Determining Area Ratio Rule for Type 4 and Type 5 Solder Paste

Joe Belmonte, Vatsal Shah, Rita Mohanty PhD
Speedline Technologies, Franklin, MA
Tim Jensen, Ron Lasky PhD
Indium Corporation, Utica, NY

Abstract

Stencil design is one of the key factors in determining how well any particular stencil will print solder paste. Today's high volume, 24 hour a day, seven days a week manufacturing operations require stencils that will reliably and repeatably print solder paste with minimum stencil wiping required.

The area ratio of the stencil apertures is a primary factor in determining how well any particular stencil will print solder paste. Area ratio is the ratio between the area of the stencil aperture and the area of the aperture walls. Until the last few years the only stencil design calculation that was required was aspect ratio. Aspect ratio is the ratio between the width of the aperture and the thickness of the stencil. Aspect ratio was an excellent predictor of how well a stencil would print solder paste.

However, as smaller and smaller component packages have been introduced into electronic products, smaller stencil apertures have been required. The smaller apertures now have opening areas that are very close to if not smaller than the area of the walls of that aperture. Since there are two competing forces for the solder paste, the force attempting to hold the solder paste in the aperture and the force attempting to pull the solder paste out of the aperture, area ratio is now the key factor in determining how well a stencil will print solder paste. The higher the area ratio the higher transfer efficiency of the solder paste. Transfer efficiency is a calculation of the percentage of solder paste printed into the aperture that is printed onto the printed circuit board pad.)

The area ratio rule identifies an area ratio of 0.66 or higher to produce a stencil that will print solder paste well. Many experiments by Speedline Technologies and others have confirmed the minimum 0.66-area ratio requirement. The 0.66 area ratio requirement experiments were conducted using solder paste with type 3 solder powder size. This paper will discuss experiments that have been conducted by Speedline Technologies and Indium Corporation to determine if a lower area ratio can be used when using solder paste with type 4 and type 5-powder size. If a lower area ratio can be identified for solder paste using type 4 and/or type 5 solder paste, electronic manufacturing operations will have another option in designing stencil for products using miniature components such as 0201 and 01005 resistors and capacitors.

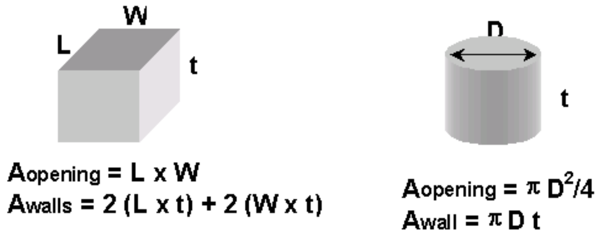
Introduction

With the advent of miniature components such as the 01005 (10 x 5 mil or 0.25 x 0.125 mm) passives, designing a stencil that will reliably print the small volumes of solder paste required for these miniature components while still providing the solder paste volume required for the larger components on the same product is becoming a challenge.

We hear so much about "01005s" that we can become jaded as to how small they really are. Their width (5 mils) is only slightly larger than the thickness of a human hair and their length about the thickness of a sheet of resume paper!

Electronic manufacturers are often asking if a solder paste printing process can be developed for miniature components such as 01005's or even printing solder paste on silicon wafers to create the bumps for flip chips., Clearly the answer is yes. Developing a printing process for one size miniature feature is not easy but possible since only one stencil aperture size, stencil thickness, and subsequently solder paste volume is required. In the case of printing solder paste on silicon wafer for flip chip applications that is the exact process required. All the bumps on the flip chip have to be the same exact size. To create a stencil that will print the miniature solder paste volumes for flip chip bumps we can use a thin stencil (as thin as .002" or .05mm) to obtain "stencil aperture area ratios" that will allow a very high percentage of the solder paste to release from the stencil.

The area ratio of the stencil apertures is the primary factor in determining how well any particular stencil will print. Area ratio is defined as the ratio between the area of the stencil aperture and the area of the aperture walls as shown in figure 1. The higher the area ratio the higher transfer efficiency of the solder paste. Transfer efficiency is a calculation of the percentage of solder paste printed into the aperture that is transferred onto the PCB pad. Figure 2 shows the relationship between transfer efficiency, area ratio and standard deviation. This figure shows that as the area ratio increases, the transfer efficiency increases and the standard deviation decreases.



Pitch **BGA**	Pad	Aperture(Dia)	Thickness	Area Ratio
60	32	30	6 – 8	1.25 – 0.94
50	25	22	6 – 8	0.92 – 0.69
32	18	16	5 – 6	0.80 – 0.66
25	15	13	4 – 5	0.81 – 0.65
20	12	10	3 – 4	0.83 – 0.63

Figure 1 - Area Ratio calculations

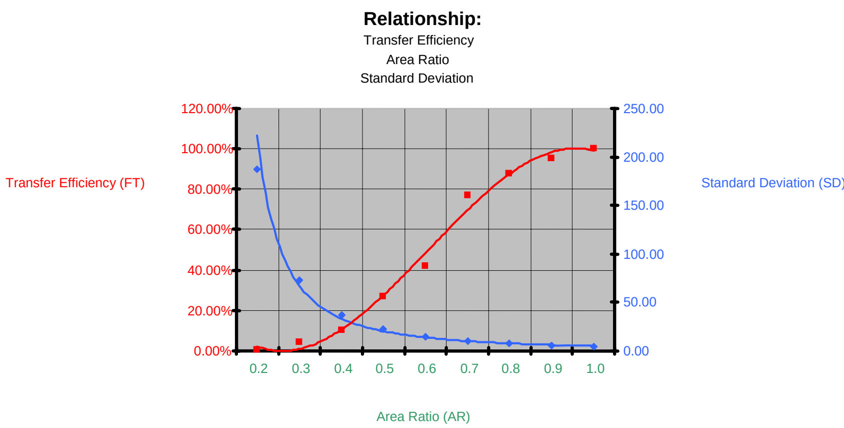


Figure 2 - Relationship between Transfer Efficiency, Area Ratio and Standard Deviation

However in the case of electronic products, we have large variety of component sizes and subsequently solder paste volume requirements on every board. We obviously cannot design a stencil to optimize the printing of the miniature components if it will not provide the required solder paste volumes for the larger components. To design the optimum-printing stencil we must understand the solder paste volume requirements for all of the components used on that particular product. With products that include both miniature components and large components requiring much larger solder paste volumes, conventional stencil design and fabrication technology may be at its limit.

Dual thickness or stepped stencils may be capable of providing the correct solder paste volume in the correct area depending on the printed circuit board design and component variety on that particular product. Dual thickness or stepped stencils have been used almost from the inception of surface mount technology (SMT). They are a solution to solder paste volume variety in many cases but they have their limitations and other inherent problems.

Another possible solution is the dual stencil printing process. This process incorporates the use of two stencils and two stencil printing machines. The first stencil will be thin to print the solder paste volumes of the miniature components while the second stencil will be of the thickness required to provide sufficient solder paste volume for the larger components. Figure 3, depicts such a process.. The dual stencil printing process has been in use for many years by customers employing the “Pin in Paste” or “Intrusive Reflow” Process where often large solder paste volumes are required to create an acceptable solder joint for the through hole components

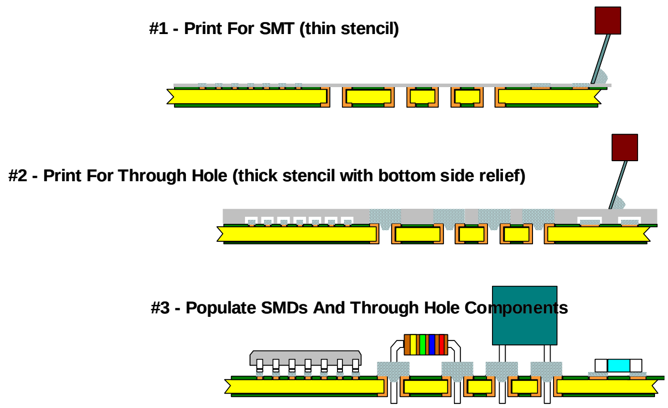


Figure 3 - Dual Stencil Printing Process

A third alternative to stencil design that will satisfy both miniature solder paste volumes and larger solder paste volume requirements and the subject of our work is to determine if a lower area ratio can be used if the solder paste printing process uses solder paste with type 4 or type 5 powder. Table 1 shows mesh size for separation of solder paste powder. The higher the powder size designation (number) the smaller the individual metal balls in the metal powder. For example: A type 4 solder powder ball will pass through a .0017 inch square mesh but will not pass through a .0015 inch square mesh.

The hypothesis behind this work is; the use of solder paste with smaller metal powder may allow us to use lower area ratios and still achieve acceptable solder paste release from the stencil. Based on the above hypothesis, this work focuses on understanding the stencil printing process through experimentation and technical approaches for miniature components, such as 0201 and 01005. In so doing, this work compares the stencil design elements, such as aperture shapes, and sizes that play a major role in the print performance of the small apertures by affecting the area ratio. Designed experiments are performed to determine the effect of area ratio and paste powder size on the paste transfer ratio for miniature components. This study also compares two major stencil manufacturing techniques (laser cutting and electroforming) for small aperture printing.

Table 1. Mesh Sizes for the Separation of Solder Paste Powder

ASTM Mesh		Opening Size		
Designation		**(µm)**		**(in)**
200		**74**		**0.0027**
250		**58**		**0.0023**
325 (Type 3)		**44**		**0.0017**
400 (Type 4)		**37**		**0.0015**
500 (Type 5)		**30**		**0.0012**
625 (Type 6)		**20**		**0.00078**

Stencil Design

Stencil design is a very important factor affecting the volume of paste deposited. Print volume and consistency for miniature components could be maximized by carefully choosing the stencil design parameters. To determine the best aperture shape factor (hence, area ratio) the stencil design consisted of square, circular and two different shaped "home plate" designs as shown in Figure 4. The stencil had 5 different locations for the 01005 passives with both 0 degree and 90 degree orientations to the direction of printing. Each location had 200 components. These locations were divided with the 4 different aperture shapes, hence each shape have 50 components at each location. The resulting stencil test vehicle is shown in Figure 5. Larger, 0201, passives were also considered as a reference.

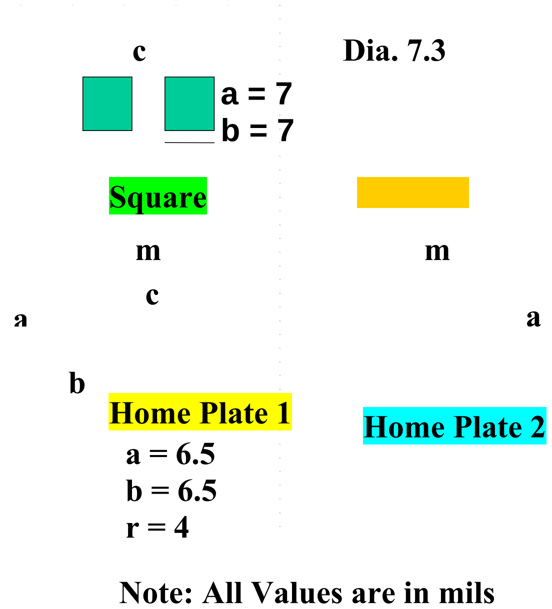


Figure 4 - The different stencil design tested in the experiment

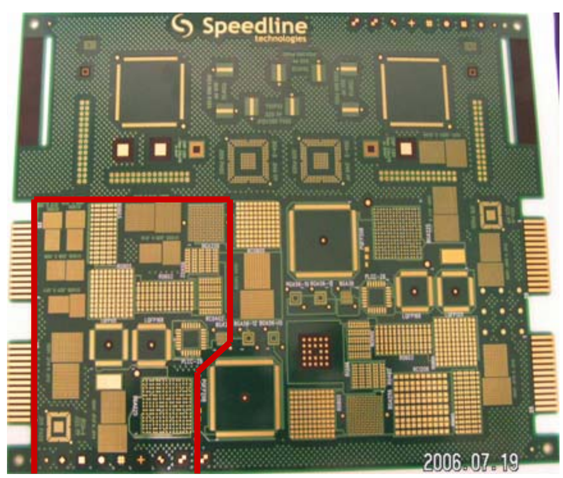


Figure 5 - The test vehicle for the DOE. The marked area represents the print inspection location

Experimental Design
A randomized, full factorial design with 3 factors, at 2 levels, was performed to develop optimized printing experiment. The factors used for the experiment are as follows:

- Paste Type (PT) – Type 4 (T4) and Type 5 (T5)
- Stencil Thickness (SThk) – 3 mil (3) and 4 mil (4)
- Stencil Technology (STech) – Laser cut (L) and E-Fab (E)

The standard order design table is shown in table 2. To achieve optimum printing for each stencil thickness, the print parameters were changed for the different stencil types (3 mil and 4 mil), however, they were kept constant for the stencil technology (Laser cut and electroformed). For example, the print parameters for 3 mil laser cut stencil was same as 3 mil E-Fab stencil but different than 4 mil laser cut stencil. The print parameters used for different stencil thickness is shown in table 3. The response considered for this work was the transfer ratio (ratio between theoretical volume of the aperture to the actual volume of the solder paste deposited on the pad). The transfer ratios were measured using an Agilent SP50 laser canning system.

A “repeat” noise strategy was adopted for this experiment to address run-to-run variations. Four boards per treatment were printed; two boards with ‘front to rear’ squeegee stroke and two boards with ‘rear to front’ squeegee stroke. Again, this strategy was adopted to minimize noise effects due to squeegee stroke direction on the print quality. JMP statistical software was used to analyze DOE result.

Table 2. Standard Order Design Table

Treatment	RunOrder	Pattern	PT	SThk	Stech
1	1	−−+	T4	3	E
3	2	+−+	T5	3	E
5	3	−−−	T4	3	L
6	4	+−−	T5	3	L
2	5	−++	T4	4	E
4	6	+++	T5	4	E
8	7	−+−	T4	4	L
7	8	++−	T5	4	L

Table 3. Print parameters used for 3 mil and 4 mil thick stencils

	3 mil		4 mil
Print Speed (ips)	2.0		1.5
Print Pressure (lbs)	15		15
Separation Speed (ips)	0.1		0.1

Gage Repeatability Experiment

To ensure minimum experimental variability, a comprehensive gage repeatability studies was performed to determine the precision of the Agilent SP50 in measuring the volume of the printed solder paste. An average precision to tolerance ratio (P/T = 6 * St. Dev/(USL-LSL) of 22.3% was achieved for the Agilent SP50. An upper spec limit (USL) of 150% and a lower spec limit of 50% of the nominal aperture were used for this evaluation. This was acceptable, as typically a P/T ratio of <30% is considered acceptable for challenging state of the art work such as these.

Printing Experiment & Results

The printing experiment was carried out as fully randomized experiment as shown in table 3. The fixed factors used in this experiments are as follow:

Fixed Factors:

1. Printer — Speedline Accela Printer
2. Squeegee — Speedline Metal Squeegee
3. Squeegee size — 12”
4. Test board — As shown in fig. 5
5. Volume inspection tool — Agilent SP50
6. Stencil cleaning method — After each print with solvent

The highlighted area shown in Figure 5 was the only area inspected and used for the analysis. This area was considered for the analysis because it covers all the locations of the 01005 components, 0201's and also some larger components. However, for this experiment the main focus was given to 01005 and 0201 passive components. Hence, the data was segregated for 01005 and 0201 components.

The detail analysis of the DOE (using JMP) is too large to be included here in detail. Hence, we will summarize the findings by presenting the main effect plot, interaction plot, normal probability plot, and the Pareto plot in respect to the response variable "transfer ratio" or as it is known as "stencil printed release value". As it was mentioned earlier, release efficiency is defined as the volume of the actual paste deposit divided by the volume of the aperture. Figure 6 and 7 represent the main effect and the interaction plots respectively, as obtained from JMP analysis. As it can be seen from Figure 6, stencil thickness and paste type have statistically significant effects while stencil technologies show no statistical significance. In addition, Figure 7 shows there is a significant factor interaction between paste type and stencil thickness. Figure 8 and 9, which shows the Normal probability and Pareto plots support the above findings.

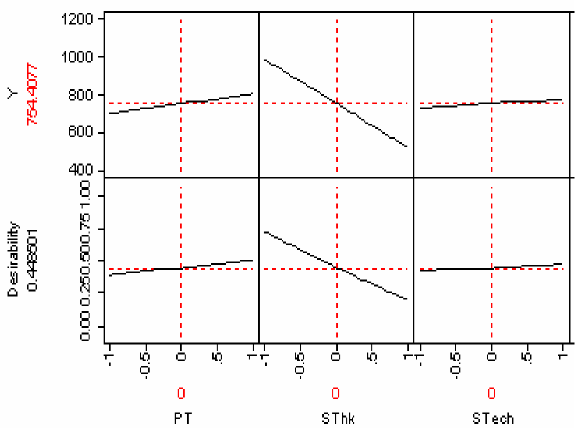


Figure 6 - Main effect plot for 01005 components

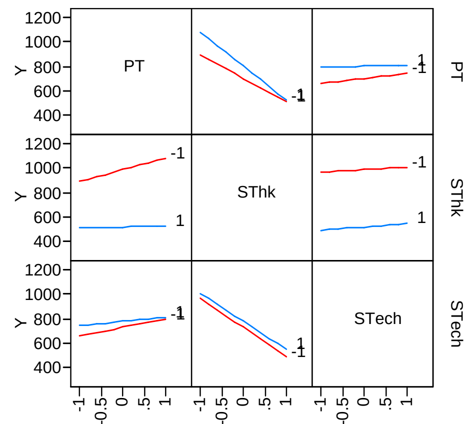


Figure 7 - Interaction Plot for 01005

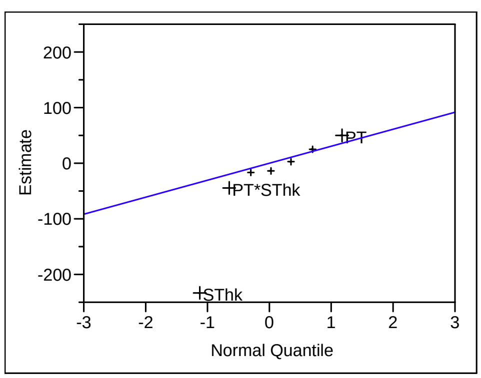


Figure 8 - Normal Probability Plot for 01005

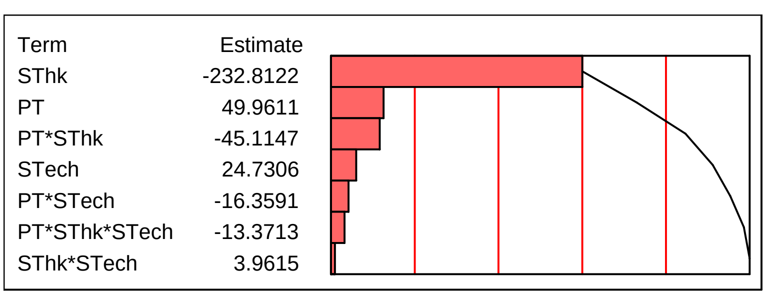


Figure 9 - Pareto plot for 01005

In addition to the JMP analysis, the result was plotted using simple tools such as Excel to understand the effect of area ratio on transfer efficiency for paste type and stencil technologies. Figures 10-11 shows the relationship between transfer efficiency and area ratio as a function of solder paste type for both 0201 and 01005 components. . As the Figure 10 indicates since the area ratios were high for the 0201 components the transfer efficiency for both the Type 4 and Type 5 solder paste was generally between 80% and 100%. In the case of the 01005 components where the area ratio was much lower than the 0201 components the transfer efficiency for the Type 5 solder paste was slightly better then the transfer efficiency of the Type 4 solder paste (figure 11).
However the minimum area ratio for both the type 4 and Type 5 solder paste that would provide transfer efficiency above 90% was 0.58.

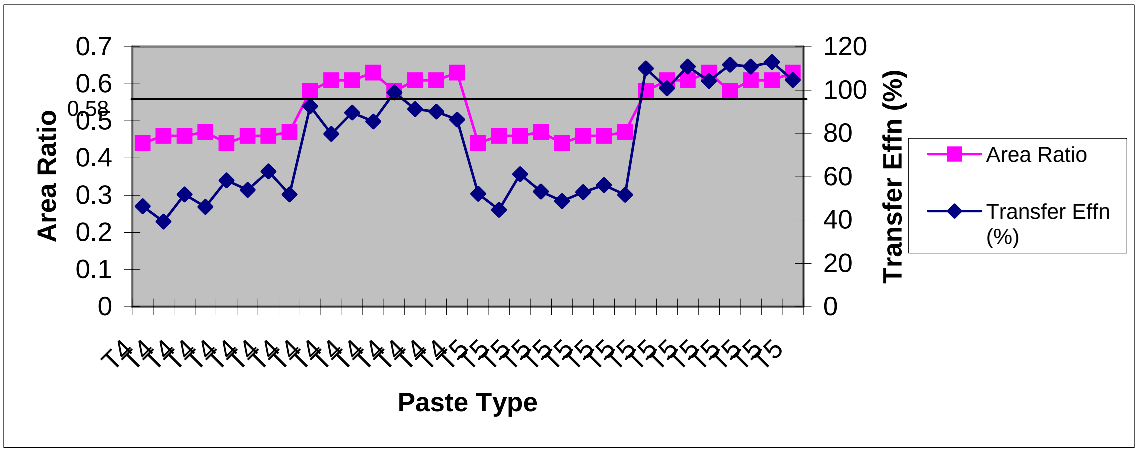


Figure 10 - 0201 – Paste Type versus Transfer Efficiency for Type 4 and Type 5 Solder Paste

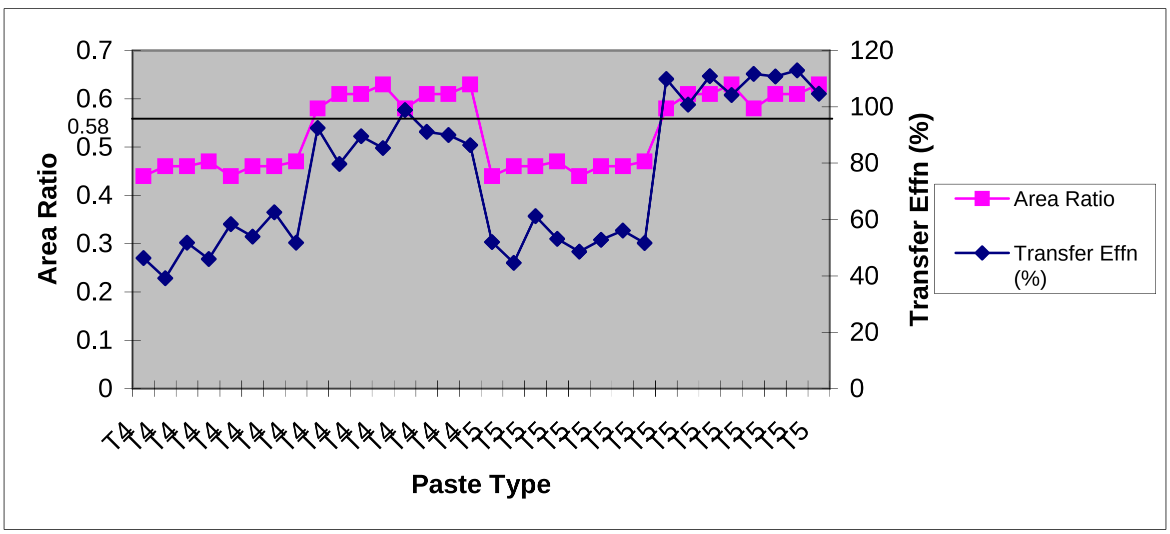


Figure 11 - 01005 – Paste Type versus Transfer Efficiency for Type 4 and Type 5 Solder Paste

The relationship between area ratio and transfer efficiency as a function of stencil technologies is shown in Figure 12-13. As it can be seen from these figures, the transfer efficiencies for both stencil technologies were virtually the same regardless of the component size.

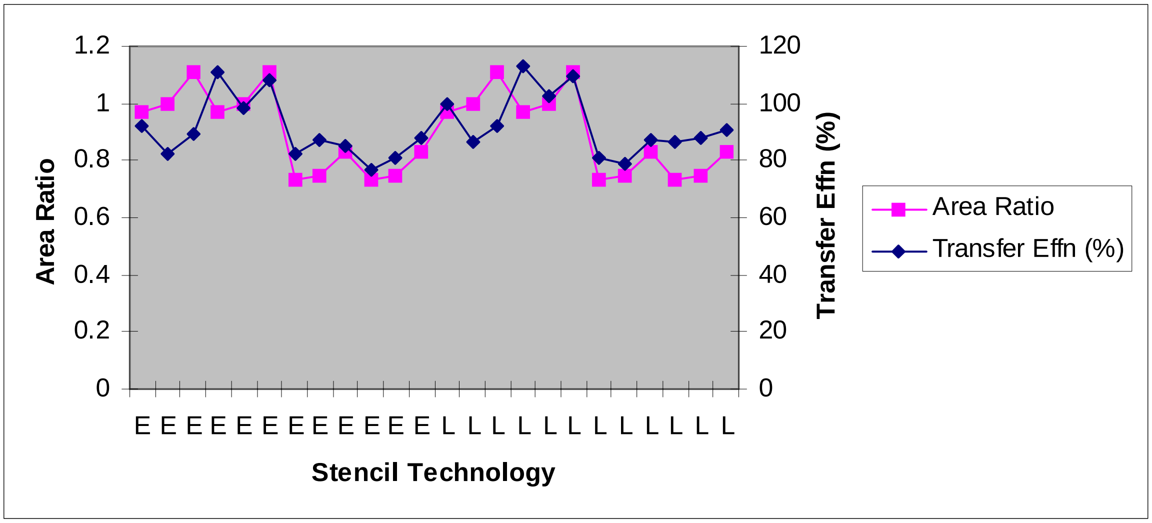


Figure 12 - 0201 – Stencil Technology versus Transfer Efficiency

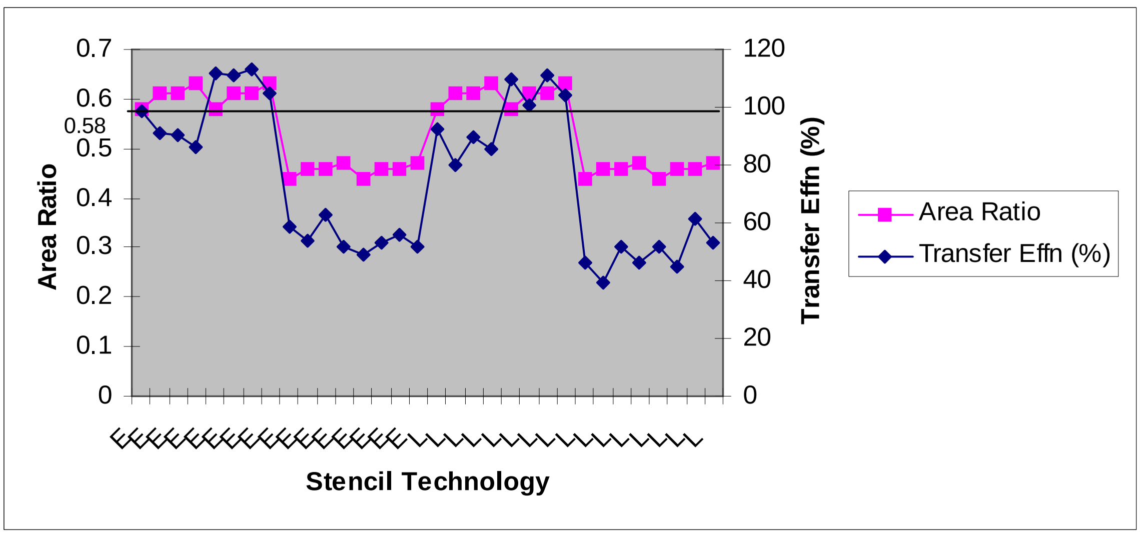


Figure 13 - 01005 – Stencil Technology versus Transfer Efficiency

Conclusions

The above findings are just the beginning of a lengthy process in the development activity for miniature component assembly process. The preliminary experimental data indicates that the use of type 4 or type 5 solder paste will only marginally reduce the stencil aperture area ratio requirement. The current acceptable area ratio with type 3 solder paste is 0.66 to produce a stencil that will provide high solder paste transfer efficiency in a high volume manufacturing operation.

Our experiments indicate that the use of Type 4 and Type 5 solder paste will reduce the required area ratio to 0.58. Certainly this area ratio reduction using type 4 or type 5 solder paste may be useful in some stencil designs. However the additional costs of the type 4 or type 5 solder paste to achieve this reduced area ratio stencil design will have to be evaluated against the benefits.

This marginal advantage in area ratio requirement can be achieved using several other approaches such as slightly increasing the size of the stencil aperture or reducing the stencil thickness.

In the case of stencil technology versus solder paste transfer efficiency our data indicates that there is a marginal advantage in electroformed stencil's transfer efficiency in comparison to the laser cut stencil's transfer efficiency.