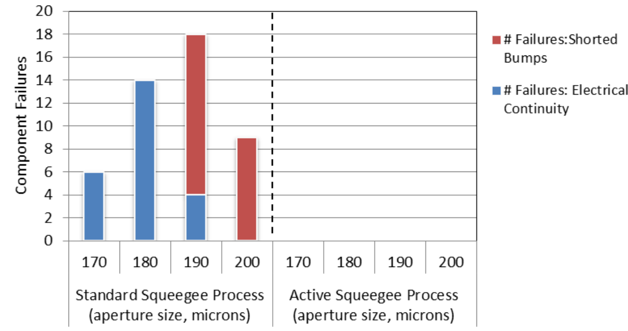

Figure 15. Assembly yield failures due to lack of electrical continuity and shorted solder bumps (maximum possible is 30).

Delving deeper into the SPI data for the 190 micron aperture assembled components helps provide a hypothesis. Comparing the volume histograms for both standard and active squeegee printing processes (Figure 16A & B) – the standard squeegee process has a left sided shoulder indicating the presence of some low volume printed deposits.

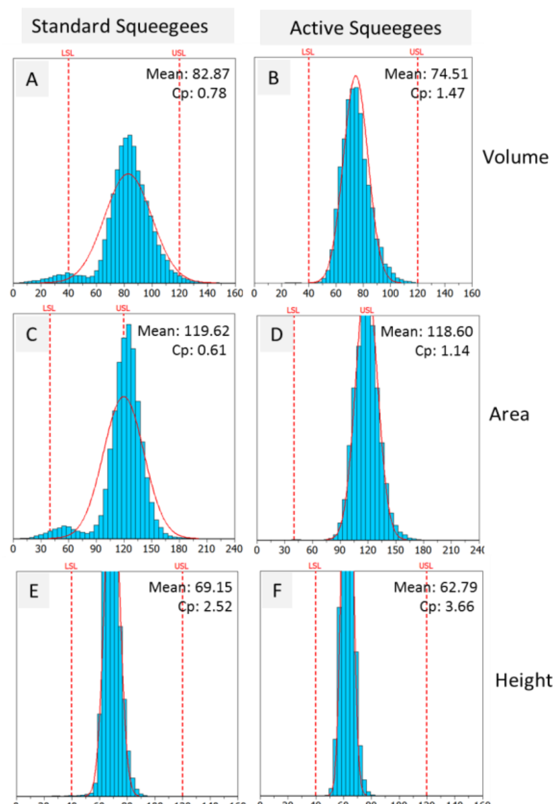

Figure 16. Volume, area and height SPI data for 190 micron circular apertures using standard and active squeegees.

All volume numbers are driven by height and area data and when histograms for these factors were examined a similar left sided shoulder with a standard squeegee process was seen for area measurements (Figure 16C), indicating print deposits with low areas. However, with regards to height data, normal distributions were observed for both squeegee processes (Figure 16E & F), but the mean height achieved with standard squeegees was some 11% greater than with active squeegees. The tallest deposit with standard squeegees was measured at 96 microns compared with 80 microns for active squeegees. The hypothesis is that a small number of tall, thin “tower” like deposits were printed that collapsed during placement causing the solder shorts observed after reflow.

With the 200 micron aperture assemblies, aperture area ratio release dynamics are different and the effect was not as prevalent, as indicated by fewer shorted bump occurrences. In fact 20 of the 24 shorted bumps recorded were from the last (8th) print so there is an argument that other print process factors such as a contaminated stencil could have caused the shorting. The small, 100 micron interspace between apertures could also be compounding this effect. From a manufacturing perspective this is potentially an indication that the print process is not quite as robust as first thought, and that more frequent under-stencil cleaning might be a requirement.

Following assembly yield analysis, all components were placed into a thermal chamber and subjected to a -40/125°C thermal cycle regime. At the point of writing, the assemblies had experienced just over 1000 thermal excursions with the plan to continue until a total of 1500 cycles have been completed.

The fall out rate from thermal cycling has been minimal to date (Figure 17 refers). Seven components assembled using 170 & 180 micron stencil apertures and a standard squeegee process failed within 250 thermal cycles and one further failure has been recorded after 692 cycles. No failures have been recorded with components assembled using an active squeegee process.

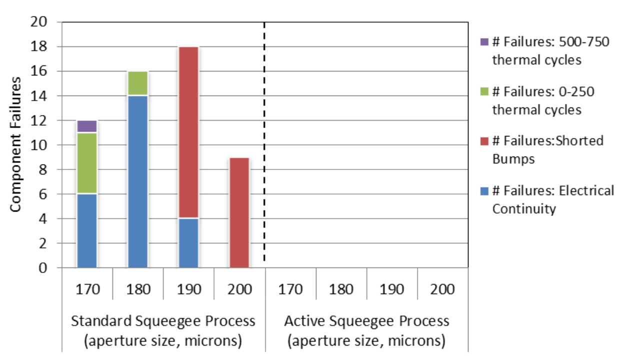

Figure 17. Total component failures by assembly defect and thermal cycling failure (maximum possible is 30).

SUMMARY

When pooling the thermal reliability data together with the assembly yield data (Figure 17), it becomes quite clear that there are benefits to using active squeegees. No failures were experienced with any component assembled using an active squeegee print process, even with apertures down to 170 microns in diameter. In contrast 47 components of 120 assembled with a standard squeegee process were lost to assembly defects and a further 5 thru thermal cycling failure.

This has some significant implications for future, sub 0.5 area ratio assembly challenges. Being able to print using 170 micron circular apertures on a 100 micron thickness stencil (aperture area ratio 0.425) will permit 0.3mm pitch CSP components to be assembled alongside today’s standard components (which currently utilize 100 micron thick stencils) in a true heterogeneous assembly process.
It would also appear that the actual print deposit produced from an active squeegee has a positive effect on assembly yield criteria, although the mechanism behind this cannot yet be explained.

For those wanting to use a “standard” squeegee print process, a 100 micron thick foil with 200 micron circular apertures could provide an option, but the minimal 100 micron interspacing between apertures is delicate and would necessitate a high under stencil cleaning frequency in production.

A stepped stencil could be a further alternative. By reducing the stencil thickness locally for 0.3mm pitch CSP components to 80 microns, circular apertures of 160 microns can be utilized, providing a favorable printing area ratio of 0.5. This however, adds cost and complexity to the process which is always of major consideration in a production environment.

Overall the best solution for heterogeneous assembly and sub 0.5 area ratio printing would appear to be thru the use of activated squeegees. Not only do they open up the print process window for sub 0.5 area ratio apertures, but potentially they impact the quality of the printed deposit in such a way that assembly yield and productivity criteria are enhanced aswell.

These bold statements however need to be tempered; all of the testing was conducted under ideal laboratory conditions, far removed from a production environment, and the experiment was relatively small in terms of sample size. However, the trends were strong and it is clear that the use of activated squeegees warrants further, more detailed investigation.

FURTHER WORK

Thermal cycling of assembled components will continue until 1500 cycles have been experienced.

Further in-depth data mining will be conducted in an attempt to understand in more detail the root cause of the solder bump bridged joints.

Opportunities will be sought to run larger, production scale assembly trials to confirm the potential benefits of active squeegees seen within the experiment reported here.

REFERENCES

[1] M. Whitmore, J. Schake, "The Development of a 0.3mm Pitch CSP Assembly Process, Part 1: Stencil Printing Considerations" Proceedings of SMTA SE Asia, Penang, Malaysia, April 2015.
[2] M. Whitmore, J. Schake, "The Development of a 0.3mm Pitch CSP Assembly Process, Part 1: Stencil Printing Considerations" Proceedings of SMTA ICSR, Toronto, ON, May 2015.
[3] Stencil Design Guidelines, IPC-7525B, October 2011.
[4] C. Ashmore, M. Whitmore, S. Clasper, "Optimising the Print Process for Mixed Technology," Proceedings of SMTA International, San Diego, CA, October 2009.
[5] R. Dervaes, J. Poulos, S. Williams, "Conquering SMT Stencil Printing Challenges with Today's Miniature Components", Proceedings of IPC APEX Expo, Las Vegas, NV, April 2009.
[6] W.Coleman, M. Burgess, "Stencil Performance Comparison / AMTX Electroform vs Laser-Cut Electroform Nickel Foil, Proceedings of SMTA International, Chicago, IL, October, 2006.
[7] R. Mohanty, "What's in a Squeegee Blade?" Circuits Assembly, May 2009.
[8] M, Rösch, J. Franke, C. Läntzsch, "Characteristics and Potentials of Nano-Coated Stencils for Stencil Printing Optimization, Proceedings of SMTA International, Orlando, FL, October 2010.
[9] M. Whitmore, C. Ashmore, "New Developments in Broadband Printing Techniques," Proceedings of SMTA International, Orlando, FL, October 2010.
[10] M. Whitmore, C. Ashmore, "The Development of New SMT Printing Techniques for Mixed Technology (Heterogeneous) Assembly," 34th International Electronic Manufacturing Conference, Melaka, Malaysia, November 2010.
[11] M. Whitmore, C. Ashmore, "The Next Big Challenge For Stencil Printing – Sub 0.5 Area Ratio Apertures," Proceedings of SMTA International, Chicago, IL, October 2015.
[12] M. Whitmore, J. Schake, "Factors Affecting Stencil Aperture Design for the Next Generation Ultra-Fine Pitch Printing", Proceedings of SMTA ICSR, Toronto, ON May 2013.
[13] J. Schake, M. Whitmore, C. Ashmore, "Stencil Aperture Design Guidelines for 0.3CSP Ultra Fine Pitch Printing," Proceedings of SMTA International, Fort Worth, TX, October 2013.