Stencil Printing Process Guidelines for 0.3mm Pitch Chip Scale Packages

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Abstract

With the form factor of electronic assemblies continuing to shrink, designers are being forced towards smaller, more complex components with decreasing interconnection pitches. As a consequence, the Surface Mount assembly process is becoming increasingly challenged.

For the stencil printing process, todays accepted stencil area ratio rules, (which dictate what can or cannot be printed), need to be significantly pushed to extend the printing process for next generation ultra -fine pitch components.

With aperture geometries shrinking, anything which can influence solder paste transfer efficiency has to be considered. New process technologies such as ultrasonic squeegees have emerged in recent years to assist the process with some degree of success. However, something which is often overlooked in terms of stencil design influence is that a square shaped aperture, size for size, has a volume which is 21.5% than its circular counterpart. In a process where quite literally every solder particle that can be printed is becoming significant then this fact can be utilized to the process engineer's advantage.

In this paper, the merits of stencil aperture shape, in conjunction with ultrasonic squeegees are investigated with the purpose of developing stencil printing guidelines for ultra-fine pitch components such as 0.3mm pitch CSP's.

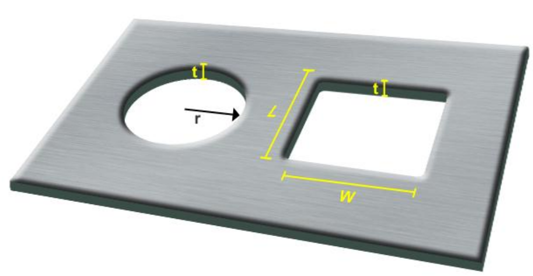
Key words

Stencil printing, 0.3mm pitch CSP's, paste transfer efficiency, area ratio, aperture design.

I. Introduction

It is fair to say that today we are operating close to the limits of the stencil printing process. Whilst there are many facets to the print process it is the stencil aperture area ratio that fundamentally dictates what can be achieved in a print process. For next generation components and assembly processes the current rules need to be broken!

The area ratio rule (Fig.1) is a simple ratio between the surface area of an aperture wall and the surface area of the aperture opening (which effectively is the landing area of the pad onto which the solder paste is to 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 'sticking' to the pad rather than the



$$\text{Area Ratio (Rect)} = \frac{\text{Aperture Open Area (L x W)}}{\text{Aperture Wall Surface Area } 2t(L+W)}$$

$$\text{Area Ratio (Circle)} = \frac{\text{Aperture Open Area } (\pi r^2)}{\text{Aperture Wall Surface Area } (2\,\pi r)t}$$

Figure 1. Stencil Aperture Area Ratio

aperture wall leading to a more complete printed deposit. From this, it can be appreciated that as the stencil aperture area ratio decreases then the chances of successful printing with full deposits become slimmer.

Historically, engineers have worked with area ratios in excess of 0.6 to maintain a successful process. However, in recent years, aided by improvements in material sets and understanding [1]–[7] process engineers have pushed the process to ratios of 0.5 to accommodate today's leading edge components. With the imminent arrival of 0.3 CSP's, area ratio capabilities need to be pushed towards the 0.4 mark to meet near future demands (Fig. 2).

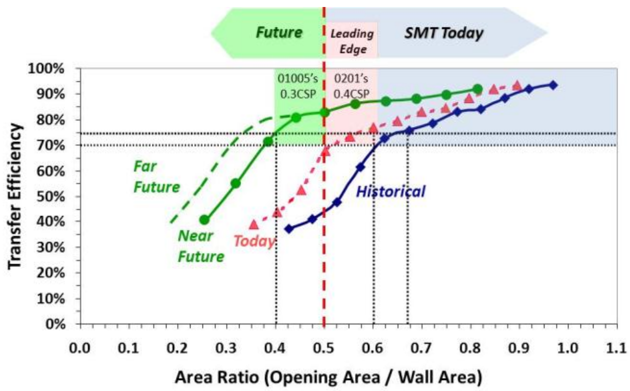


Figure 2. Area Ratio vs. Solder Paste Transfer Efficiency Requirements; Past, Present and Future.

In this research work the effect of ultrasonic squeegees and the interaction of square versus circular apertures have been studied in an attempt to push area ratio boundaries and gain a better understanding of process capabilities for ultra-fine pitch printing.

II. Experimental

A. Outline

30 board print runs were conducted using a test pattern consisting of both circular and square apertures. Individual experiments were ran with and without ultrasonic squeegees with a type 4 solder paste.

B. Equipment & Materials

A DEK Horizon automatic stencil printer fitted with a "ProActiv" squeegee assembly (ultrasonic squeegee system) was used to print a test pattern through an industry standard 100 micron thick laser cut stainless steel stencil. Printed deposits were measured for volume using a CyberOptics SE500 fitted with a micropad sensor. The test substrates used throughout the investigation were a set of numbered 1.6mm thick, FR4 boards. 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 (with 15mm overhang) were used for all testing in both the standard and ultrasonic print mode. For a standard print process the ultrasonic capability was simply disabled. Prior to each test run the squeegees were automatically calibrated. An industry standard lead-free type 4 solder paste from a single solder paste vendor was used for printing.

C. Test Substrate & Stencil Design

An example of the test substrate used is shown in Fig. 3. The simple design contains a range of industry standard components. However, for the purpose of this experiment, focus was placed on the four area arrays highlighted in Fig.3. These arrays consist of 0.5mm diameter pads on a 1mm pitch. With the corresponding stencil design, a combination of square and circular apertures were incorporated with reducing aperture sizes, ranging between 100 microns and 550 microns (relating to area ratios of between 0.25 and 1.375). The outline of one of these arrays is shown in Fig. 4. Each stencil aperture was measured using a semi automatic co-ordinate measuring machine (CMM) to enable "true" transfer efficiency curves to be generated (as opposed to using stencil gerber dimensions).

D. Experimental Run Procedure

For each experimental condition, 30 consecutive prints were made. After the 10^{th} and 20^{th} print, the stencil was manually cleaned. Print runs were conducted with and without the ultrasonic squeegee system activated.

The main process parameters are listed in Table I. Immediately following each print run the individual boards were measured using a CyberOptics SE 500 inspection tool. The 30 board print runs provided 1080 replicates for each individual aperture shape and design.

Table I. Print Parameter Summary.

Print Speed	50mm/sec
Print Pressure	4kg
Separation Speed	3mm/sec
Separation Distance	3mm
Temperature	21-22^{O}C
Relative Humidity	50-55%

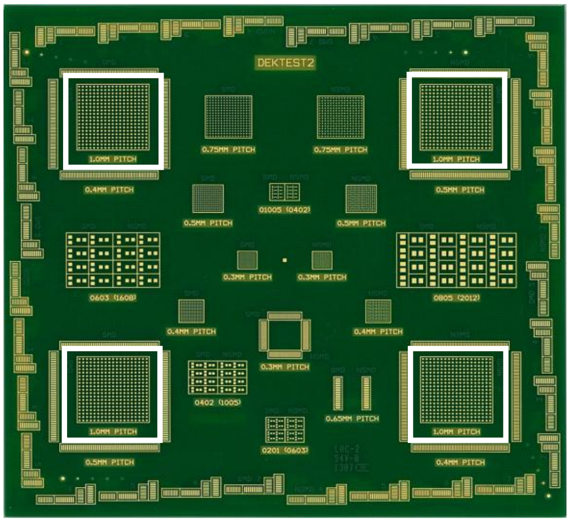


Figure 3. Test substrate with the four arrays used for the reducing array apertures highlighted.

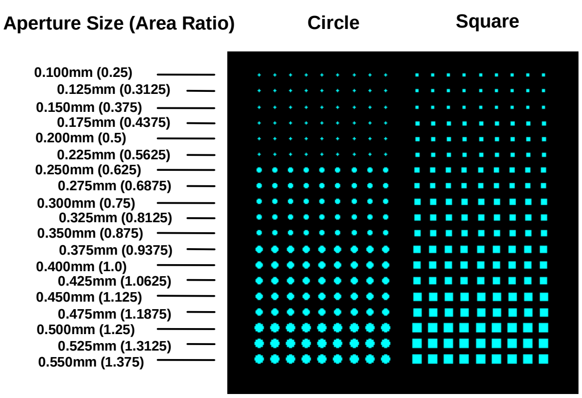


Figure 4. Reducing area array pattern used for generating solder paste transfer efficiency curves. *Note: figures based on a stencil thickness of 100 microns.*

III. Results & Discussion

Fig. 5 plots the average transfer efficiency for both circular and square apertures with and without the ultrasonic squeegee blades activated. Each data point represents the average of 1080 measurements made over the 30 board print run. The benefits of using ultrasonic squeegees have been reported by these authors before and in this study similar trends were observed [8]–[10].

For aperture area ratios below 0.5, the use of ultrasonics affords an increase in solder paste transfer efficiency over a standard squeegee process. Effectively, the knee of the transfer efficiency curve is kicked out resulting in the opportunity to work with aperture area ratios down to 0.4, whilst still maintaining paste transfer efficiency around 70%. The charts in Fig. 6 are scaled to highlight this.

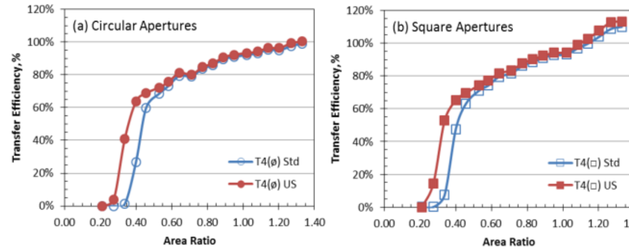


Figure 5. Paste transfer efficiency for various circular (a) and square (b) aperture area ratios; with/without Ultrasonic (US) squeegee activation.

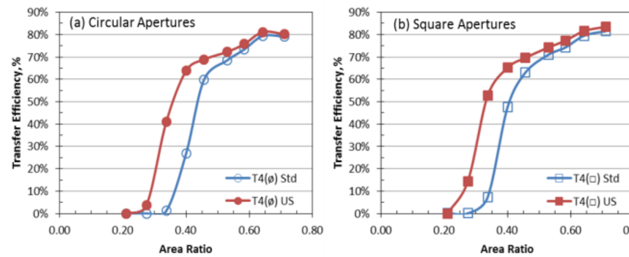


Figure 6. Paste transfer efficiency for circular (a) and square (b) aperture with area ratios below 0.8; with/without Ultrasonic (US) squeegee activation.

Whilst transfer efficiency data is a good reference point for the effectiveness of a process, a solder joint ultimately requires a "certain" amount of solder for a good connection; therefore actual volume is a more critical and useful measurement.

Fig. 7 plots the average volume of solder paste printed for both circular and square apertures, with and without the squeegees ultrasonically activated. Again, each data point represents the average of 1080 measurements made over a 30 board print run.

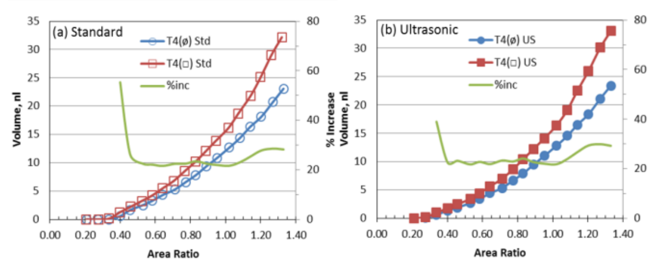


Figure 7. Solder paste volume deposited for various circular (ø) aperture area ratios versus square (□) aperture area ratios; with and without ultrasonically squeegee activation. The % increase in volume deposited with square apertures is also charted. *(Note: 1 nanoliter = 1,000,000 cubic microns).*

A square aperture of a given size has a volume that is 21.5% greater than its circular counterpart. Generally, for apertures with area ratios between 0.44 and 1.00, this trend was observed in all prints both with the ultrasonic squeegees on and off. With apertures having area ratios above ~1.00, then the volume increase in paste deposited with a square rose to 29%. This implies that the filling and release dynamics are different with apertures over a certain area ratio, although the exact mechanism was not investigated further.

To put further context to this data, it is re-plotted individually for circular and square apertures and compared against actual aperture volumes and a theoretical 70% paste transfer efficiency boundary in Fig. 8.

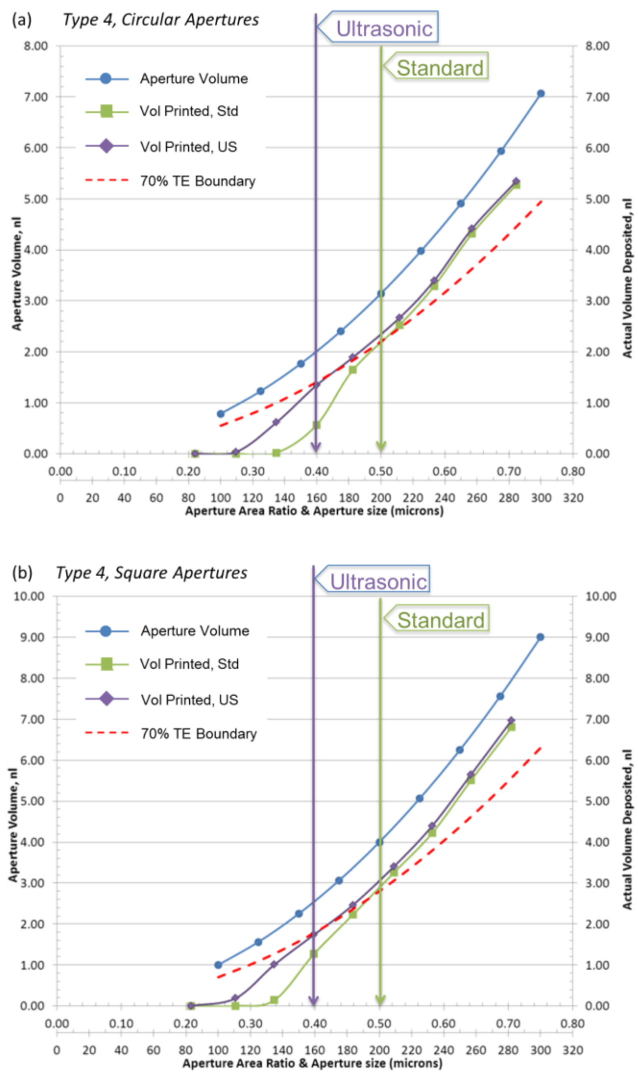


Figure 8. Paste volumes deposited with circular (a) and square (b) apertures with and without squeegee ultrasonics in relation to actual aperture volumes and 70% paste transfer efficiency.

Typically, a process engineer will design stencil apertures to achieve at least 70% paste transfer efficiency. For this reason, process engineers prefer to work with stencil apertures having an area ratio greater than 0.60 (to guarantee paste transfer efficiency greater than 70%). With today's common leading edge components (0.4CSP's, 01005's), process engineers are having to work with stencil feature sizes of 220-260 microns. As can be seen from the above, when using a 100 micron thick stencil this means having to print with aperture area ratios in the 0.54-0.60 range. For a standard squeegee process this skirts the 70% paste transfer efficiency boundary, so extreme control of all material & process properties is required to achieve a successful process. Below aperture area ratios of 0.5 then the transfer efficiency of a standard squeegee process (with both circular and square aperture designs) fall rapidly away from the 70% boundary.

In contrast, the data indicates that by using ultrasonic squeegees, 70% transfer efficiency can be maintained with apertures having area ratios all the way down to 0.4. This is a huge leap in process capability and will allow the process engineer to work with features down to 160 microns (in a 100 micron thick foil). This will accommodate next generation ultra fine pitch components such as 0.3CSP's.

Volume/transfer efficiency data however should never be viewed in isolation. Such data is compiled based on averages of many data points, but it does not give a true insight into full process capability. The information should always be viewed in conjunction with either full data plots, or as is more typical, alongside cp/standard deviation data.

Building on the volume data charts already discussed, the standard deviation data has been added for each process condition in Fig. 9. In these charts, standard deviation is quoted as a % of the actual volume printed. It is generally accepted that if the % standard deviation is maintained below 10% then a process is in control.

With circular apertures and a standard squeegee process, it was possible to maintain a standard deviation below 10% with aperture area ratios down to 0.5. With ultrasonic squeegees, the 10% standard deviation limit was extended to encompass aperture area ratios down to 0.4 (Fig. 9a). Interestingly, both these inflection points corresponded with the 70% paste transfer efficiency limits for each process, providing clearly defined process capability limits for circular apertures.

With square apertures, the 10% standard deviation cut off point was extended still further to area ratios of 0.46 for a standard squeegee process and 0.38 with the ultrasonic squeegee (Fig. 9b). Whilst on the 70% paste transfer efficiency criteria, area ratio limits of 0.5 (standard squeegees) and 0.4 (ultrasonic squeegees) prevailed with square apertures (similarly to circular apertures), the standard deviation data suggests that engineers can maintain a process with lower area ratio apertures than previously accomplished provided it is accepted that paste transfer efficiency will be reduced. This opens the scope up further for engineers to design stencil apertures to provide a specific volume of printed paste.

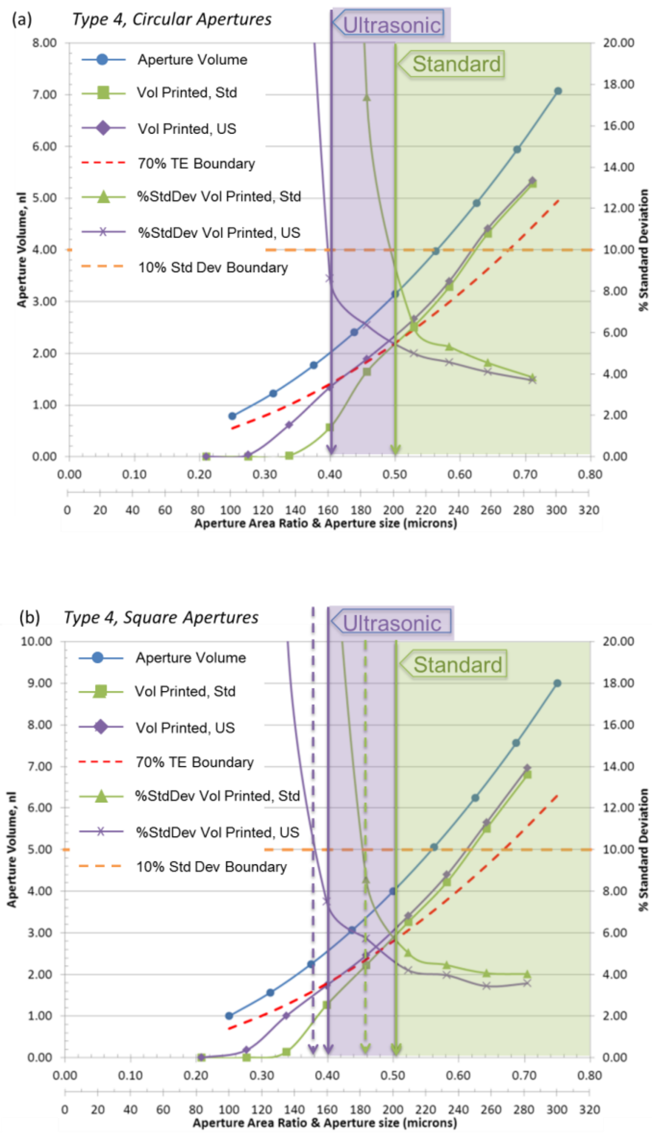


Figure 9. Paste volumes deposited and Standard deviation data with circular (a) and square (b) apertures with and without squeegee ultrasonics.

IV. Conclusion

It is clear that miniaturisation is set to challenge the surface mount assembly process. Next generation ultra fine pitch components such as 0.3CSP's will place extreme demands on the stencil printing process and as such, the requirement for printing solder paste through stencil apertures with area ratios below 0.5 will become common place.

To optimise a print process it is becoming increasingly important that an engineer has a good understanding of stencil aperture design specification, material properties and process options/aids available to him. The interactions between all of these facets is becoming more complex and critical to the successful implementation of a process.

The data presented here indicates that with judicial choice of stencil design and materials it will be possible for designers to work with aperture area ratios down to 0.4 and deliver a range of solder paste volumes for 0.3CSP's and heterogeneous assembly. In this study, the use of ultrasonic squeegees was seen to have the biggest impact on achieving this goal.

It must be borne in mind however, that there are a number of other interacting factors which affect the development of a successful process. This study provides a good starting guide but it was conducted with a simplistic test vehicle. Full component array designs, pad definition (solder mask defined or non solder mask defined) and the density & mix of components on a board will all impact print process capabilities. As we strive for future-proofing print process solutions, all of these facets are now being studied within current research activities.

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