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An Investigation into Printing Miniaturised Devices for the Automotive and Industrial Manufacturing Sectors

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Abstract

The electronics market is divided into many segments each having its own challenges; but one theme that connects the electronics community together is a need for higher yield with lower costs. Or simply the manufacturing process needs to become ever efficient.

Within the consumer sector miniaturisation is the watch-word and all eyes are on the 0.3mm CSP and metric 03015 components. Both of these devices will pose serious heterogeneous questions for High Volume Manufactures, especially if the current stencil thickness of 100 microns is required for standard technology.

The Automotive and Industrial electronics sector which are not normally brushed with the challenges of miniaturisation have started to become connected to this demanding world. The reason for this is not through the consumer driver of increased functionality, but one of pure supply and demand economics. The demands for large foot print devices are decreasing therefore the unit price and scarcity is increasing; whereas smaller foot print devices are increasing in demand and availability and as a consequence the unit price and scarcity is reducing. For this reason Automotive and Industrial electronic manufacturers are now faced with implementing fine pitch devices due to availability and cost.

The Automotive and Industrial electronics sector have several large obstructions when engaging with miniaturised devices: - the addition of large devices on the same product, harsh environmental concerns and safety/reliability demands. All of these issues require a highly capable heterogeneous solder paste printing process.

This paper investigates a solution the Automotive and Industrial electronics community can implement to ensure a high yield print process in which fine pitch footprint devices can be printed alongside traditional larger footprint devices.

Introduction

Within the Automotive sector a transition from mechanical systems to electronic assemblies continues to transform the automotive landscape[1]. Automotive electronics currently represents one of the higher semiconductor growth segments with a CAGR of 6.8% (2012-2017)[2] According to a leading Semicon supplier, todays electronics system account for more than one-third of the total cost of a new vehicle. The main drivers of this growth are safety, connectivity, efficiency and comfort. In addition to today's growth within the automotive sector, hybrid and electric vehicles are forecasted to integrate significant electronic content in automobiles[3].

Due to component availability and cost the Automotive and Industrial sectors are now faced with the challenge of implementing 0.4mm CSP devices into the manufacturing process. The printing techniques for the 0.4mm CSP device have been covered in many past technical papers. However these investigations and recommendations have been focused on the three C's (Consumer, Communication and Computing Sectors) which benefit from the use of 100 um stencil architectures. The Automotive and Industrial sector tend to deliver products which contain larger footprint devices therefore requiring greater volumes of solder. To achieve the increased solder volume the Automotive and Industrial sectors tend to use 127um stencil foils.

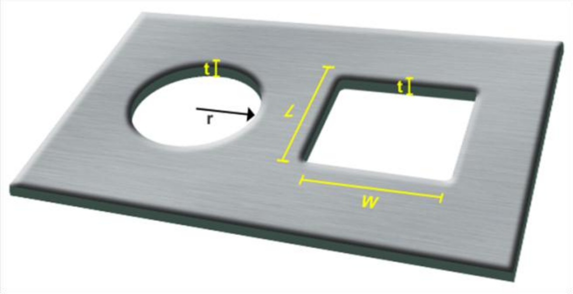
The dilemma that a slightly thicker stencil presents is one of Area Ratio. The Area ratio calculation in its simplest form is a ratio between the Aperture opening area and Aperture wall surface. Figure 1 illustrates the calculation for both circles and squares.

The factors that make up an aperture - Stencil thickness, aperture diameter, width and length all influence the resultant Area Ratio. If we take two examples we can observe the effects; a stencil of 100 microns and a circular aperture of 240micron would result in an Area Ratio of 0.6; by changing the diameter to 20um the Area ratio becomes 0.5. Needless to say the act of calculating Area Ratio simply allows the Engineer to quickly register an apertures dimension and produce an Area Ratio integer. The significance of this value is correlated to the transfer efficiency or "how much solder paste is expected to release from the aperture".

To aid the process engineer, IPC have produced a stencil guideline, IPC 7525B[4], which recommends that aperture area ratios should be kept within a range of 0.5 -0.66 (material set dependant) to ensure a minimum 70-75% transfer efficiency and therefore an acceptable stencil printing process.

Figure 2 illustrates the "Historical" transfer efficiency curves which have been the accepted point of reference, as can be seen the transfer efficiency of 70% falls off after Area Ratios of 0.66.

During recent years the solder paste, stencil and capital equipment suppliers have invested resources into extending the process window thus allowing smaller Area Ratio apertures to achieve the required minimum 70-75% transfer efficiency. These incremental developments are illustrated within Figure 2 (today curve); with careful selection of material sets and process setup the smallest Area Ratio which can achieve 70-75% transfer efficiency has been extended to 0.5.



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

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

Figure 1 - Area Ratio Calculation

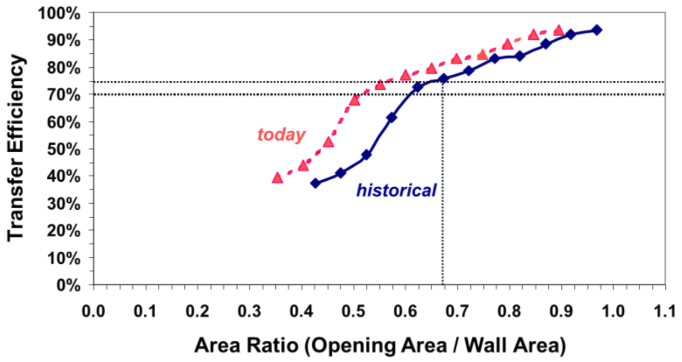


Figure 2 - Transfer Efficiency curves (Historical and Today)

Dilemma

To illustrate the dilemma the Automotive and Industrial sector are facing the aperture range associated with the 0.4mm CSP device and calculated Area Ratios for both 100um and 127um stencil foil thicknesses are shown in Table 1.

Table 1 - Area Ratio values

Aperture Size	100um Stencil Thickness	127um Stencil Thickness
200um aperture Diameter	0.50	0.39
225um aperture Diameter	0.56	0.44

Although today's leading edge print process can achieve Area Ratios of 0.5, it is clear to see the 0.4mm CSP aperture range when combined with 127um stencil thicknesses falls outside today's capability.

Proposal

Within the three C's sector, innovative solutions such as Nano coatings [5-6], stencil manufacturing techniques, stencil finish [7-8] and ultrasonic squeegees [9-10] have been investigated to break through the 0.5 Area Ratio barrier. From these documented innovations the ultrasonic squeegee has shown the most capability therefore this device will be used throughout this investigation to establish if apertures ranging from 200um to 225um with associated Area Ratios of 0.39 to 0.44 can be printed.

Test Vehicle

The test vehicle used through the investigation is shown in Figure 3. This substrate contains standard device layouts which follow IPC recommendations. The outer dimensions are 150mm x 150mm with a thickness of 1mm. The substrate is fabricated from FR4 and all pads are none solder mask defined (NSMD).

The two 0.4mm CSP were used to measure the success of the investigation. The land dimensions follow the IPC recommendations. The aperture designs used for the investigation are shown in Figure 4. The associated Area Ratios are calculated assuming the stencil thickness is 127um, as can be seen the two designs are way below the currently 0.5 limit.

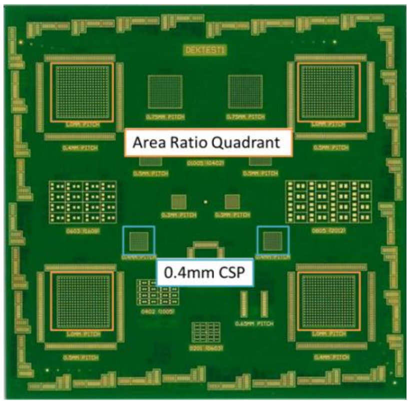


Figure 3 - Test Vehicle

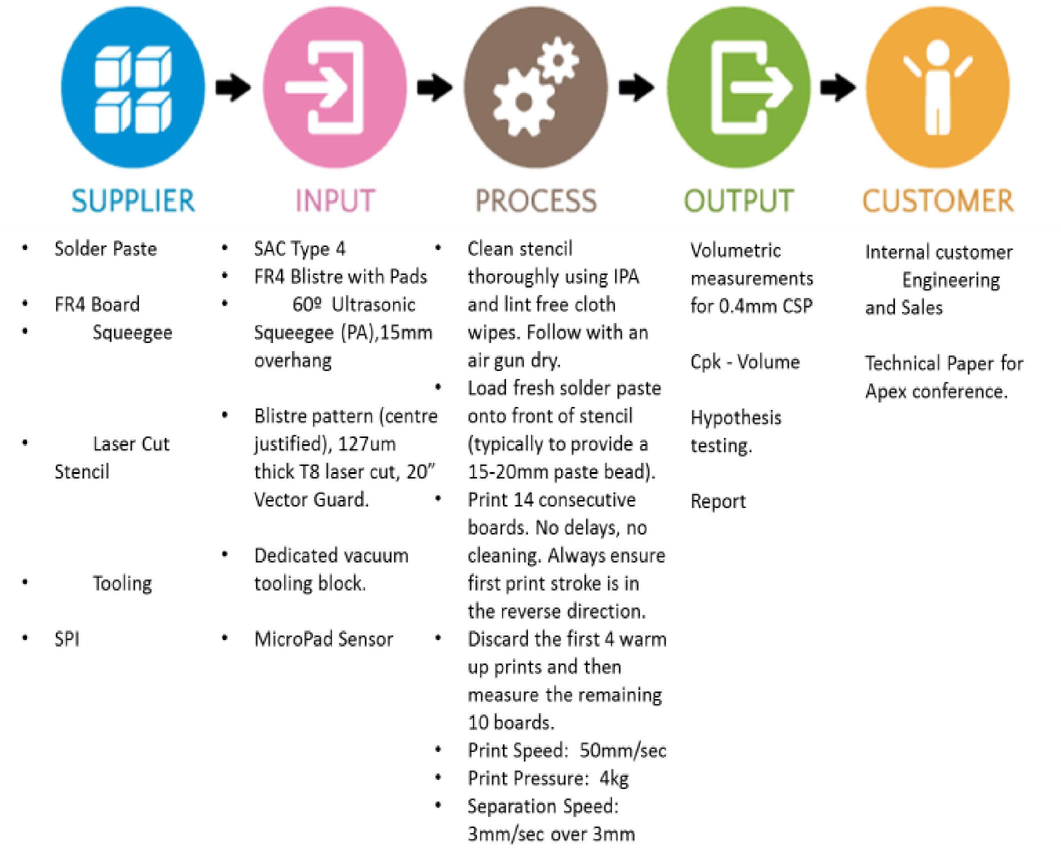
Aperture: 0.200mm circle
Area Ratio: 0.394

Aperture: 0.225mm circle
Area Ratio: 0.443

Figure 4- Aperture designs

SIPOC

Figure 5 shows the SIPOC used throughout this investigation



SUPPLIER	INPUT	PROCESS	OUTPUT	CUSTOMER
• Solder Paste	• SAC Type 4	• Clean stencil thoroughly using IPA and lint free cloth wipes. Follow with an air gun dry. • Load fresh solder paste onto front of stencil (typically to provide a 15-20mm paste bead). • Print 14 consecutive boards. No delays, no cleaning. Always ensure first print stroke is in the reverse direction. • Discard the first 4 warm up prints and then measure the remaining 10 boards. • Print Speed: 50mm/sec • Print Pressure: 4kg • Separation Speed: 3mm/sec over 3mm	Volumetric measurements for 0.4mm CSP Cpk - Volume Hypothesis testing. Report	Internal customer Engineering and Sales Technical Paper for Apex conference.
• FR4 Board	• FR4 Blistre with Pads			
• Squeegee	• 60º Ultrasonic Squeegee (PA),15mm overhang			
• Laser Cut Stencil	• Blistre pattern (centre justified), 127um thick T8 laser cut, 20" Vector Guard.			
• Tooling	• Dedicated vacuum tooling block.			
• SPI	• MicroPad Sensor			

Figure 5 - SIPOC

Measurement tool

The measurement tool used through the investigation was a production Solder Paste Inspection (SPI) machine with a micro-pad sensor. The measurement tool was setup to record solder paste height, area and volume for each printed deposit. The following section outlines the Gage R&R performed on the SPI tool to ensure that the precision errors were acceptable.

Gage R&R

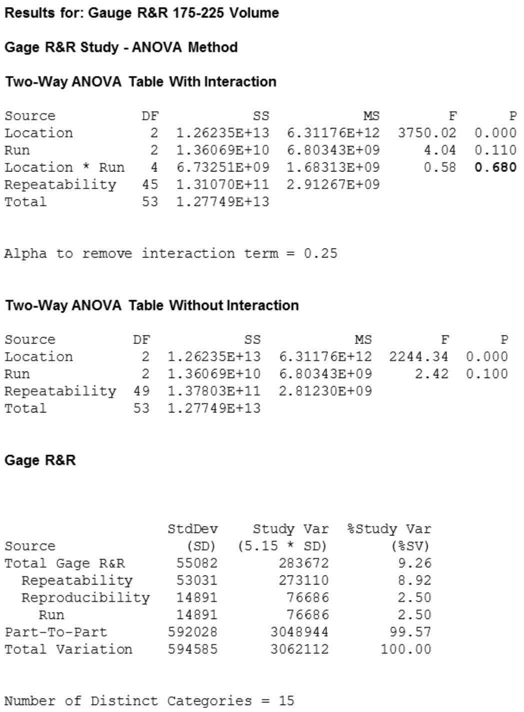
The Gage R&R test program comprised of a printed substrate which was allowed to dry to ensure stability. This substrate was used for all Gage R&R trials. The Gage R&R test plan is outlined in table 2, each trail included six inspection cycles. Aperture sizes of 175,200 and 225um were measured to understand the precision of the SPI machine. The design of the Gage R&R provides the study with 36 parts for each run which generates 108 data points. The results of the Gage R&R are shown in Table 3 and Figure 6.

Table 2 - Gage Test Plan

Run Number	Observation
Run 1	Straight Run
Run 2	Machine left for 2 hours before run
Run 3	Machine power cycled and reset before run

The Anova table shown in Table 3 and Figure 6 shows the P value for "*Run*" is greater than 0.05 (alpha level 95%) indicating that this factor has no effect on the Gage R&R. Therefore the only source that has an effect on the Gage R&R study is location. The % study variation figures for total Gage R&R, repeatability and reproducibility were below 10%, indicating the measurement tool has an acceptability rating of "Excellent"; therefore this tool was used with confidence throughout the investigation.

Table 3 - Gage R&R ANOVA



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Results for: Gauge R&R 175-225 Volume

Gage R&R Study - ANOVA Method

Two-Way ANOVA  Table With Interaction

Source          DF          SS          MS        F      P
Location         2  1.26235E+13  6.31176E+12  3750.02  0.000
Run              2  1.36069E+10  6.80343E+09     4.04  0.110
Location * Run   4  6.73251E+09  1.68313E+09     0.58  0.680
Repeatability   45  1.31070E+11  2.91267E+09
Total           53  1.27749E+13


Alpha to remove interaction term = 0.25


Two-Way ANOVA  Table Without Interaction

Source         DF          SS          MS        F      P
Location        2  1.26235E+13  6.31176E+12  2244.34  0.000
Run             2  1.36069E+10  6.80343E+09     2.42  0.100
Repeatability  49  1.37803E+11  2.81230E+09
Total          53  1.27749E+13


Gage R&R


                   StdDev    Study Var  %Study Var
Source               (SD)  (5.15 * SD)       (%SV)
Total Gage R&R      55082       283672        9.26
  Repeatability     53031       273110        8.92
  Reproducibility   14891        76686        2.50
    Run             14891        76686        2.50
Part-To-Part       592028      3048944       99.57
Total Variation    594585      3062112      100.00


Number of Distinct Categories = 15
```

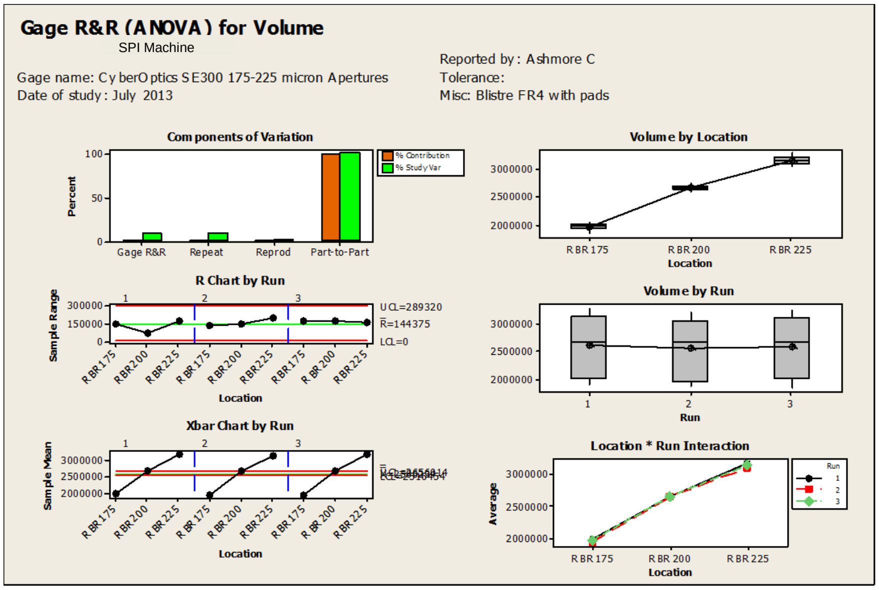


Figure 6 - Gage R&R ANOVA

Baseline Results

Although the Area Ratio calculations and historical references predict failure for the 200 and 225um aperture designs, the next stage is to test and benchmark the predicted output. The setups for these tests are outlined in the SIPOC.

The process capability for this benchmarking activity and subsequent test will be measured against transfer efficiency (TE). Transfer Efficiency is the ratio between the measured volume and the theoretical volume. Note due to legacy the results are reported in a decimalised percentage (i.e. 0.5 = 50%). A Cp and Cpk index of 1.33 or greater is required to verify a stable process output.

Figure 7 and 8 shows the process output achieved from the 200um aperture design (Area Ratio = 0.394) with a standard print process setup. As can be seen the 200um apertures process capability analysis indicates the process has a relatively low standard deviation (13%) but a mean volume of only 36%, producing a Cp of 1.1 and a Cpk of -0.67; indicating that the process is not capable.

Figure 9 and 10 show the process output achieved from the 225um aperture design (Area Ratio = 0.443) with a standard print process setup. As can be seen the 225um aperture process capability analysis indicates the process has a relatively high standard deviation (31%) with a mean volume of only 59%, producing a Cp of 0.45 and a Cpk of -0.01; indicating that the process is not capable.

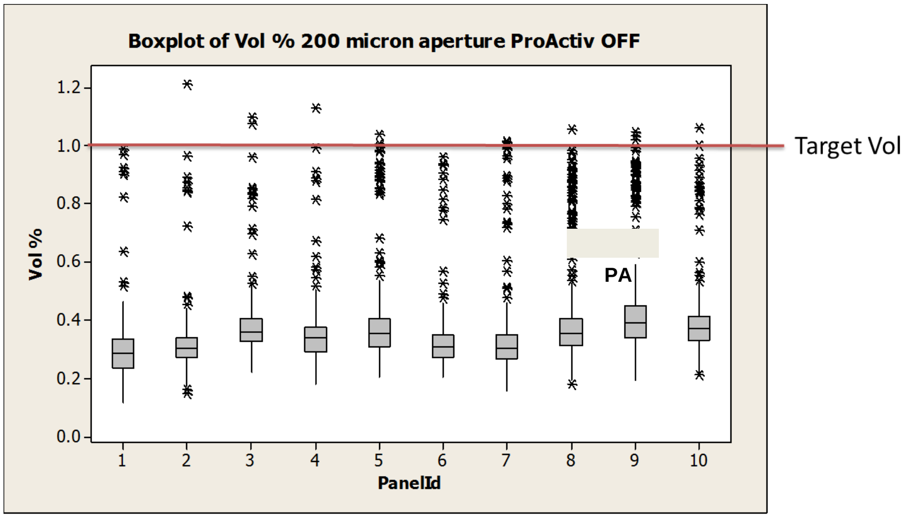
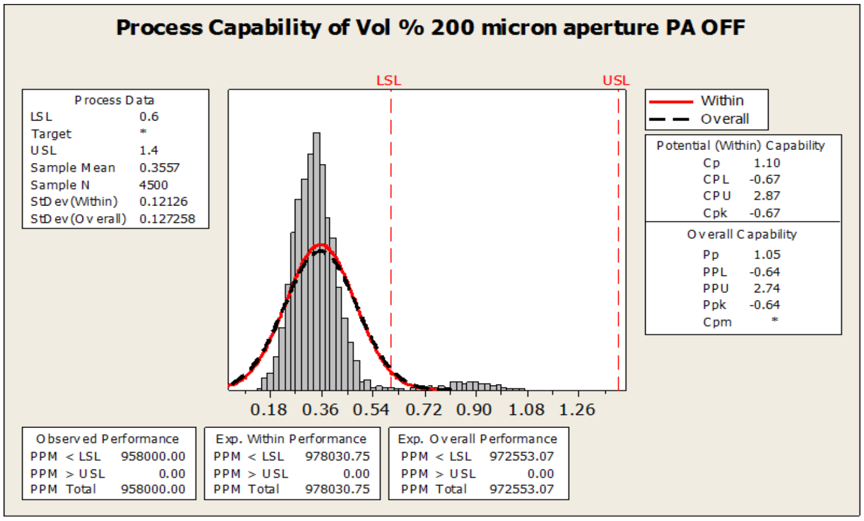


Figure 7 - Boxplot 200um Aperture Diameter Standard Process - Ultrasonic Off



Process Data
LSL 0.6
Target *
USL 1.4
Sample Mean 0.3557
Sample N 4500
StDev(Within) 0.12126
StDev(Overall) 0.127258

Potential (Within) Capability
Cp 1.10
CPL -0.67
CPU 2.87
Cpk -0.67

Overall Capability
Pp 1.05
PPL -0.64
PPU 2.74
Ppk -0.64
Cpm *

Observed Performance
PPM < LSL 958000.00
PPM > USL 0.00
PPM Total 958000.00

Exp. Within Performance
PPM < LSL 978030.75
PPM > USL 0.00
PPM Total 978030.75

Exp. Overall Performance
PPM < LSL 972553.07
PPM > USL 0.00
PPM Total 972553.07

Figure 8 - Process Capability 200um Aperture Diameter Standard Process- Ultrasonic Off

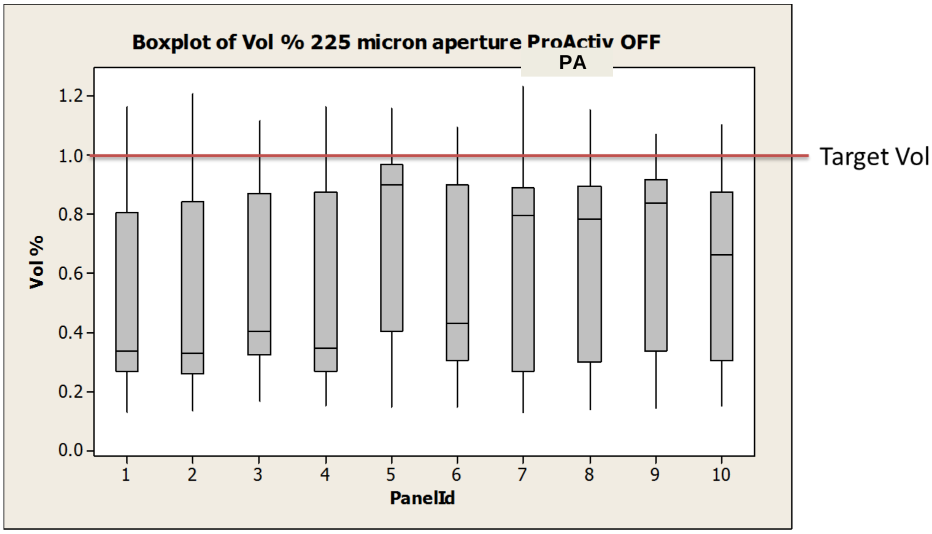


Figure 9 - Boxplot 225um Aperture Diameter Standard Process- Ultrasonic Off

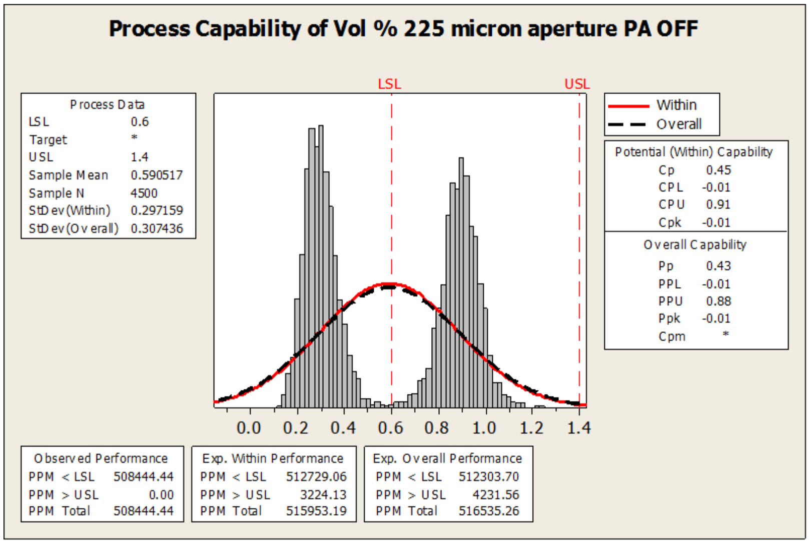


Figure 10 - Process Capability 225um Aperture Diameter Standard Process- Ultrasonic Off

Benchmark conclusions

The results from the baseline show that both aperture sizes deliver a process which falls outside the target Cp/Cpk. The 200 micron aperture produces an output which has a low standard deviation (13%) but only manages a mean output of 36% volume. The 225 shows a tendency to improve the volumetric output but the histogram shows that a bimodal output is present indicating poor process stability.

Both experiments have failed to produce a satisfactory process and have therefore matched the predicted outcome of the Area Ratio model.

Design of Experiment (DoE)

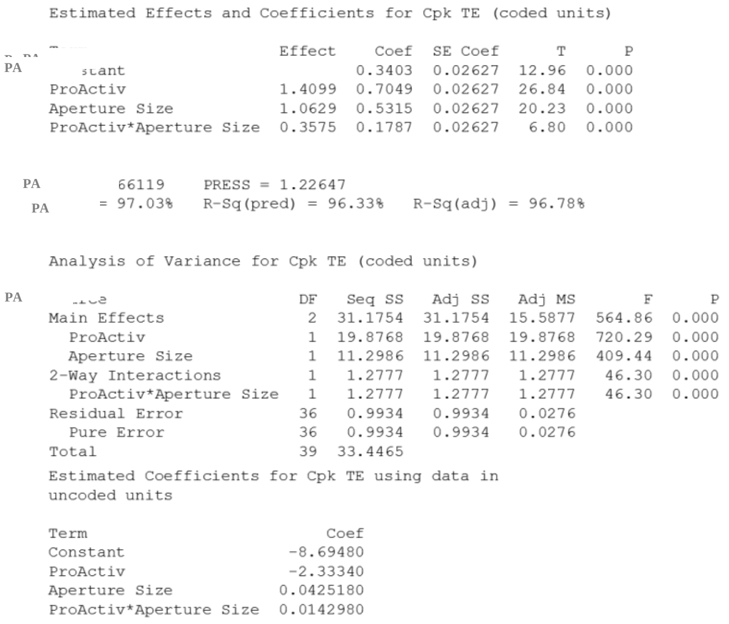
As concluded from the benchmark analysis, the aperture range which is required to print 0.4mm CSP devices is not capable with a standard process setup. A DoE technique will be employed to determine the effect and interaction of both aperture size and squeegee type. The factors to be included are aperture size and squeegee type. The 2 level full factorial experiment is illustrated in Table 4, each experiment is to be replicated 10 times. The DoE was conducted under the conditions outlined in the SIPOC.

Table 4 - Design of experiment

	Level 1	Level -1
Aperture Size	225	200
Squeegee Type	Ultrasonic (PA)	Standard

Analysis

Figure 11 outlines the design of experiment ANOVA table. As can be seen the P values of the terms are 0, this indicates that that all terms are significant and the R-Sq. value of 97.03% indicates that the majority of the resultant output is explained by the experiment.



```
     Estimated Effects and Coefficients for Cpk TE (coded units)

PA                          Effect    Coef  SE Coef      T      P
PA     stant                          0.3403  0.02627  12.96  0.000
     ProActiv                1.4099  0.7049  0.02627  26.84  0.000
     Aperture Size           1.0629  0.5315  0.02627  20.23  0.000
     ProActiv*Aperture Size  0.3575  0.1787  0.02627   6.80  0.000

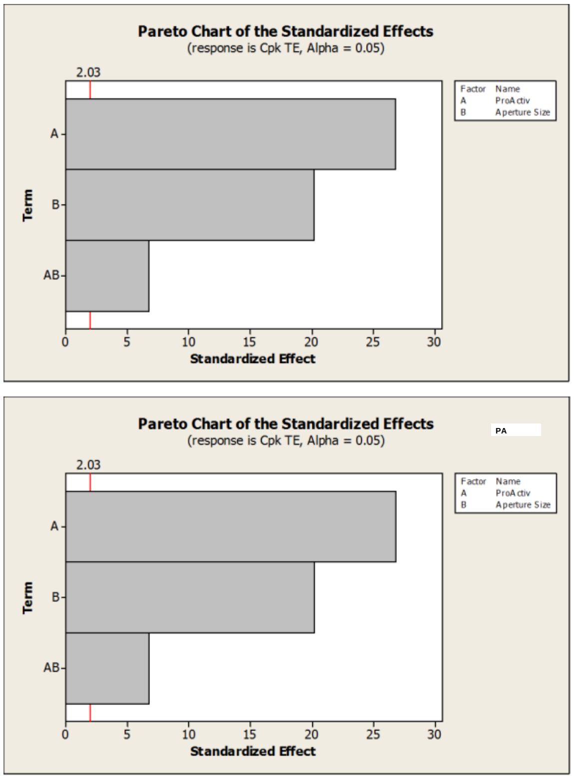

  PA         66119    PRESS = 1.22647
   PA      = 97.03%   R-Sq(pred) = 96.33%   R-Sq(adj) = 96.78%


     Analysis of Variance for Cpk TE (coded units)

PA                            DF   Seq SS   Adj SS   Adj MS       F      P
     Main Effects              2  31.1754  31.1754  15.5877  564.86  0.000
       ProActiv                1  19.8768  19.8768  19.8768  720.29  0.000
       Aperture Size           1  11.2986  11.2986  11.2986  409.44  0.000
     2-Way Interactions        1   1.2777   1.2777   1.2777   46.30  0.000
       ProActiv*Aperture Size  1   1.2777   1.2777   1.2777   46.30  0.000
     Residual Error           36   0.9934   0.9934   0.0276
       Pure Error             36   0.9934   0.9934   0.0276
     Total                    39  33.4465
     Estimated Coefficients for Cpk TE using data in
     uncoded units

     Term                        Coef
     Constant                -8.69480
     ProActiv                -2.33340
     Aperture Size          0.0425180
     ProActiv*Aperture Size 0.0142980
```

Figure 11 - Design of Experiment ANOVA



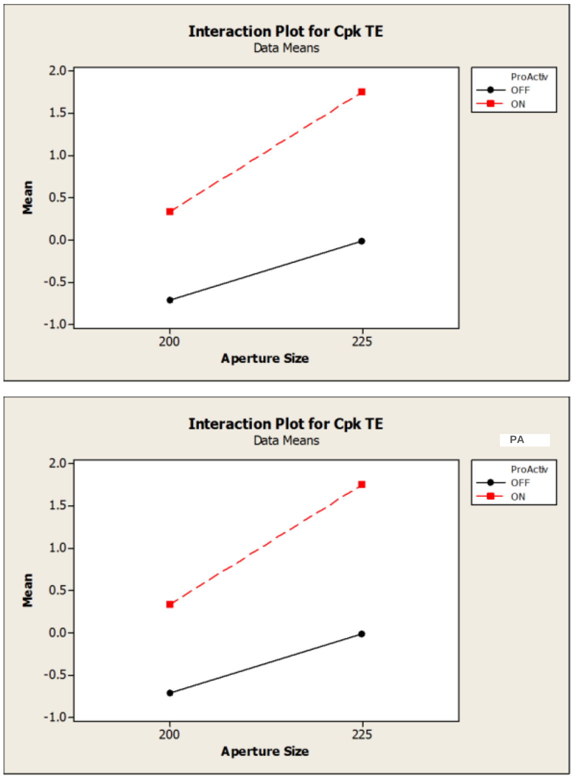


Figure 12 – DoE Pareto Chart **Figure 13 DoE Interaction Plot**

Figure 12 clearly shows the impact of both factors; the pereto chart indicates all features are important, with the ultrasonic squeegee (factor A) the most significant. Figure 13 illustrates the interaction plot, the graph show that even with the ultrasonic squeegee active the 200um aperture is not meeting the minimum 1.33 Cpk value therefore this aperture will be discounted from the subsequent analysis.

To better understand the impact of both factors the coefficients derived from the ANOVA (table 3), can be used to model the process; figure 14 illustrates the derived mathematical model.

*C1*PA + C2 Aperture Size + C3 (PA x Aperture Size) + Constant = Transfer Efficiency Cpk*

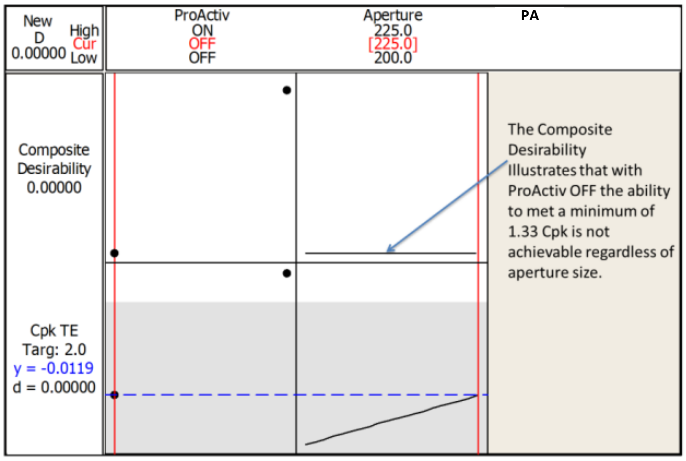
Figure 14 – Mathematical Model

This model can also be used to ascertain the effect on the process output as incremental changes are made to the aperture size, thus allowing the smallest capable aperture size to be discovered.

The software optimizer tool uses the mathematical model outlined in Figure 14 to graphically represent the changes in process output as the factors are modified. Figure 15 to 17 illustrate the output of this analysis.

Figure 15 illustrates that with the ultrasonic squeegee OFF; the composite desirability yields a value of 0, thus indicating that no solution is possible independent of aperture size. Figure 16 illustrates that the model predicts the smallest aperture in which a Cpk of 1.33 is achievable is 217.5um whereas Figure 17 illustrates that the model predicts the 225um aperture produces a Cpk value of 1.76.

Apertures larger than 225um are outside the experimental space and therefore are not covered in this analysis. From an experienced based view point larger apertures will tend to print much easier due to the larger corresponding Area Ratio; however as the aperture size increases the interspace between the deposits decrease. This decrease in interspace will tend to generate wet bridging between adjacent deposits, as a result apertures 225um or less are recommended for a high volume manufacturing 0.4mm pitch CSP assembly process.

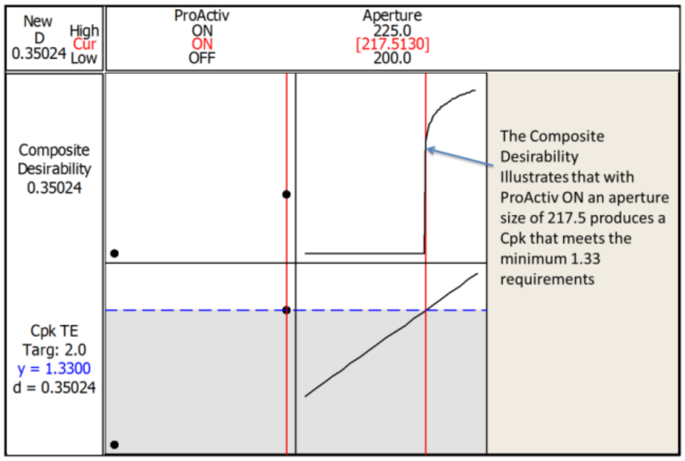


The Composite Desirability Illustrates that with ProActiv OFF the ability to met a minimum of 1.33 Cpk is not achievable regardless of aperture size.

PA

Figure 15 - Predicted Cpk with no ultrasonic squeegee

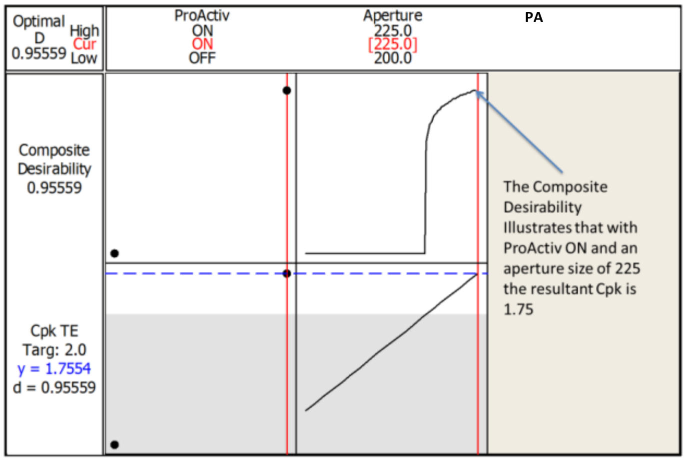
PA



The Composite Desirability Illustrates that with ProActiv ON an aperture size of 217.5 produces a Cpk that meets the minimum 1.33 requirements

PA

Figure 16 - Predicted minimum aperture size with ultrasonic squeegee



The Composite Desirability Illustrates that with ProActiv ON and an aperture size of 225 the resultant Cpk is 1.75

PA

Figure 17 - Predicted Cpk with largest aperture size with ultrasonic squeegee

Further Statistical Testing

To complete the statistical analysis, the following section will investigate the 225um aperture to establish if any statistical difference in transfer efficiency between ultrasonic and standard squeegee exists.

Figure 18 and 19 show the non-normal distribution curves of the data therefore the moods medium test and test for equal variance will be employed to perform the null hypothesis testing.

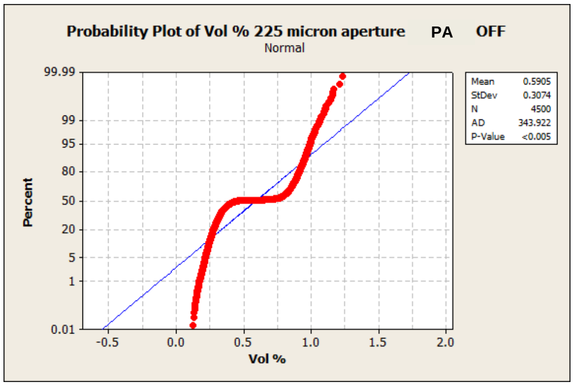


Figure 18 – Probability Plot 225um Ultrasonic OFF

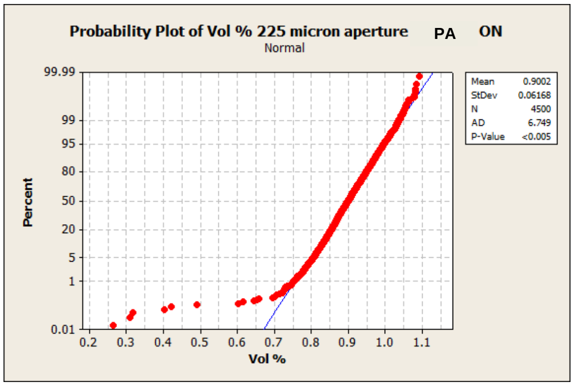
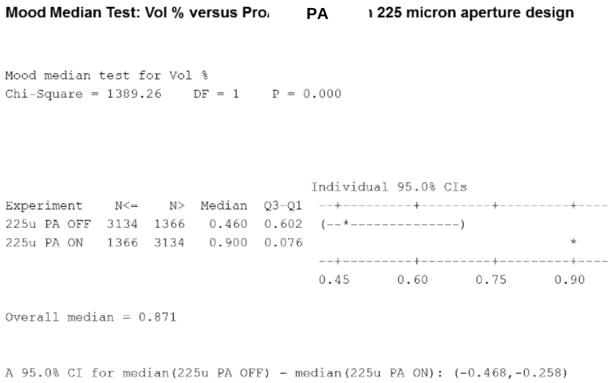


Figure 19 – Probability Plot 225um Ultrasonic ON

Figure 20 illustrates the results from the Moods Medians. The results show a P value of 0, indicating that within a confidence level of 95% the medians are different. The Confidence Intervals (with 95% confidence) indicate that the transfer efficiency from an ultrasonic squeegee is improved between 25.8 and 46.8% with respect to a standard squeegee.



Mood Median Test: Vol % versus Pro PA 225 micron aperture design

```
Mood median test for Vol %
Chi-Square = 1389.26    DF = 1    P = 0.000



                                        Individual 95.0% CIs
Experiment    N<=    N>  Median  Q3-Q1  --+---------+---------+---------+----
225u PA OFF  3134  1366   0.460  0.602  (--*--------------)
225u PA ON   1366  3134   0.900  0.076                                 *
                                        --+---------+---------+---------+----
                                         0.45      0.60      0.75      0.90

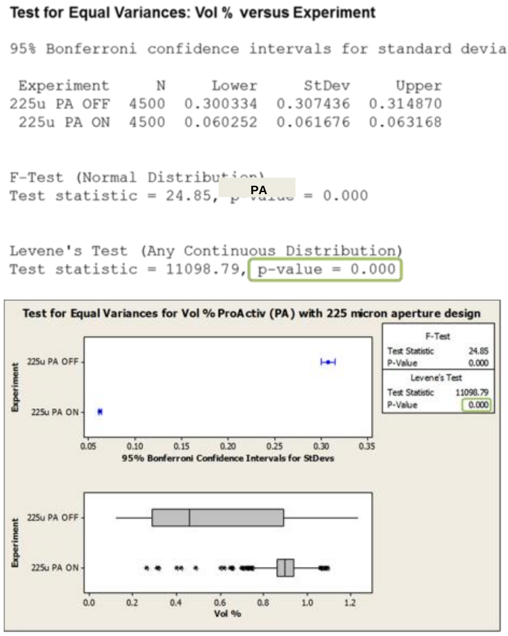
Overall median = 0.871


A 95.0% CI for median(225u PA OFF) - median(225u PA ON): (-0.468,-0.258)
```

Figure 20 - Moods Median Test 225um aperture

Figure 21 shows the results from the test for equal variance, these results illustrate the standard deviation of each data set. As can be seen the Levene's test shows a value of zero, indicating that within the two subsets the standard deviations are different. The Bonferroni confidence intervals indicated that the Ultrasonic Squeegee ON data set produces the lowest Standard Deviation.

The Moods Median and Test for equal variance analysis shows that for the 255um aperture there **is** a positive transformation in transfer efficiency between the standard and ultrasonic squeegee system.



Test for Equal Variances: Vol % versus Experiment

```
95% Bonferroni confidence intervals for standard deviations

 Experiment      N     Lower     StDev     Upper
225u PA OFF   4500  0.300334  0.307436  0.314870
 225u PA ON   4500  0.060252  0.061676  0.063168


F-Test (Normal Distribution)
Test statistic = 24.85, p-value = 0.000


Levene's Test (Any Continuous Distribution)
Test statistic = 11098.79, p-value = 0.000
```

Figure 21 - Test for equal variance 225um aperture

Confirmation Run

From the design of experiments and statistical testing, the 225um aperture with ultrasonic squeegee demonstrated a capable process. The following section shows a confirmation run which uses the 225um aperture and ultrasonic squeegee in order to verify the finding. The confirmation run included a rebuild of the experiment setup as outlines in Figure 5.

Figure 22 illustrates the process output from the confirmation run. The resultant Cp/Cpk values are 2.31 and 1.73; both these values are greater than the minimum required 1.33. This verifies the 225um with ultrasonic squeegee is capable of printing 0.4mm CSP devices alongside 127um stencil foils and other standard material sets used within the solder paste printing process.

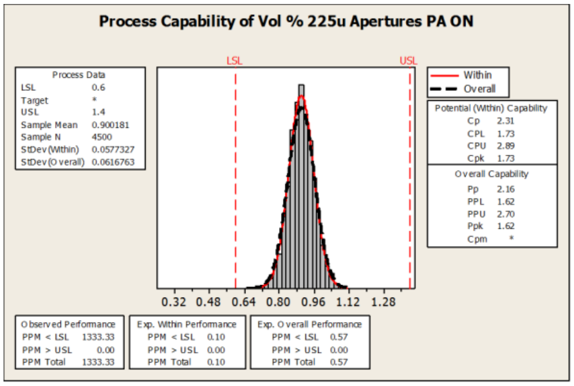


Figure 22 – Rerun process capability

Heterogeneous View

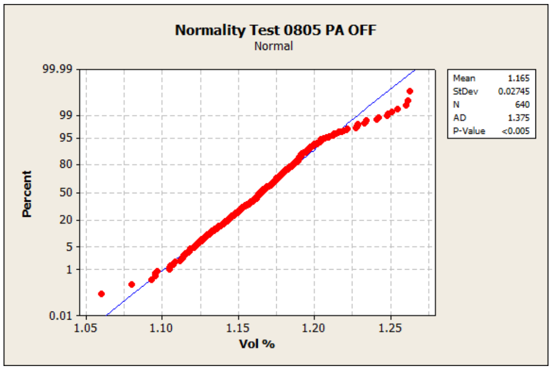
The testing so far has exclusively been focused on implementing 0.4mm CSP technology for the 127um stencil user. Obviously for any solder paste printing solution to be accepted; its capability needs to cover a full range of size and shaped deposits. The following section will investigate the proposed 0.4mm CSP ultrasonic solution and the impact to a heterogeneous process.

The components to be included in this heterogeneous study are 0805 and 0.4mm Quad Flat Packs (QFP), aperture dimensions are outlines in table 5. The process setup followed the SIPOC outlined in Figure 5 with the exception of the heterogeneous devices.

Table 5 - Aperture size for heterogeneous study

	0805	0.4mm QFP
Width (um)	1400	170
Length (um)	1100	1570

Figure 23 to 26 illustrate the normality testing of the 0805 and 0.4mm QFP with and without the ultrasonic squeegee solution. As can be seen the P values from the normality tests are less than 0.05, expect for 0.4mm QFP Ultrasonic OFF (Figure 25), for the sake of symmetry all datasets to be declared non-normally distributed.



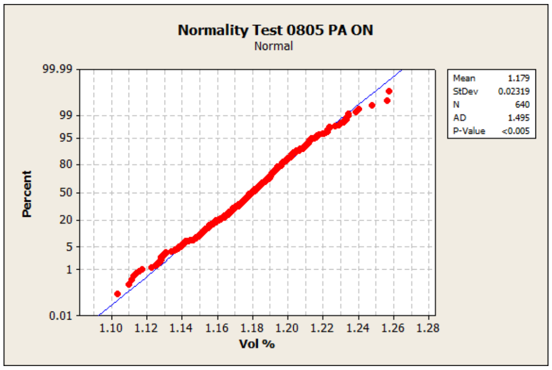
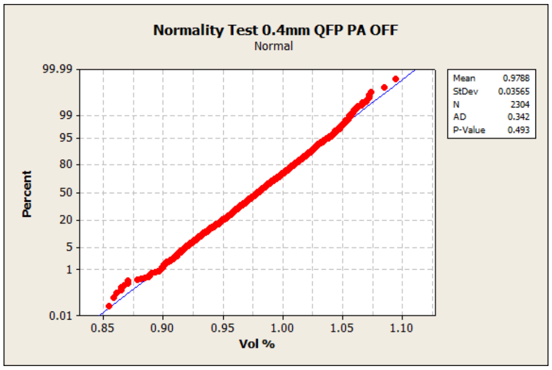


Figure 23 – Normality Test 0805 Standard Squeegee

Figure 24 – Normality Test 0805 Ultrasonic Squeegee



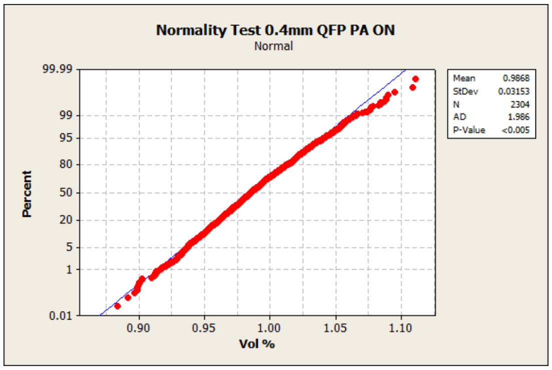


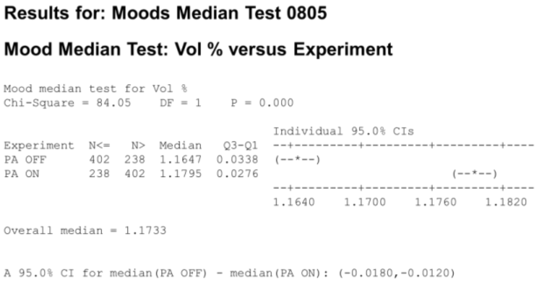
Figure 25 – Normality Test 0.4mm QFP Standard Squeegee

Figure 26 – Normality Test 0.4mm QFP Ultrasonic Squeegee

To understand if the ultrasonic squeegee yields an impact on the heterogeneous aspect of solder paste printing the data will be analysed using a Moods Median, Test for Equal Variance and Process Capability study.

Figure 27 to 30 illustrate the analysis of the 0805 and 0.4mm QFP devices. The Moods Median analysis displays a P value of zero for both the 0805 and 0.4m QFP device types. This indicates that with 95% confidence the medians of the subgroups (ultrasonic squeegee ON/OFF) are dissimilar. The test for equal variance displays a P value (Levene's Test) of zero for both the 0805 and 0.4mm QFP package types. Therefore indicting that with 95% confidence the variation (standard deviation) of the subgroups (ultrasonic squeegee ON/OFF) are dissimilar.

The following analysis investigates and answers if the differences between the subsets affect the process output.



Results for: Moods Median Test 0805

Mood Median Test: Vol % versus Experiment

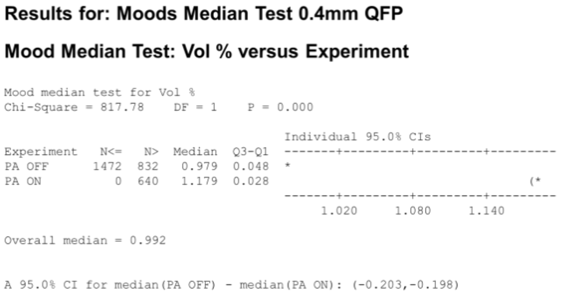
```
Mood median test for Vol %
Chi-Square = 84.05    DF = 1    P = 0.000

                                       Individual 95.0% CIs
Experiment  N<=   N>  Median   Q3-Q1  --+---------+---------+---------+----
PA OFF      402  238  1.1647  0.0338  (--*--)
PA ON       238  402  1.1795  0.0276                         (--*--)
                                      --+---------+---------+---------+----
                                      1.1640    1.1700    1.1760    1.1820

Overall median = 1.1733


A 95.0% CI for median(PA OFF) - median(PA ON): (-0.0180,-0.0120)
```

Figure 27 Moods Median Test 0805



Results for: Moods Median Test 0.4mm QFP

Mood Median Test: Vol % versus Experiment

```
Mood median test for Vol %
Chi-Square = 817.78    DF = 1    P = 0.000

                                      Individual 95.0% CIs
Experiment   N<=   N>  Median  Q3-Q1  -------+---------+---------+---------
PA OFF      1472  832   0.979  0.048  *
PA ON          0  640   1.179  0.028                                      (*
                                      -------+---------+---------+---------
                                           1.020     1.080     1.140

Overall median = 0.992


A 95.0% CI for median(PA OFF) - median(PA ON): (-0.203,-0.198)
```

Figure 28 Moods Median Test 0.4mm QFP

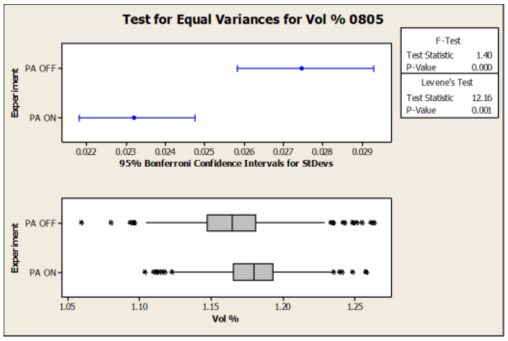


Figure 29 Test for equal variance 0805

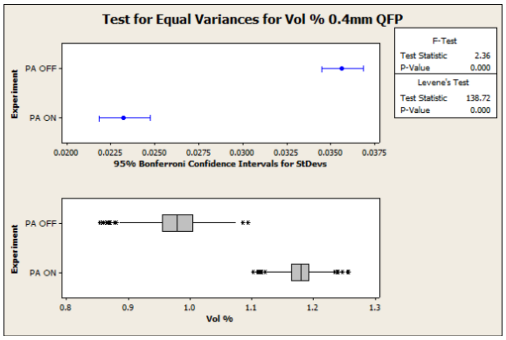


Figure 30 Test for equal variance 0.4mm QFP

Figure 30 to 33 illustrate the process capability output for the 0805 and 0.4mm QFP packages. Each package type is analysed under the condition of ultrasonic squeegee ON/OFF.

The process capability curves shown in Figure 30 and 32 show the output from a standard system (ultrasonic squeegee OFF). The results show both devices to be within the required ≥ 1.33 Cpk value, this is an expected outcome as both devices are representative of "todays" standard assembly processes

The process capability curves shown in Figure 31 and 33 show the output from an ultrasonic activated squeegee system. As can be seen, the Cpk index value is greater when the ultrasonic condition is ON; indicating that the addition of an ultrasonic device has process capability benefits to the larger footprint devices. For reference the results for both conditions are presented in Table 6.

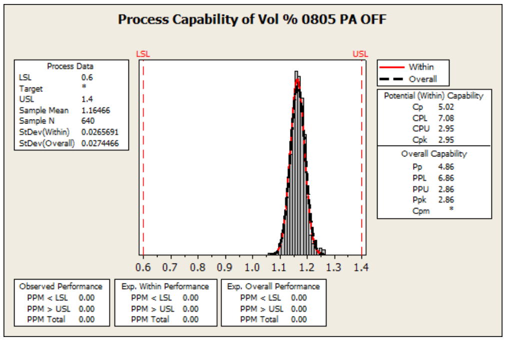


Fig 30 – Process Capability 0805
Standard Squeegee

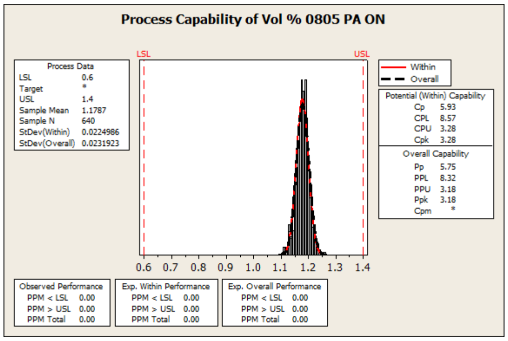


Fig 31 – Process Capability 0805
Ultrasonic Squeegee

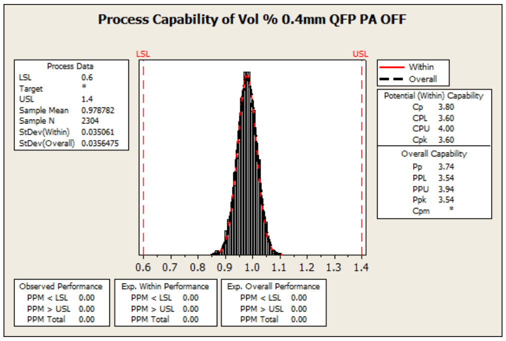


Fig 32 – Process Capability 0.4mm QFP
Standard Squeegee

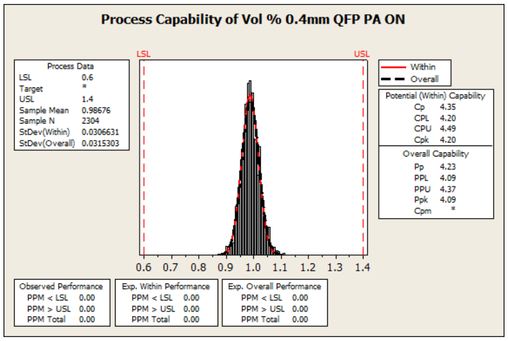


Fig 33 – Process Capability 0.4mm QFP
Ultrasonic Squeegee

Table 6 – Cpk values for 0805 and 0.4mm QFP

	0805 Cpk	0.4mm QFP Cpk
Ultrasonic Squeegee OFF	2.095	3.6
Ultrasonic Squeegee ON	3.28	4.2

Conclusions

The purpose of this paper was to answer the question, “Can 0.4mm CSP devices be printed within an Automotive and Industrial assembly environment”? As considered throughout this paper, the issues of printing 0.4mm CSP compatible apertures through the established 127um stencil foil thickness leads to an infringement of industry recognised Area Ratio rules. Therefore this investigation focused around the possibility of breaking these established Area Ratios with no detrimental effect on standard depositions.

The findings from this investigation are listed below:

- The results from this investigation demonstrated the ultrasonic squeegees ability to extend the print process window to include Area Ratios ≥ 0.45. This allows 225um apertures to be printed using 127um stencil foils.
- The analysis has demonstrated the 200um diameter apertures were outside the ultrasonic squeegees capability. Therefore the ability to print Area Ratio’s below 0.4 is still an unknown.
- The ability to print 225um diameter apertures using 127um foil thicknesses gives the Automotive and Industrial sector the possibility of printing solder paste deposits for the 0.4mm CSP.
- The inclusion of an ultrasonic squeegee does not adversely affect the paste deposition of larger footprint devices

Therefore the ability to print 0.4mm CSP compatible apertures using incumbent material sets is possible when ultrasonic squeegee technology is employed.

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