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Design Guidelines for Ultra Fine Pitch Solder Paste Printing

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ABSTRACT

Competitive pressures to reduce equipment size and to maximise circuit performance have resulted in new challenges for ultra fine pitch solder paste printing. The ratio between the open area of the stencil aperture and the area of the aperture wall (AAR) significantly affect the quality of solder paste printing. The AARs for today's ultra fine pitch components printing are below 0.5, and much lower than that for coarser pitch components such as SOIC (above 1.5). To over come this ratio reduction and to improve printing performance through ultra fine pitch apertures, all aspects of the print process required a great deal of attention to achieve optimisation. The design guidelines for ultra fine pitch solder paste printing are considered, and the effect of stencil type, stencil wall aperture finish, aperture design and paste choice on printing investigated.

1. Introduction

Since it's widespread introduction in the Seventies and Eighties, surface mount technology has become the dominant assembly technology for electronics components. It's impact continues to grow and reflow technology (print + place + reflow) has become the major assembly route. As component pitches have continued to reduce, the requirements for solder paste printing have become more stringent. In particular the introduction of area array devices (BGAs, CSPs etc.) whilst initially increasing the component pitch, have now heralded a reduction in the pitch, which has further made aperture shape and aspect ratio critical. The development of aperture designs are shown in Figure 1.

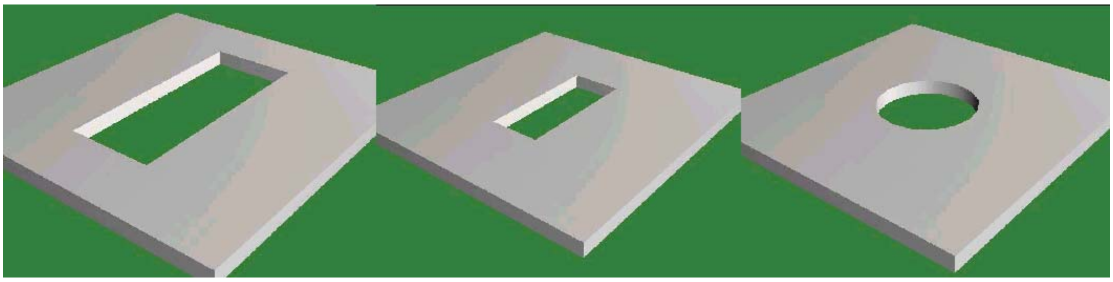

Figure 1: Development of stencil apertures through fine pitch to area arrays

The introduction of smaller, square and round apertures decreases the ratio between the open area of the aperture and the area of the aperture walls.

Aperture Area Ratio (AAR) = Aperture Area/Wall Area

This ratio is significant in the release of the solder paste from the aperture. In order for the paste to release cleanly from the aperture the adhesion of the paste to the PCB needs to be greater than the adhesion of the paste to the sidewalls of the stencil as shown in Figure 2.

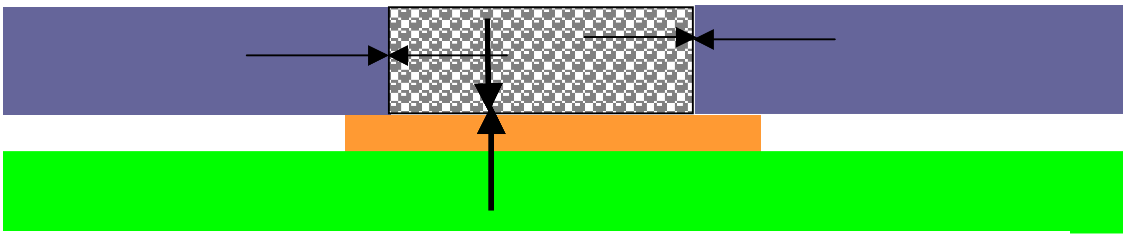

Figure2: Comparison of paste adhesion to PCB and stencil wall

For coarser pitch components such as SOIC, this ratio is well above 1.5 and for larger chip components (1206) the ratio can be above 2.5. The ratio for different components is shown in Figure 3. This figure takes account of the typical stencil thickness used for each device type. As component pitches have decreased, the AAR has also decreased so that for today's ultra fine pitch area array devices, the typical AARs are below 0.5.

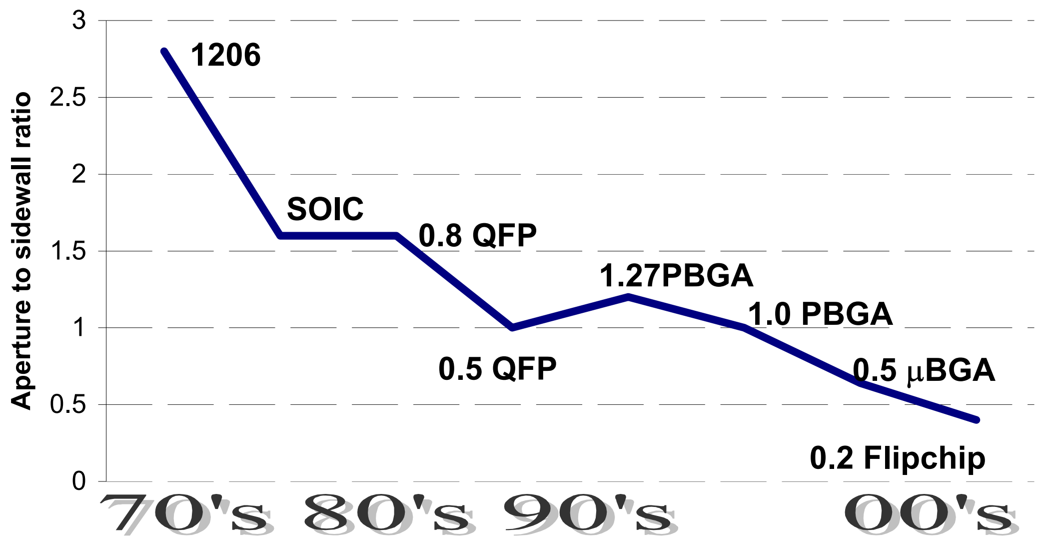

Figure 3: Comparison of aperture area to sidewall area ration for typical components

To over come this ratio reduction and to improve printing performance through ultra fine pitch apertures, all aspects of the print process need to be addressed. This includes stencil type, stencil wall aperture finish, aperture design and paste choice, all of which are discussed below.

2. Stencil Aspects of Ultra Fine Pitch Printing

2.1. Stencil Thickness

Essentially the thinner the stencil, the better. This is because for thinner stencils, the area of the stencil wall is smaller and therefore the AAR is greater, easing paste release. Table 1 shows how the AAR varies for a 1mm pitch BGA for a range of stencil thicknesses.

Table 1: Comparison of Aperture Area to AAR for Different Aperture Widths for 1mm Pitch BGA and Different Stencil Thicknesses

Stencil Thickness (µm)	Wall Area For Typical Aperture (mm^2)	AAR
200	0.32	0.63
150	0.24	0.83
125	0.2	1.0
100	0.16	1.25
75	0.12	1.67

However, thin stencils have two main disadvantages: (i) they are less mechanically robust than their thicker counterparts and are therefore more prone to damage during handling and particularly cleaning; (ii) they will also deposit less paste and hence cause lean solder joints, which may be a problem if the assembly also has coarser pitch components on the same side as the ultra fine pitch components. Table 2 shows how the volume of paste deposited through common component apertures varies with different stencil thickness.

Table 2 : Variation in volume of paste deposited through common component stencil apertures with different stencil thickness

Stencil Thickness (□m)	1206 Aperture Volume (mm^2)	SOIC Aperture Volume (mm^2)	1.0mm BGA Aperture Vol.(mm^2)
150	0.432	0.528	0.03
100	0.288	0.352	0.02
75	0.216	0.264	0.015

Many suppliers offer stencils down to 0.05mm or even in some cases 0.025mm thick but many users feel that 0.075mm is the lowest practicable thickness.

2.2. Stencil Material

Three different methods of stencil manufacture are readily available from a range of manufacturers. Chemically etching and laser cutting are subtractive processes which start with a metal foil of desired thickness and then remove the apertures. Electroforming is an additive process that creates a stencil by plating nickel onto photoresist on a mandral.

Etched stencils tend to be lower cost but their method of manufacture is normally by etching from both sides of the base foil and this leads to an aperture which is narrower at the centre of the stencil compared to the top and bottom (Figure 4). Electropolishing can smooth this profile but this can still lead to problems with paste release at finer pitches. Today this effect is relatively minor compared to earlier etched stencils.

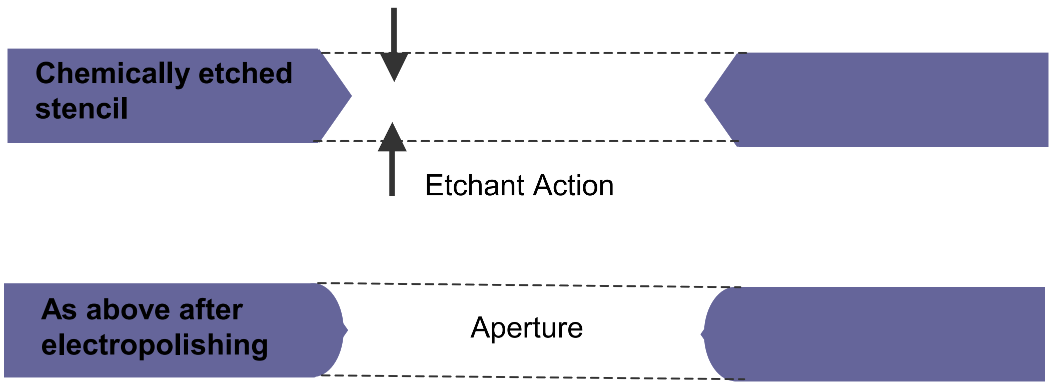

Figure 4: Comparison of edge profiles of chemically etched stencil before and after electro-polishing

Trapezoidal section apertures, that is apertures which are effectively just etched from one side, are possible with etched stencils but these are higher cost, effectively negating the primary benefit of this type of stencil. The main drawback with this type of stencil for fine pitch work is that the limitation in aspect ratio of apertures than can be etched (Ref 1).

Aperture Aspect Ratio (ASR) = Aperture Width/Stencil Thickness

To get good aperture formation, the ASR of the aperture needs to be 1.5:1 or greater. Thus in a 75µm thick stencil, the minimum aperture pitch would be around 115µm. Both the laser cutting and electroforming processes can achieve better ASRs (closer to 1:1).

Laser-cut stencils are produced directly from Gerber data on YAG lasers. Each aperture is cut sequentially and therefore this can add to the stencil cost. However, the aperture walls created are straighter than for chemical etching. The walls can be further smoothed by electro-polishing. Minimum feature sizes again depend on material thickness but in recent stencils manufactured for NPL, 100µm features were achieved in 75µm stencils.

Electro-formed stencils have similar performance to laser cut stencils but the process of electroplating onto a photo resist covered mandrel naturally leads to trapezoidal shaped apertures as shown in. This shape further aids paste release.

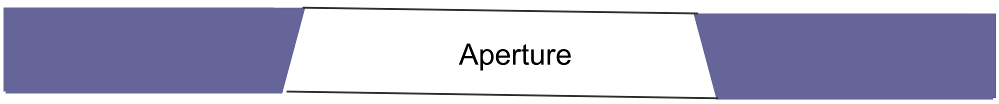

Figure 5: Electroformed stencil aperture (trapezoidal shape)

2.3. Minimum Aperture Sizes

If it is assumed that 75µm stencils are the practical minimum, then the minimum achievable apertures sizes are shown in Table 3. Some manufacturers quote smaller apertures but do not specify the thickness of material in which such apertures can be achieved. The capabilities of manufacturers will also differ significantly, so end users are advised, when specifying stencils with apertures at or near this minimums, to independently verify their suppliers capability. If the end user requires smaller apertures, then a stencil thinner than 75µm can be considered but such a stencil will be more prone to damage during use and handling.

Table 3: Minimum achievable apertures in 0.075mm stencil

Stencil Type	**Minimum achievable aperture width (µm)**
Chemically Etched	125
Laser-Cut	75
Electroformed	50

However, even if the end user restricts the aperture size to above the limits suggested above, paste release characteristics will be highly dependent on the paste used and the stencil aspect ratio (stencil thickness to aperture width). Table 4 shows recommended aspect ratios for common stencil types to achieve good paste release and these always be born in mind when design stencils. Both these limits have been verified by the inspection of stencils and solder paste prints undertaken in a recent NPL ultra fine pitch evaluation programme.

Table 4: Recommended minimum aperture ratios in stencils

to achieve good paste release

Stencil Type	Minimum ASR for Successful Printing
Chemically Etched	1:1.5
Laser-Cut	1:1.2
Electroformed	1:1.1

2.4. Aperture Shape

When printing through ultra fine pitch apertures, the aperture shape can have a significant effect on print quality. Generally, rectangular apertures will print better that square apertures of the same width. This is essentially an edge effect. Consider a rectangular aperture to be formed of multiple square apertures. Paste will be retained by all four sides of a square aperture, but in the case of a rectangular aperture, retention by all four sides will only occur in the outer most "squares" of the print. With the inner "squares", paste will only be retained by the outer edges not the edges adjacent to other paste squares. This is shown diagrammatically in Figure 6. A sample print of a type 5 paste through a 75μm electroformed stencil is shown in Figure 7 indicating the better paste deposition associated with rectangular apertures compared to square and circular apertures.

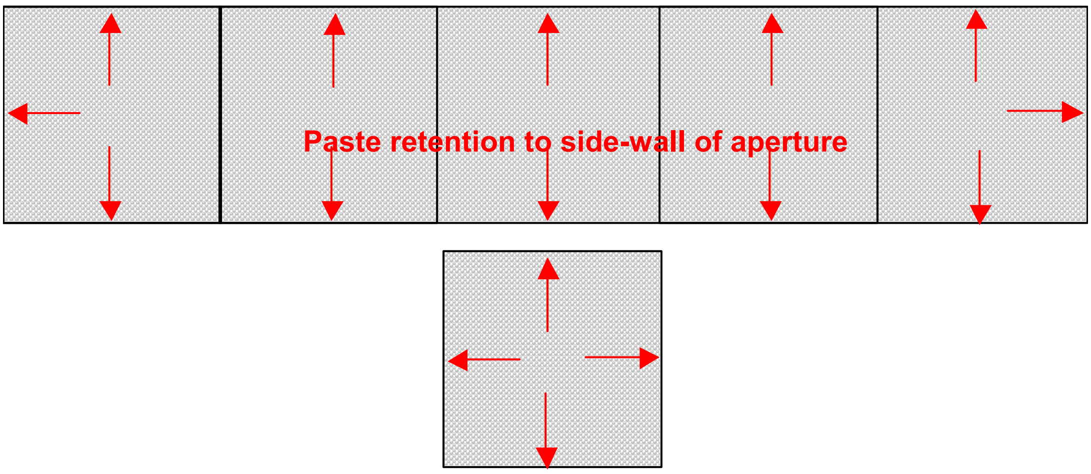

Figure 6: Diagrammatical representation of paste retention comparison between rectangular and square apertures

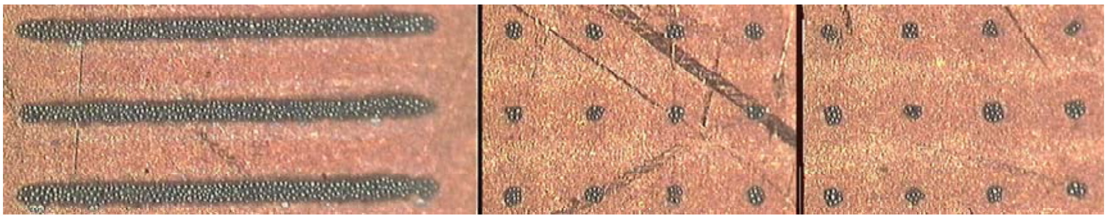

Figure 7: Comparison of Type 5 paste printing though 75µm wide apertures in 75µm electroformed stencil (print direction top to bottom, rectangular apertures (left), circular apertures (centre) and square apertures (right))

As the purpose of the stencil print operation is to deliver a known consistent volume of paste to the substrate, it is perhaps more meaningful to compare the printing efficiency of circular and square apertures. Careful examination of circular and square prints from Figure 7 indicated that print quality is slightly better for the circular apertures in the centre. The reasons for this are twofold. Firstly a circular aperture has less wall area for the same open area compared to a square aperture and thus less paste will be retained in the aperture. Secondly, because a circular aperture has no corners, paste particles can only touch one edge at one time whilst with square apertures, some paste particle will be able to touch two edges at once, thereby increasing that particles chances of being retaining in the aperture after printing. This is shown diagrammatically in Figure 8.

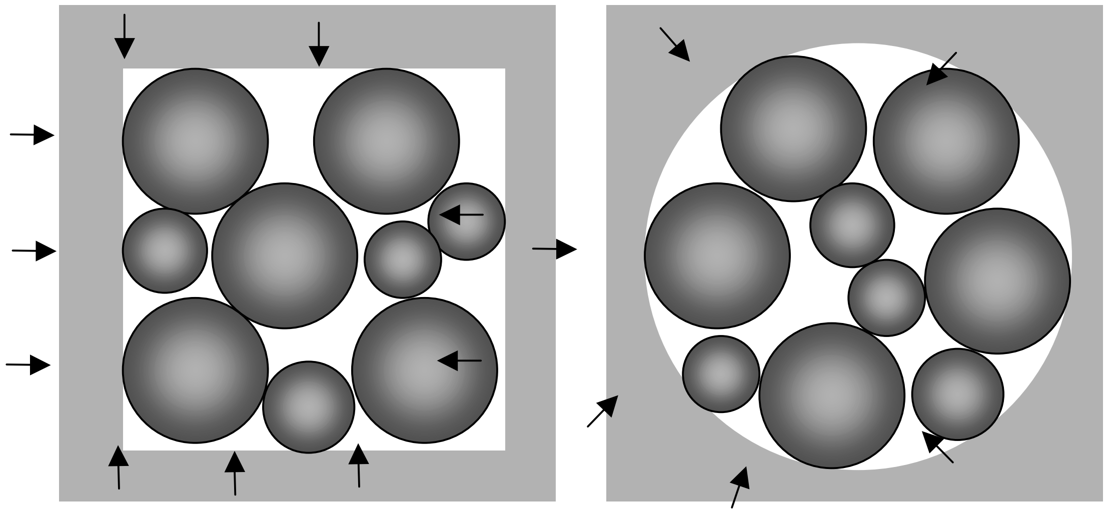

Figure 8: Comparison of particle edge touching in square and circular apertures

with touching particles marked

3. Solder Pastes for Ultra Fine Pitch Printing

Solder pastes are available in a range of particle sizes, the three most popular being as shown in Table 4 (reference 2). Generally for ultra fine pitch printing, the finer the particle size the better. This is obviously because the smaller particle should achieve a better packing density.

Example prints for types 3, 4 and 5 solder pastes are shown in Figure . Higher magnification examples of this packing process for types 3, 4 and 5 solder pastes in given in Figure . It should also be noted that for a 75m stencil a type 3 paste print will be only 2 particles thick, a type 4 paste print 3 particles thick and a type 5 print 4 to 5 particles thick.

Table 5: Solder paste particle sizes

IPC Particle Type	Size (Microns)	Mesh Size
3	45-25	-325+500
4	38-20	-400+635
5	25-15	-635

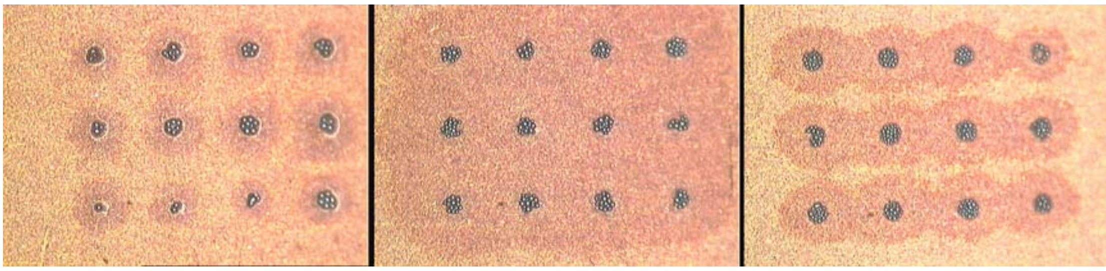

Figure 9: Example prints of types 3 (left), 4 (centre) and 5 (right) solder pastes through 100µm circular apertures in 75m thick electropolished laser cut stencil (magnification 25X)

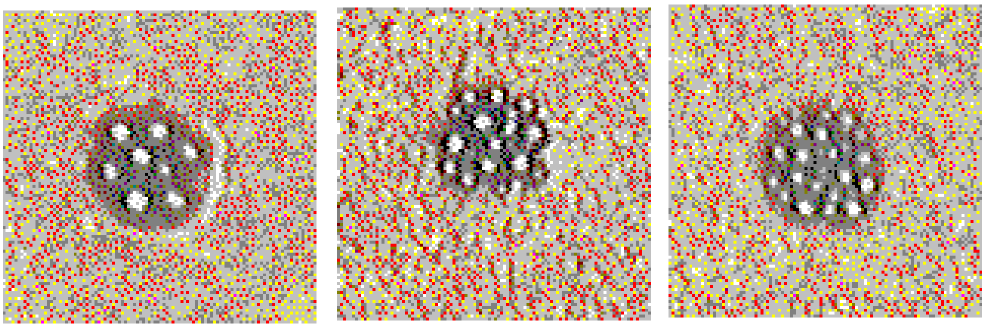

Figure 10: Prints of Type 3 (left), Type 4 (centre) and Type 5 (right) solder pastes through 100µm width aperture of an 75µm electro-polished laser cut stencil (magnification 150X)

Figure 11 shows a comparison of the relative print quality for circular apertures in a 75 µm electroformed stencil. A print quality of 100% is based on an aperture release efficiency (ARE = print volume/aperture volume x 100%) of around 90%. Results shown are for types 3, 4 and 5 solder pastes. As can be seen, type 5 solder paste out performs both the other paste types, particularly at aperture sizes below 125 µm.

Figure 12 shows a similar comparison for a type 5 paste between three different stencil types of 75m thickness. Visually, there is little apparent difference between the laser-cut and laser-cut electro-polished performances. But marginal improves can be noted for the electro-polished stencil, particularly at apertures of less than 125 µm diameter**.**

Figure 13 shows the printing efficiency (print volume/aperture volume) for 150□m diameter circular apertures in both electro-formed and laser cut stencils. This confirms earlier conclusions, with type 5 pastes outperforming both type 4 and type 3 pastes. This work also confirms the slight benefits experiences by utilising electroformed stencils over equivalent laser-cut stencils.

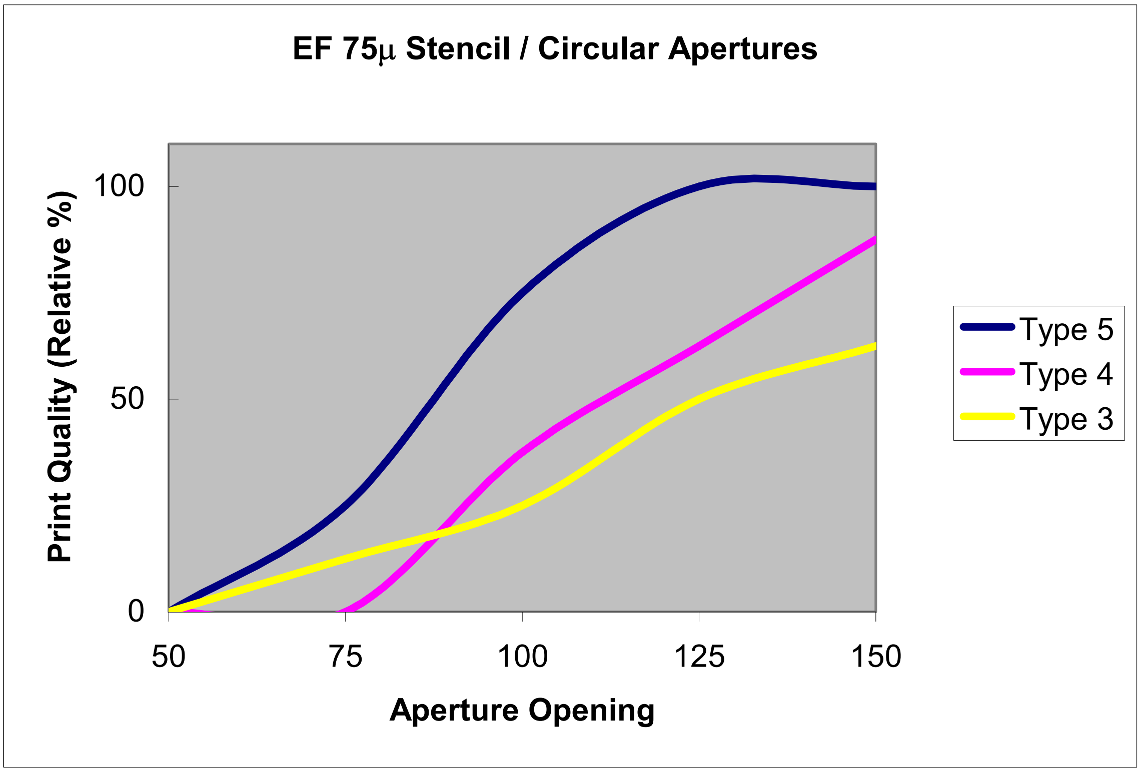

Figure 11: Comparison of relative print quality for 75µm electroformed stencil

for 3 different paste types

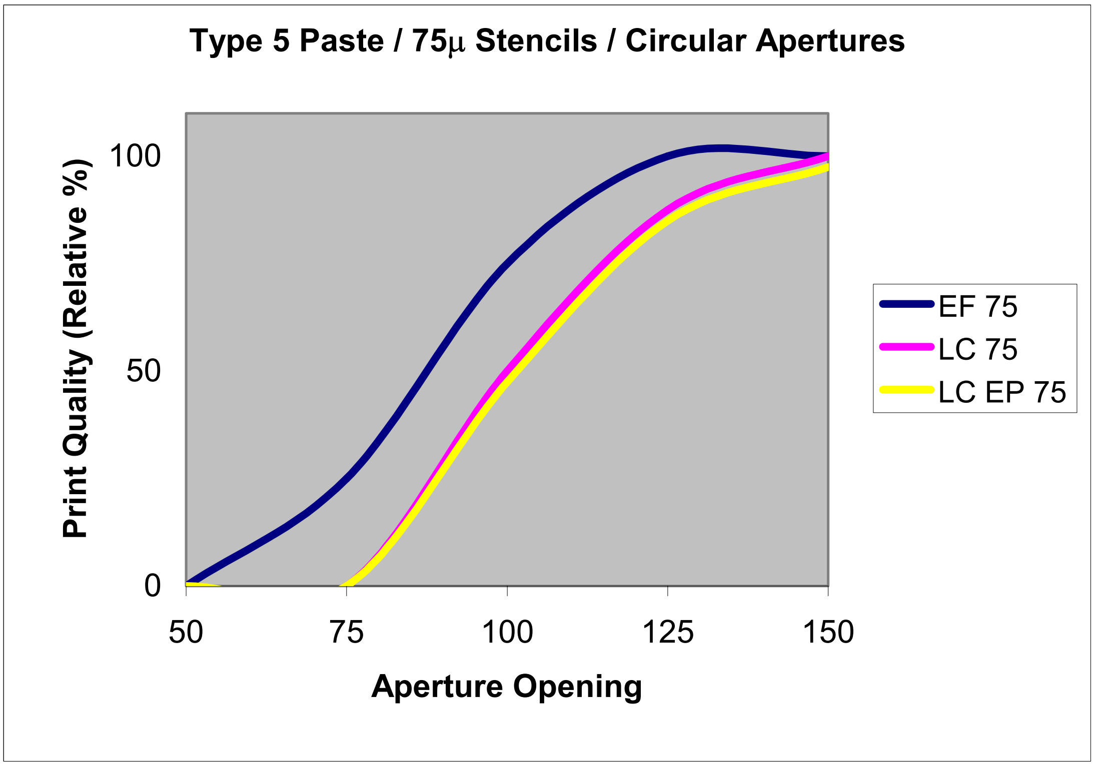

Figure 12: Comparison of relative print quality of circular apertures in 75µm stencils of three different types (EF = electroformed, LC = laser-cut, LC EP = laser-cut electro-polished)

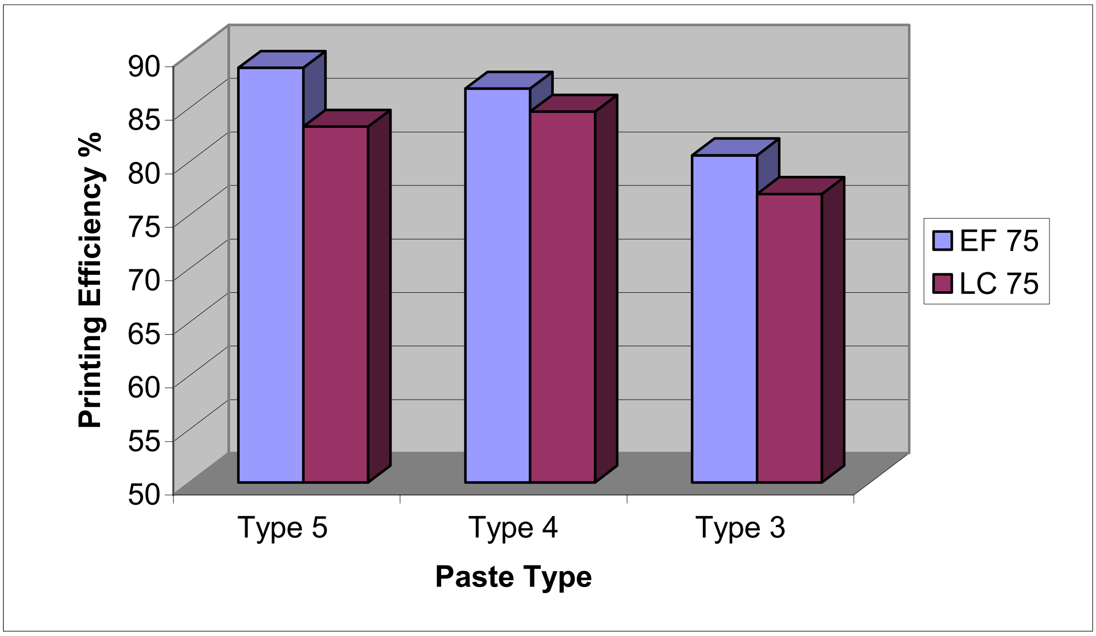

Figure 13: Printing efficiency for 150□m wide apertures in 75□m stencils

However, there are disadvantages in using solder particles containing smaller particles. All solder particles are prone to surface oxidation and the smaller the particle the greater the surface area to oxidise for a given volume. In addition, the average particle weight is lower and therefore can be more prone to being ejected from the joint during reflow soldering. Thus smaller particle pastes are more prone to solder balling. It should also be noted that type 5 solder pastes are not currently available as off the shelf products from all solder paste suppliers.

4. Conclusions

To achieve quality printing for ultra fine pitch (<= 150µm aperture opening), the following aspects of the process need to be carefully considered.

1. Thinner stencils achieve better paste release.
2. The shape of the aperture is less important than maximising the open area of the aperture, while retaining consistent quality printing.
3. 75µm is practicable minimum stencil thickness. Thinner stencils can be sourced but will be more prone to damage during use.
4. Thinner stencils may not provide sufficient paste volume for larger pitch components
5. Minimum aperture openings are dictated by stencil thickness and manufacturing technology, aperture openings of diameters or widths smaller than stencil thickness are not recommended for any stencil technology
6. For apertures at and below 100µm width, electroformed stencils perform slightly better than electro-polished laser cut or laser cut stencils
7. Circular apertures achieve slightly better paste release than square apertures of the same open area
8. Pastes with finer particle sizes achieve better packing densities for small aperture openings but may be prone to greater solder balling
9. Practicable limits for square and circular apertures for ultra fine pitch printing should be considered as following (finer printing may be possible with individual combinations of paste, stencil, aperture design):

Type 3 pastes:	150µm wide apertures in 75µm stencils
Type 4 pastes:	125µm wide apertures in 75µm stencils
Type 5 pastes:	100µm wide apertures in 75µm stencils 125µm wide apertures in 100µm stencils 125µm wide apertures in 125µm stencils

5. Acknowledgements

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Indium Corporation

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