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A STUDY OF SMALL AND TAPERED APERTURE TRANSFER EFFICIENCY

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ABSTRACT
The objectives of this study are to determine the point at which the stencil printing process becomes inefficient and to compare the difference in performance between aperture geometry (thickness, shape and taper) for typical aperture sizes ranging from 6 to 20 mils. Two laser cut stencil thicknesses (4 and 5 mils) and three levels of positive taper, low (3°), medium (5°) and high (7°) are investigated.

KEY WORDS
Surface Mount, Fine Feature, Transfer Efficiencies, Solder Paste, Stencil Printing

INTRODUCTION
The demands put on the surface mount process are becoming increasingly more stringent. A few examples are the integration of 0201 passives in standard packages and the use of conventional printing techniques to assemble chip scale packages. A better understanding of the current process capabilities and the underlying physical mechanisms will help to meet these demands. This paper investigates the stencil printing portion of the SMT process, in particular, the effect of aperture taper and shape on transfer efficiency. The objective is to determine the point at which the print process becomes significantly inefficient.

The stencils used in the study were laser cut, 4 and 5 mil thick. There were two aperture shapes, circular and square. The apertures ranged in size from 6 to 20 mils. There were three levels of aperture taper, low (3°), medium (5°) and high (7°). To determine the point at which stencil printing becomes inefficient, the aperture transfer efficiencies were correlated to the theoretical aperture volumes and area ratios. For this study the area ratio was modified to take into account the taper of the aperture wall. The stability of the process was quantified by dividing the standard deviation of the measured deposit volumes by the average volume of the deposits.

PRINT CONDITIONS, MEASUREMENTS AND CALCULATIONS
The studied aperture sizes ranged from 152 μm to 508 μm for a 102 μm thick laser cut stencil and from 203 μm to 508 μm for a 127 μm thick laser cut stencil. The stencil layout was such that there were three cells, each with a different degree of taper, low (3°), medium (5°) and high (7°). The average standard deviation of the aperture angle was 0.61°. All cells had the same level of electro-polish. Each cell contained 14 apertures of a given size and shape.

The theoretical volume of the apertures was calculated from measurements made using an optical coordinate measuring machine (CMM) and a 12 inch (30.5 cm) deep throat micrometer. The CMM was used to measure the aperture opening area of the top (squeegee) and bottom (board) side of the stencil and the micrometer was used to measure the stencil thickness. Solder paste volume measurements were made with a laser scanning profiler. A Precision to Tolerance ratio was calculated and the gage was found acceptable for the study.

A fully automated stencil printing machine and a type 3 powder, no clean paste were used for printing. Print speed was 5 inches per second

(12.7 cm/sec). The squeegee force was 22.5 lbs for a 10 inch (25.4 cm) metal blade.

The two response factors of the test were the transfer efficiency, defined as the volume of paste transferred from the stencil to the substrate normalized by the measured volume of the aperture, and the second was the ratio of the standard deviation of the deposited volume measurements to the measured aperture volume.

MODIFIED AREA RATIO

The conventional area ratio, defined as the ratio of the wetted pad area to the aperture wall surface area, does not account for taper in the aperture wall. Fundamentally, the concept of area ratio was put forward as a means to compare the force of adhesion acting at the surface of the pad to the shear force acting at the aperture wall. While the former assists the release of paste from the aperture, the latter works against better release performances. For tapered apertures, the force the aperture wall exerts on the paste has two components: 1) a shear force that is aligned with the stencil wall surface F_{SW} and 2) an adhesion force that acts in a direction normal to the aperture wall surface F_{AW} (See Fig.1). Only the *Y* (vertical) components of these two forces are taken into consideration in formulating the modified area ratio. Taking the ratio of adhesion to shear forces one arrives at Eq. 1 that can be reduced to a ratio of effective surface areas as indicated in Eq. 2. The effective wall area represented in the denominator is the aperture wall area projected onto the vertical or *Y* axis. The effective board side aperture area is the difference between the measured aperture opening and the aperture wall area projected onto the horizontal or *X* axis. This quantity is represented in the numerator of Eq.2. The projected aperture area is subtracted because the adhesion to the stencil wall resists the adhesion at the substrate.

For a constant aperture opening on the board side, the modified area ratio decreases, as the angle of taper increases. This is because, as the □ increases, the term sin(□) increases more rapidly than cos(□) decreases. This has the effect of reducing the numerator more quickly than the denominator, which ultimately decreases the modified area ratio.

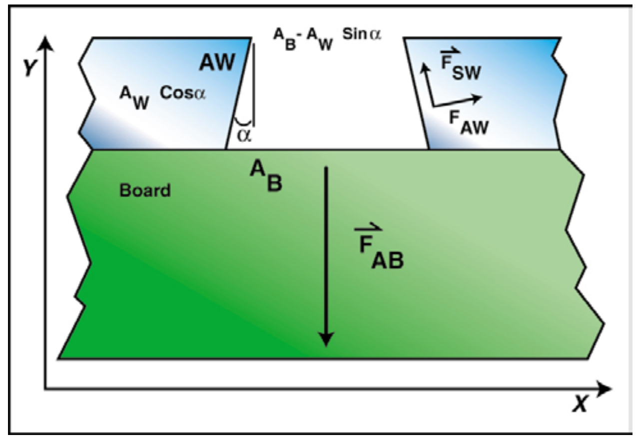

Figure 1. Forces acting on aperture wall

$$A_{RM} \propto \frac{F_{AB} - F_{AW}\sin(\alpha)}{F_{SW}\cos(\alpha)}$$

(1)

$$A_{RM} = \frac{A_B - A_W \sin(\alpha)}{A_W \cos(\alpha)}$$

(2)

A_{RM} is the modified area ratio
A_W is the aperture wall area
A_B is the aperture opening area, board side

Equations 3 and 4 are simplified forms of the modified area ratio applicable to circular and square apertures. For the case when there is no aperture taper (i.e. the board side dimension equals the squeegee side) both equations collapse to the conventional area ratio.

$$A_{RM} = \left(\frac{1}{2}\right)\left(\frac{d^2}{(D+d)T}\right)$$

(3)

d is the squeegee side diameter
D is the board side diameter

$$A_{RM} = \left(\frac{1}{2}\right)\left(\frac{2(W \times w) - (w)^2}{(W + w)T}\right)$$

(4)

w is squeegee side width

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W is board side width

EXPERIEMNTAL RESULTS

One of the main objectives of this study was to determine the point at which the stencil printing process becomes inefficient. This information provides important information to aid in the design of stencils as well as a baseline from which to gage improvements to the process. The break down point for this study was defined as the point at which the transfer efficiency of the process as well as the repeatability of the deposit volumes starts to decline rapidly. Figure 2 is a plot of the transfer efficiency vs. measured aperture volumes for a 4 and 5 mil thick stencil. The LT in the legend stands for low taper, the MT for medium taper and the HT for high taper. The C is for circular aperture and the S is for square aperture. The 4 is for the 4 mil thick stencil and the 5 is for the 5 mil thick stencil. The data is broken down by taper, stencil thickness and shape. The figure illustrates the rapid decline in transfer efficiency below about 500 mil^3 to 700 mil^3. This corresponds to a modified area ratio of 0.6.

Figure 2 shows that release efficiencies are typically higher for the thinner stencil, which is to be expected but nonetheless verified in this study. It is also interesting to note that the circles appear to lie on a curve that is slightly higher than that of the square apertures. This would imply that the circular apertures have better release efficiencies than the square, which has been corroborated by other studies[1]. Also noticeable in this figure is the fact that various degrees of taper do not seem to affect transfer efficiencies.

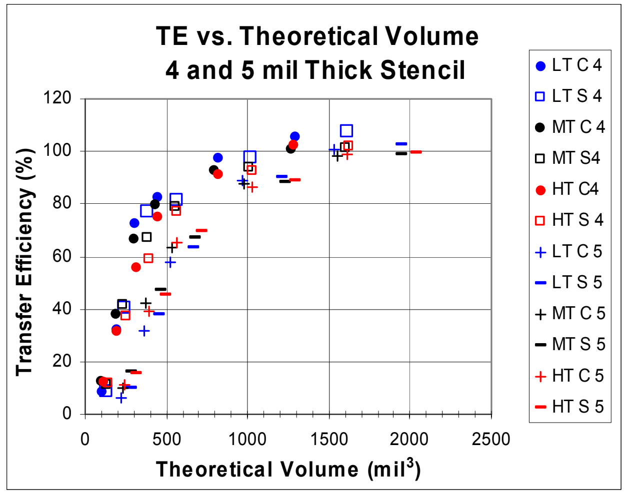

Figure 2. Transfer efficiency vs. aperture volume

Figure 3 is a plot of the transfer efficiency vs. modified area ratio for the data plotted in Fig.2. From the plot, it can be noted that the transfer efficiencies start to decline rapidly for modified area ratios that are smaller than 0.6. This is in good agreement with the widely accepted value of 0.66 for the conventional area ratio.[2]

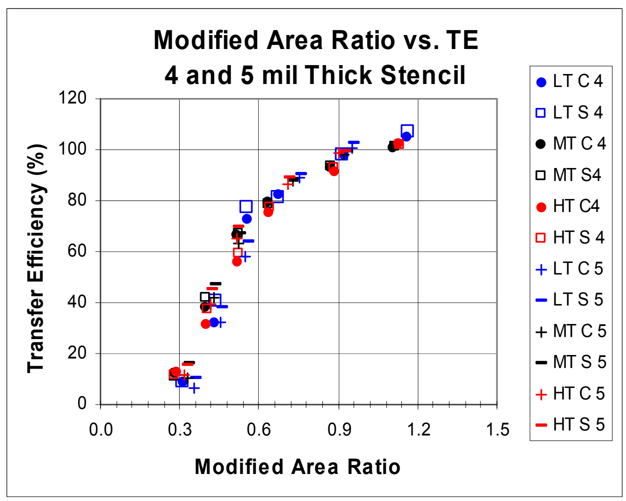

Figure 3. Transfer efficiency vs. modified area ratio

As expected, Fig. 3 shows that when plotting release efficiencies as a function of modified area ratios, variations due to stencil thickness, taper and aperture shapes can no longer be seen. This indicates that the use of the newly defined modified area ratio as a non-dimensional quantity is reasonable for tapered apertures.

Figure 3 also shows that a sharper decrease in transfer efficiencies can be observed for A_{RM} < 0.6, this implies that corresponding apertures produce prints that are less consistent because small variations in aperture area ratio will produce relative large changes in transfer efficiencies. Consequently, particular attention should be given by board manufacturers in verifying stencil specifications if apertures are designed with area ratios that are smaller than 0.6.

Figure 4 shows normalized standard deviations as a function of modified area ratios. The plot indicates that the low taper apertures tend to produce larger standard deviations while a difference in performance between circular and square apertures cannot be detected. Referring to Figs. 3 and 4, it appears that the transfer efficiency data acquired in this study strongly indicates that for modified area ratios that are smaller than 0.6, transfers efficiencies decrease dramatically while the standard deviations of the deposited volumes increase rather significantly.

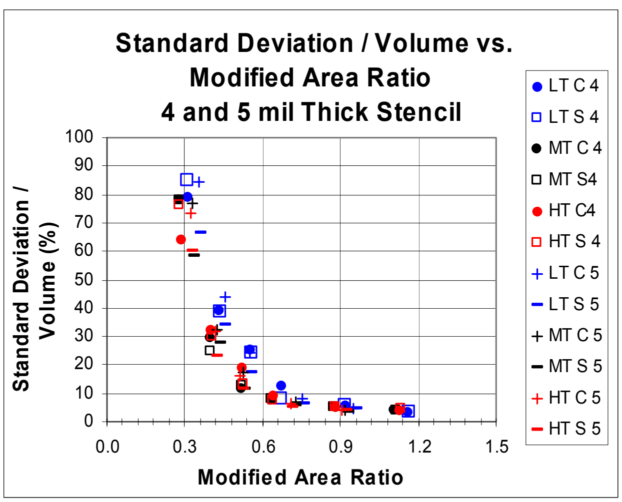

Figure 4. Standard deviation / volume vs. modified area ratio

CONCLUSIONS

A modified area ratio has been defined. This non-dimensional parameter takes into account aperture wall taper and ratios forces aiding the release of paste from the stencil to forces working against paste transfer. The newly introduced parameter appears well suited to describe tapered apertures.

This study verifies that a well-tuned print process will produce consistent prints with acceptable transfer efficiencies for modified area ratios above 0.6. While it has not been possible to measure the effects of taper on release efficiencies, it could be noticed that tapered apertures produce more consistent prints. It was also noted that circular apertures tend to have better release efficiencies than square apertures.

REFERENCES

[1] Aravamudhan, S., Santos, D., et al., "A Study of Solder Paste Release from Small Stencil Apertures of Different Geometries with Constant Volumes", 27th International Electronics Manufacturing Technology (IEMT) Symposium, San Jose, CA, July 2002. pp. 159-165.

[2] IPC-7525, "Stencil Design Guidelines", IPC, Northbrook, IL, May 2000