As originally published in the SMTA International Conference Proceedings.

OPTIMIZING THE PRINT PROCESS FOR MIXED TECHNOLOGY

Clive Ashmore, Mark Whitmore, and Simon Clasper
Dek Printing Machines
Weymouth, United Kingdom

ABSTRACT

Within this paper the method of optimising a print process in order that a mixed technology (heterogeneous) product can be successfully produced will be discussed.

INTRODUCTION

As consumers the expectation of increased functionality for a given real estate size is a given, however there comes a time where this tireless demand for product efficiency starts to stretch the design for manufacture (DFM) rules.
Fabricating products with decreasing feature size and increasing complexity is not the issue nor is producing products that have larger components; the dilemma is when products require both.

This predicament is now upon the Surface Mount Technology (SMT) community, the imminent role out of 0.3mm CSP looks to be pushing the feature size below 200 micron but still RF shields and connectors are required - or put another way Heterogeneous assembly is looming upon us.

It is the authors' intention that this will be the first of a series of papers in which solutions for heterogeneous assembly will be discussed.

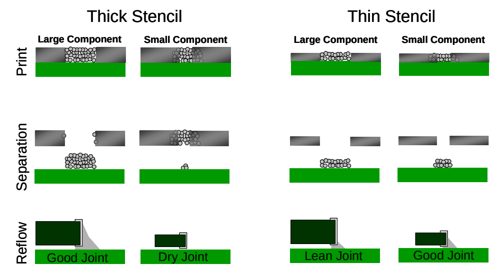
This paper will investigate how by optimising a "standard" printing process it is possible to start to bridge the issues surrounding heterogeneous assembly.

THE DILEMMA

The main issues surrounding the print process when dealing with heterogeneous assembly is area ratio. Figure 1 illustrates the inherent issues associated with area ratio.
As can be seen within Figure 1 there are two component types (small and large) that can be printed successfully using a thin stencil but the large component would suffer from a lean reflowed solder joint due to a insufficient volume of deposited solder paste.

To overcome this issue a thicker stencil could be utilised but this causes the smaller component to not fully print and result in a lean reflowed joint.

Figure 1: Heterogeneous printing issues

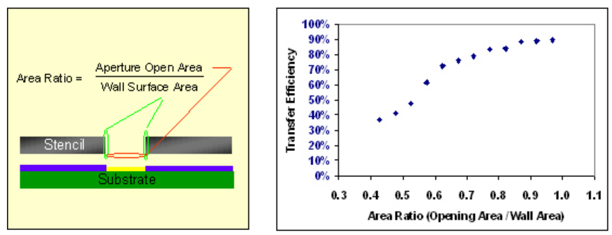


The rationale for the area ratio phenomenon is illustrated in Figure 2a and 2b. The component part of the area ratio mechanism is shown in Figure 2a. As can be seen the ratio of aperture open area and aperture wall surface area derives the area ratio, therefore if the stencil thickness is say 100 and the aperture opening is 250 microns the resultant area ratio would be 0.625, but if the stencil thickness were decreased to 75 microns the wall surface area decreases thus the resultant area ratio would become 0.833. From this simple example we can see how by adjusting the geometries of the stencil design the resultant Area Ratio can be influenced.

Area ratio on it own is a meaningless value; it is how this affects the release of paste as illustrated within Figure 2b that is significant to a print process.

From Figure 2b we can see that the transfer efficiency and area ratio retains a linear relationship until the area ratio equals 0.66, at this point the curvature of the graph becomes a non linear response and indicates a significant drop in transfer efficiency; thus we can now comprehend why when designing stencil artwork the area ratio rule of thumb is set at 0.66 and above (IPC-7525).

Figure 2a and b – Area calculation, Resultant Transfer Efficiency



The Challenge

The challenge therefore is to increase the transfer efficiency below the 0.66 ranges, thus allowing smaller apertures to be successfully imaged using a thicker stencil and therefore fulfilling the heterogeneous requirements.

Set-up

An automatic stencil printing was utilised to apply solder paste through an industry standard 100 micron thick laser cut stainless stencil, the artwork for this stencil is illustrated in Figure 3a and 3b. The design of this stencil artwork permits analysis on both standard Surface Mount Technology devices (following IPC 7525A) and a transfer efficiency arrays. The substrates used throughout the investigation were a set of numbered aluminium plates with a black anodised surface; the substrates were run in numerical sequence for all runs.

The stencil printing machine, stencil, squeegee blades, tooling, solder paste and operators were kept constant throughout the investigation to reduce variation.

Stencil Design

The intention of the stencil design is to capture data from this investigation that relates to both standard SMT technology and also creates an understanding of the process capability for each experiment.

To capture the required data sets the stencil was designed with a full range of devices, table 1a shows the device types and associated area ratios. To fully observe the process capability for each experiment a decreasing aperture array was utilised, table 1b shows the aperture size and associated area ratios.

It is the intention of this stencil design and associated experiments that a series of transfer efficiency curves for each experiment can be produced.

Table 1a – Stencil design (SMT)

Device Type	Area ratio
0201	0.98
0402	1.52
0603	2.24
0.4mm CSP	0.5
0.5mm CSP	0.6
0.75mm CSP	0.65

Table 1b – Stencil Design (Aperture decreasing array)

Aperture size	
100	0.250
125	0.313
150	0.375
175	0.438
200	0.500
225	0.563
250	0.625
275	0.688
300	0.750
325	0.813
350	0.875
375	0.938
400	1.000
425	1.063
450	1.125
475	1.188
500	1.250
525	1.313
550	1.375

Experiment

Within the stencil printing process there are many significant factors that influence the process output. Within this investigation the factors that will be included are print speed, print pressure and squeegee angle.

The squeegee assemblies to be used for this investigation will be; 45 deg 6mm overhang, 60 deg 6mm overhang and 60 deg 15mm overhang. The intention is that the 15mm overhang blades will give a variable resultant squeegee angle depending upon the print pressure. The 6mm overhang blades will be used to contrast and compare the 15mm overhang results.

Table 2 outlines the print parameters used throughout the investigation, all other parameters were not adjusted. Other process parameters that are endogenous to the set-up have been chosen from previous work.

Table 2 – Experiment overview

	60 deg 6mm Overhang		45 deg 6mm Overhang		60 deg 15mm Overhang	
	kg	mm/sec	kg	mm/sec	kg	mm/sec
Test 1	6	20	6	20	3	20
Test 2	13	20	13	20	13	20
Test 3	9.6	50	9.6	50	8	50
Test 4	6	80	6	80	3	80
Test 5	13	80	13	80	13	80

Run Procedure

To ensure that the process was run under ceteris paribus conditions the following procedure was followed.

The same batch of solder paste was homogenised before each run and a consistent amount of paste was loaded on to the stencil. The printer was located in a temperature-controlled room; therefore the environmental conditions were kept constant during the investigation. During all runs the same squeegee blades were used for all runs (the holder varied to allow for angle changes) and a squeegee assembly calibration was initiated before any printing. To ensure the investigation follows a "standard" set-up, stock materials will be used throughout, table 3 states the materials used.

The solder paste deposits were measured using a three dimensional measurement system and Excel used to analyse the quantitative data.

Table 3 - Materials used throughout investigation

Parameter	
Stencil thickness	100 microns
Stencil material	Stainless steel (grade 330)
Stencil fabrication method	YAG laser
Solder paste composite	Lead Free SAC
Solder paste size	Type 4
Solder paste metal loading	88.9%
Tooling	Vacuum Block
Squeegee holder length	150mm

To ensure the print process had stabilised substrates 1 to 4 were printed and discarded whilst the following 10 substrates were printed and measured.
By following the methodology highlighted above the only change to the study were the print speed, print pressure and resultant squeegee angle

Figure 3a illustrates the device and locations used in this investigation; Figure 3b illustrates the transfer efficiency array design. The spread of technologies help understand the area ratio/ transfer efficiency paradigm outlined above.

Figure 3a – Overview of devices and locations

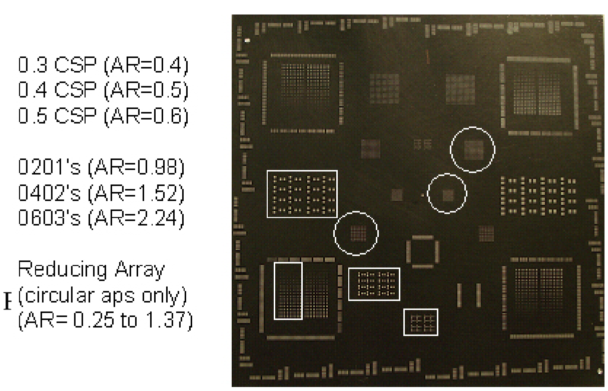
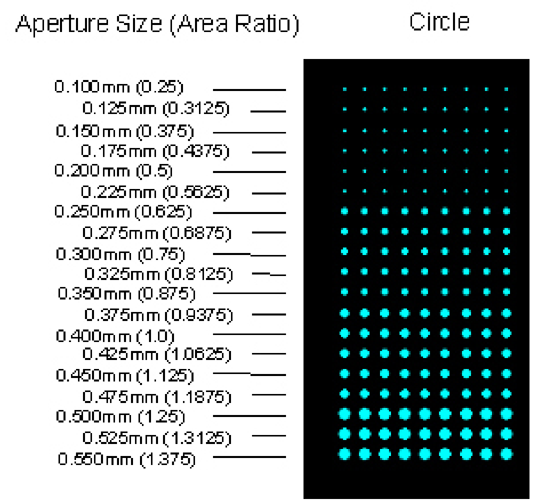


Figure 3b. Overview of the transfer efficiency array

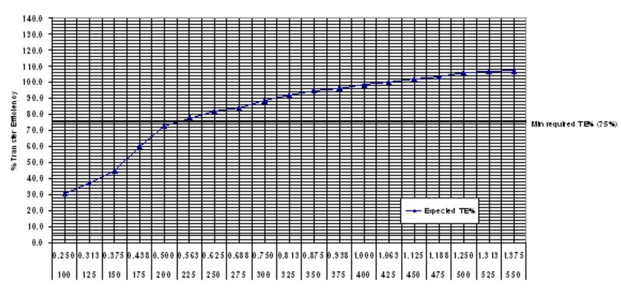


Historical Data

Before analysing the results from this investigation it would be beneficial to reflect on the historical transfer efficiency curves, as this will allow the data achieved within this investigation to be contrasted and compared.

Figure 4 illustrates the historical transfer efficiency curves. As can be seen a minimum transfer efficiency (TE) line has been included, the general rule of thumb states that a TE 75% or below demonstrates an inferior process and one that is not in control.
From this historical data we can see that the aperture diameter that correlates with the 75% cut-off is 225 microns. This observation will be used when concluding the results.

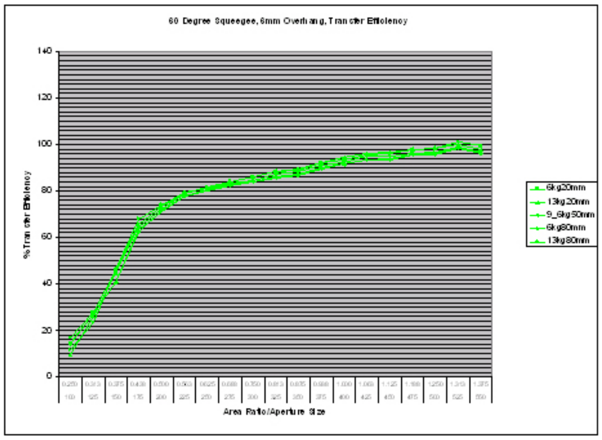
Figure 4 Historical transfer efficiency curves



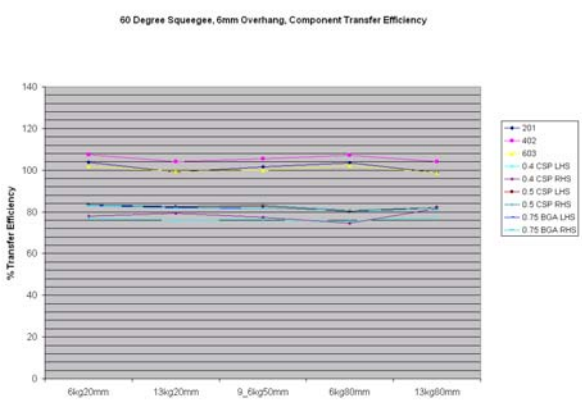
RESULTS

The following graphs are the results from the runs outlined in table 1. The graphs illustrate the resultant transfer efficiency results from both the SMT and array devices for all the five levels of parameters setting outlined in table 1.

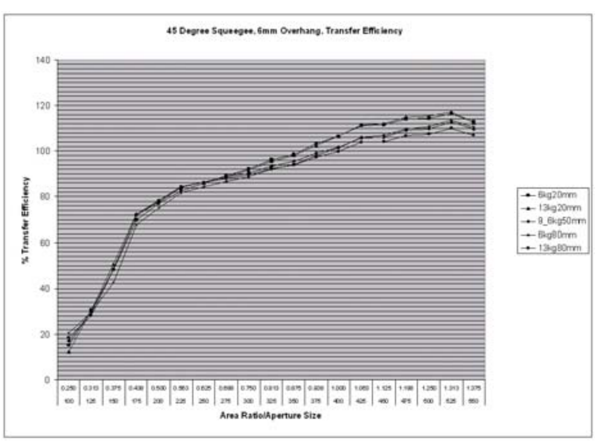
Graph 1 – Transfer Efficiency curve (60 deg, 6mm overhang)



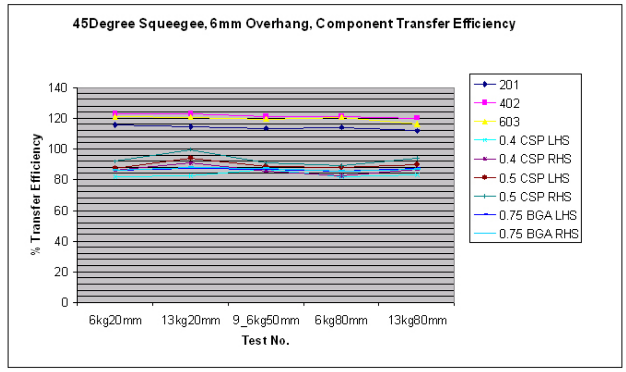
Graph 2– Transfer Efficiency for SMT devices (60 deg, 6mm overhang)



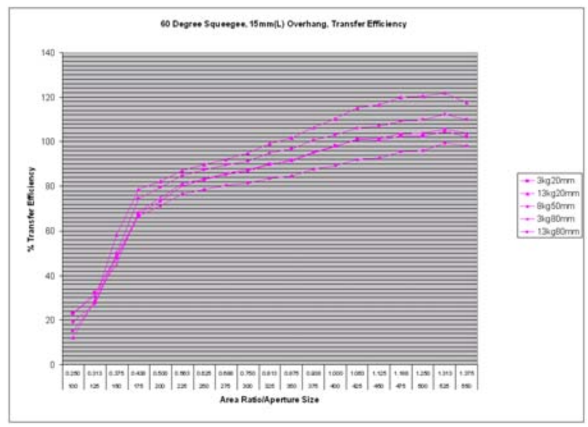
Graph 3 – Transfer Efficiency curve (45 deg, 6mm overhang)



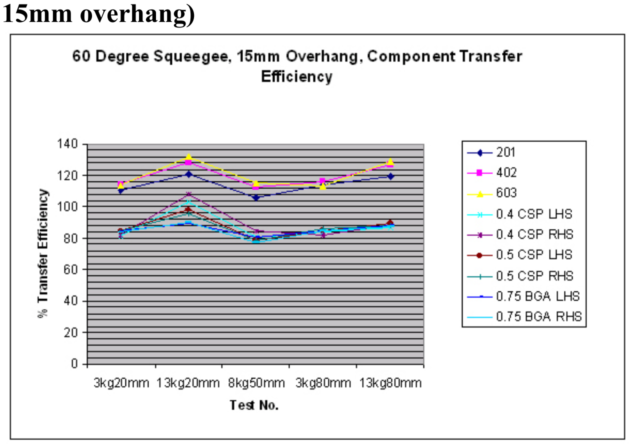
Graph 4– Transfer Efficiency for SMT devices (45 deg, 6mm overhang)



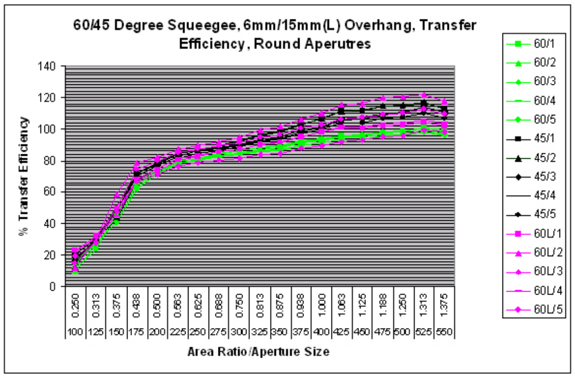
Graph 5 – Transfer Efficiency curve (60 deg, 15mm overhang)



Graph 6– Transfer Efficiency for SMT devices (60 deg, 15mm overhang)



Graph 7 – Transfer Efficiency curve for all runs



Analysis of Results

As can be seen from the results a noticeable correlation between process set-up and distribution of resultant transfer efficiency is observed.

Graph 1 shows the results obtained from the five process settings for the 60 deg 6mm overhang squeegee, we can see that the results for all apertures are very similar independent of the process settings. Thus a high pressure, low speed gives a result that has an average difference of less than 3% delta to a low pressure, high speed. Although this set of data is extremely stable, with respect to challenging the transfer efficiency curves this data set has not affected the 75% cut off point therefore 225 microns diameter apertures are still the smallest feature that can be printed.

Graph 3 presents the results from the 45 deg 6mm overhang assembly. It can be seen that this data set also exhibits a tight distribution independent of the process set-up. Within this data set the transfer efficiency curve has been positively affected with the cut off value of 75% now correlating to 200-micron diameter apertures, this signifies a process that is cable of printing area ratios of 0.5

Graph 5 presents the transfer efficiency results obtained from the 60 deg, 15mm overhang squeegee, this assembly was included to better understand the impact of a flexible blade assembly. As can be seen the impact of process parameters has the ability to significantly adjust the resultant transfer efficiency (calculated as a 15% delta). Therefore the combination of speed and pressure can dramatically influence the transfer efficiency obtained from a process.

It is also noticeable that under high pressure and low speeds the resultant transfer efficiency is significantly improved. Under these process conditions apertures of 175-micron diameters are above the 75% transfer efficiency cut off point, this indicates that this process set-up is capable of printing area ratios of 0.438.

Graph 7 over lays all the array data sets. It can be seen from this graphic the full range of results achieved from the investigation. The three squeegee assemblies are clearly identifiable; the 60 deg 6mm overhang data set can be seen as a tight band of curves. The 45 deg 6mm curves displaying a similar tight spread but with a positive offset and the 60 deg 15mm overhang exhibiting a spread of results that encompass the entire process envelope.

The graphs labelled 2,4 and 6 displays the transfer efficiency results from the SMT devices. We can observe similar trends as those observed from the transfer efficiency array data. Graph 2 displays the SMT results obtained from the 60 deg 6 mm overhang, we can see that independent of the parameter setting the transfer efficiency is within 4%. Again this shows that the data set is not influenced by print speed or pressure. Graph 4 shows the SMT transfer efficiency results from the 45 deg 6mm overhang squeegees, again the results display an increase in transfer efficiency but a very low (calculated as less than 5%) spread.

Graph 6 shows the SMT transfer efficiency results from the 60 deg 15mm overhang squeegees, these results demonstrate a similar trend as the array data, the variation to pressure and speed did significantly affect the process (calculated as 20%).

CONCLUSION

We have seen from the results that by changing the squeegee and print process it is possible to influence the transfer efficiency of the print process. The requirement of today's SMT fabricators is to produce products that have extremely small features along side large features but with one process. This paper has shown that although this is a difficult process requirement there are solutions available.

The short overhang assemblies of both the 60 deg and 45 deg squeegees have proven that they provide a process in which the external influence of process adjustment have little effect on the transfer efficiency results. This situation is probably the most suited towards a, "poka-yoke" manufacturing solution as the process is in effect locked down. From a heterogonous point of view the short overhang assembly most suited is the 45 deg assembly as the results from this squeegee exhibited increased transfer efficiency on area ratios.

The 60 deg 15mm overhang blade is compatible with heterogonous assembly but as it has been discussed in previous sections, the process parameters have a significant impact on the resultant transfer efficiency therefore this solution requires a reasonably level of process knowledge to fully optimise the process.