

# Quantifying Stencil Aperture Wall Quality

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## **Abstract**

The goal of this study was to develop a method by which stencil aperture wall quality can be inspected, and the results quantified. Additionally, we hope to establish a correlation between the stencil wall quality and the paste release performance.

Stencil quality studies have traditionally focused on release data as the main method of gauging stencil fabrication quality. While some studies have included SEM images to aid in the assessment of stencil aperture wall quality, none have provided a method for quantifying the stencil wall smoothness. In this study, we will measure aperture walls of stencils using a confocal white light sensor with a 3 micron spot size and 0.02 micron depth resolution. The results will be quantified as average surface roughness (Sa). The surface roughness of various stencil fabrication methods will be measured and compared. Vendor claims of the quality of various materials, such as 304 Stainless, more expensive premium foils and nickel, will be assessed as will different fabrication methods including laser cutting, e-form and nano coating. In order to understand how wall roughness impacts stencil performance, a paste release study will also be conducted. A single BGA pattern will be printed on a glass slide and the paste release will be measured. This study will be of interest to both fabricators and users of stencils.

## **Introduction**

SMT assembly quality is dependent on the consistent release of solder paste. This, in turn, can be greatly impacted by the quality of the stencil.

Stencil quality is traditionally judged by paste release performance. This approach only indirectly measures stencil quality. In a controlled study, using a single stencil design and single PCB type, performance differences between stencils may be identified. However outside of a controlled study, it can be very difficult to determine the quality of the stencil based on the observation of paste depositions as so many other factors affect paste release.

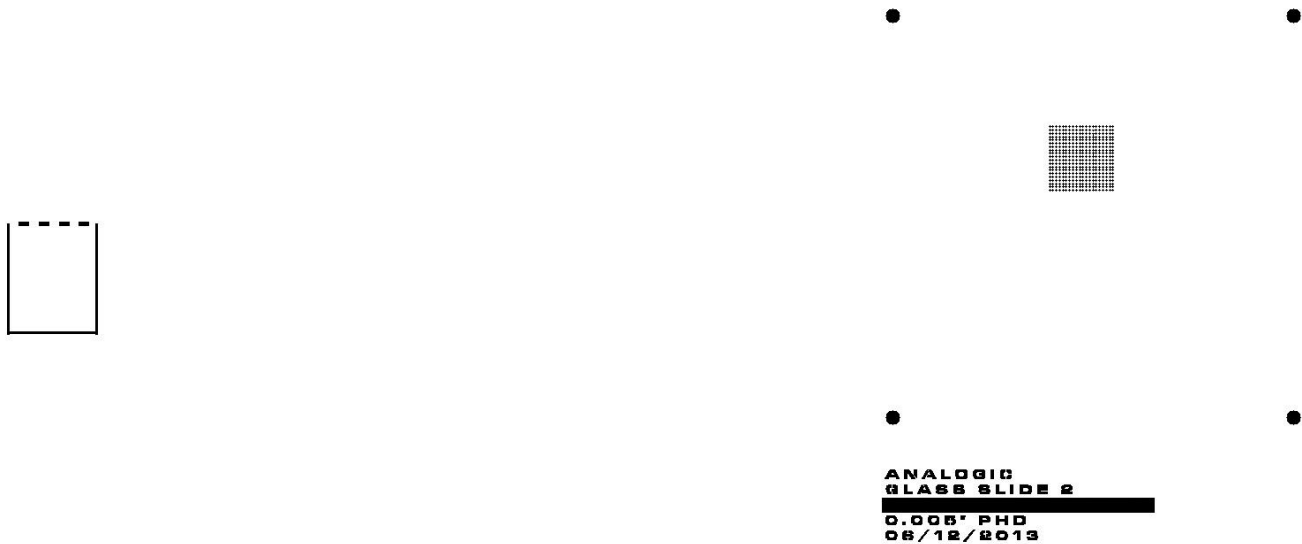
In production, poor stencil quality is often not recognized until defects are generated, with an associated cost. Since print quality is dependent not only on stencil quality, but also on the PCB surface, and screen printer programming, paste quality and many other factors, it is usually time consuming and costly to trace back poor print results to a low quality stencil.

It would advantageous if quality of stencils could be determined using an inspection method which did not require printing solder paste. Previous studies, where a subjective visual or SEM inspection of the aperture walls was performed, have suggested that there is a correlation between the smoothness of the walls and the transfer efficiency. (Add Reference)

The goal of this study was to develop a method for the measurement of stencil aperture wall roughness, producing quantifiable results which can predict paste release performance. It is hoped that this method may then be used as a way of gauging the quality of individual stencils, evaluating stencil supplier and fabrication .

## **Methodology**

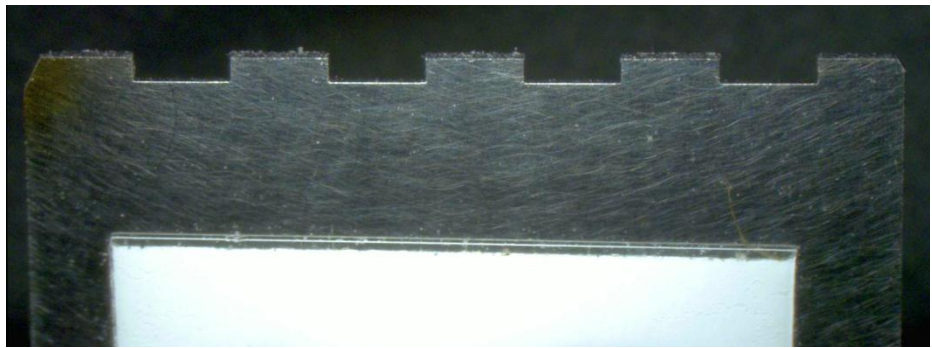
Stencils were designed to include both a single BGA site, so that paste release could be measured; and a test coupon, which was used to determine the roughness of the aperture walls.



**Figure 1-Test Stencil Design (Please remove Analogic name in Figure 1)**

It is not possible to scan the aperture walls of the BGA. The method used to measure aperture quality requires a flat surface in order to provide a statistically significant amount of data, and the walls of the BGA are curved. Also the BGA could not be scanned without cutting it out of the stencil and could not be used as a way of determining the quality of the stencil before printing.

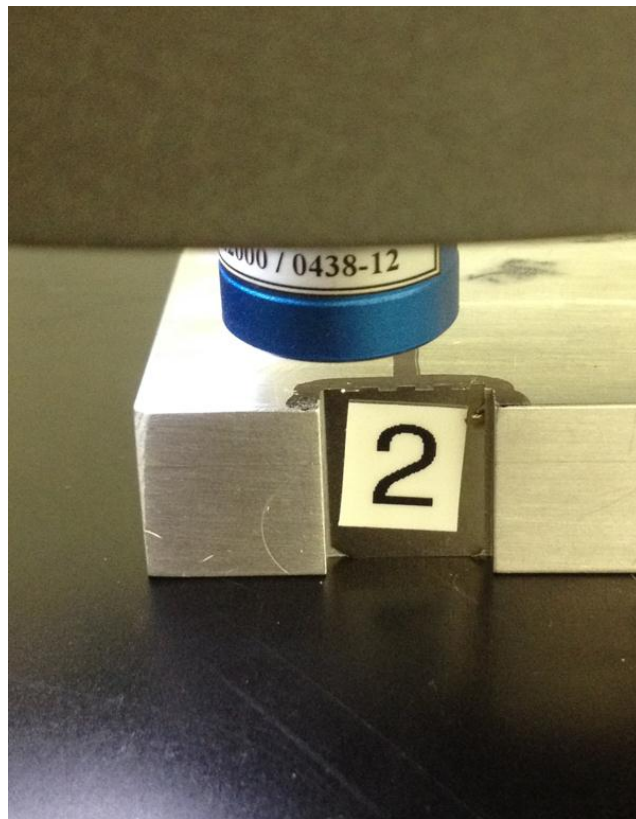
A removable coupon, shown on the left side of Figure 1, was included as a representative of aperture wall quality which could be measured before printing. It is placed far enough to the left, that the resulting hole will be outside the range of the squeegee blades. The 4 measurements slots, shown in Figure 2, are approximately 0.5x1.5mm.



**Figure 2- Measurement edge of coupon cut from stencil foil.**

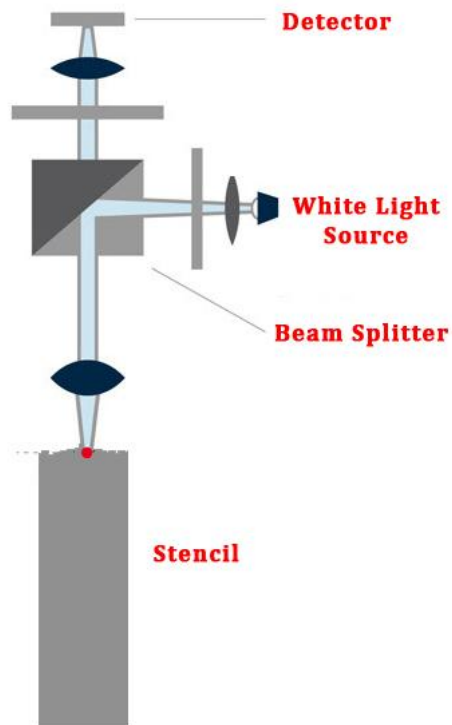
The coupons were cut from the stencil and mounted vertically below the sensor of a scanner (see Figure 3). The scanner uses a confocal white light sensor to measure surface topography with a vertical resolution of 0.02 microns (0.0008 mils). The sensor has a measurement width of 3 microns, and a line spacing of 2 microns was used.

As originally published in the IPC proceedings.



**Figure 3-Coupon mounted under a scanner sensor**

An area 1 mm in length and slightly less than the thickness of the stencils was scanned in one or more slots. The surface roughness of the area ( $S_a$ ) was calculated by the scanner.



**Figure 4-Scanner Sensor Diagram.**

The print site featured a single BGA with 10 mil round apertures, which is shown on the right side of Figure 1. The specified stencil thickness was 0.127mm (5 mils). The resulting area ratio of 0.50 makes for a very challenging design. By comparison IPC 7525 standard recommends a minimum area ratio of 0.66. The tight area ratio was selected with the hopes that it would expose differences between stencil types.

Printing was done on an production screen printing machine, with a squeegee speed of 25mm per second. The paste used was a production no-clean Type 4 solder paste. In order to minimize variation caused by changes in the environment all work was done in a clean room at 20°C and 40% RH. In order to minimize variation cause by board warpage or variation in topography, glass slides were used as substrates.

The paste deposits were also measured using the scanner sensor equipment. Due to time constraints related to the line scan method used by this scanner, only the upper left 100 paste deposits were measured.

A variety of methods were used to fabricate the stencils including laser cutting, electro forming and applying nano coating. Three types of stencil foils were used: Standard rolled foils made with type 304 stainless steel, more expensive premium foils designed to aid release, and electroformed nickel foils. (Please include some definition or technical description of what a "Premium" stencil is)

A total of 11 stencils were ordered from three different suppliers. Two were ordered from company A, seven from company B, and two from company C. Companies A and C were not aware that the stencils were being used for this experiment. Company B was aware of the purpose of the stencil and the test coupon.

## Results

(Is sample aperture size data available for the BGAs on the 11 stencils, and can this be shown. It is assumed apertures from all stencils should be of equal size, but in reality this may not be true)

Significant differences in the roughness and quality of aperture walls were observed. Figure 5 and 6 below are representative of the smoothest and roughest samples scanned.

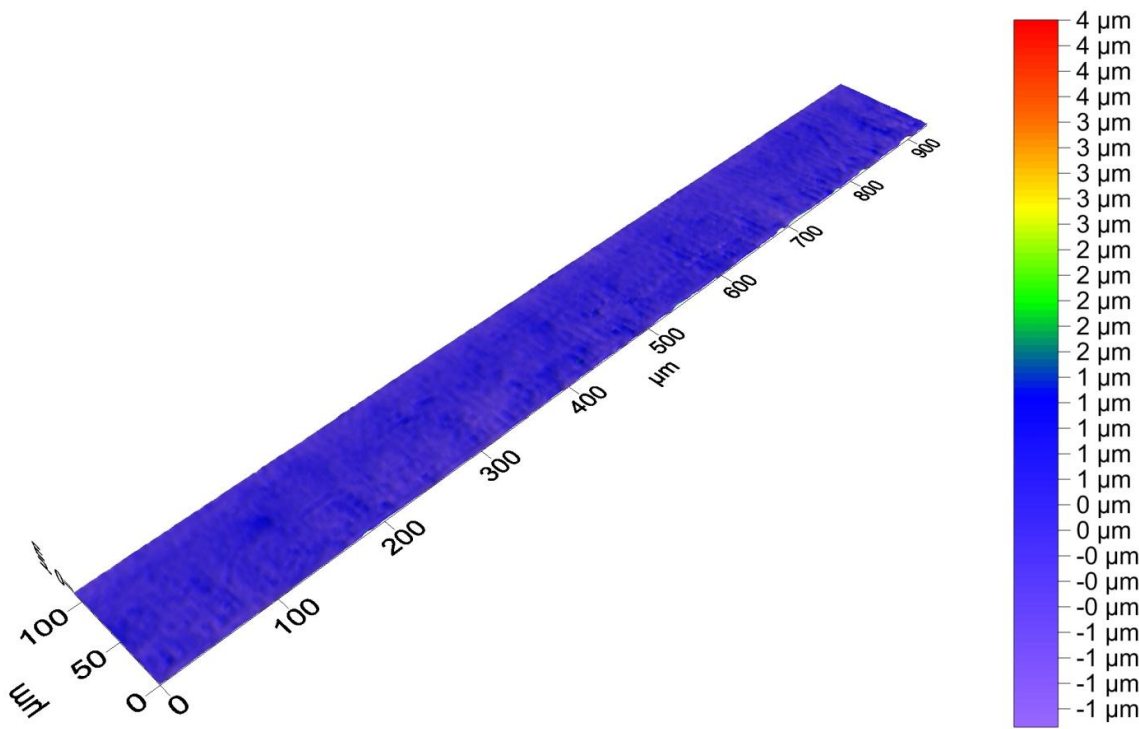
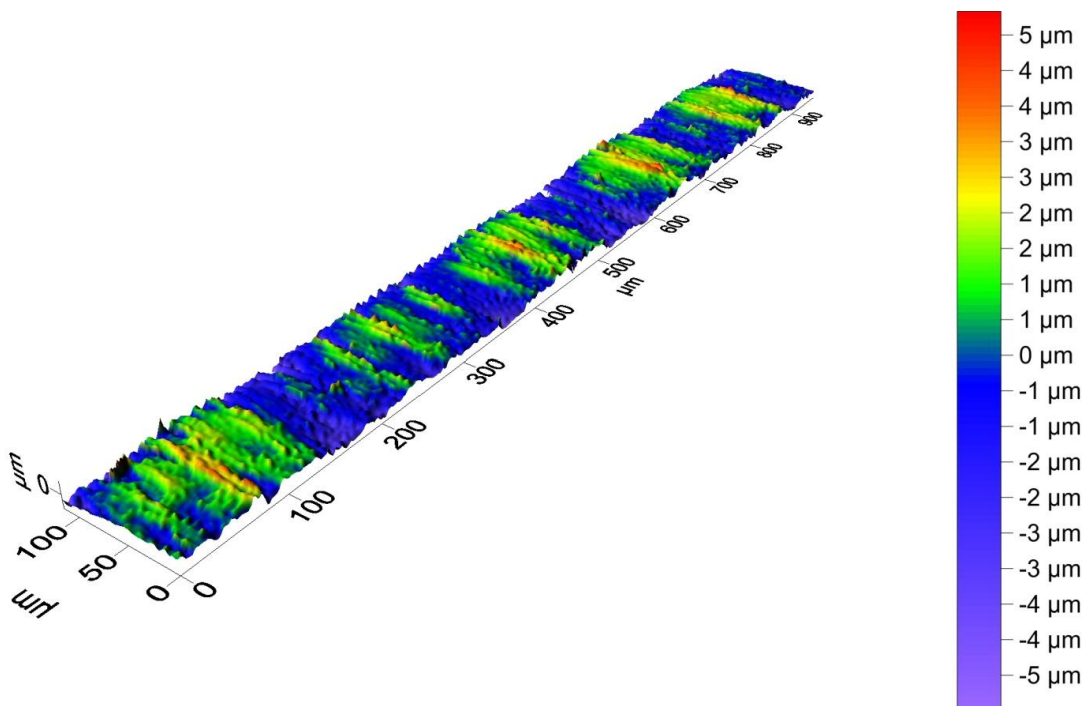


Figure 5-Stencil #6, the Smoothest.



**Figure 6-Stencil #7, The Roughest.**

The stencil surface roughness (Sa) for all 11 stencils is shown in Table 1. Roughness varied from 0.26 microns to 1.22 microns.

There is a large variation in stencil wall coupon smoothness between the three vendors. Vendor B was able to laser cut the coupon aperture walls with significantly less roughness than vendors A and C. The exception is stencil #7, which was cut by vendor B using an older, wide beam laser.

No significant difference was found in the smoothness of laser cut 304 stainless based foils and stencils made from premium foil material.

Surprisingly, the roughness of electroformed stencils was greater than many of the laser cut stencils.

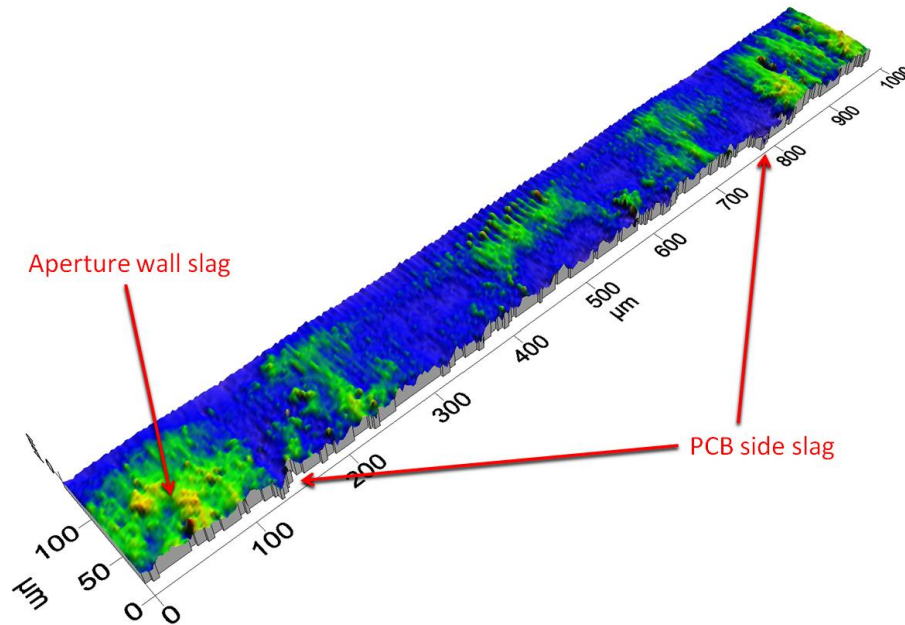
**Table 1-Stencil Wall Surface Roughness**

Number	Vendor	Type	Sa
1	A	Laser Cut Nano PREMIUM	1.01
2	A	Laser Cut 304 STAINLESS BASED FOIL	0.7
3	B	Laser Cut Nano 1 PREMIUM	0.3
4	B	Laser Cut 304 STAINLESS BASED FOIL	.31
5	B	Laser Cut PREMIUM	.34
6	B	Laser Cut Nano 1 304 STAINLESS BASED FOIL	.26
7	B	Laser 304 STAINLESS BASED FOIL (old laser)	1.22
8	B	E-form	.48 (vert lines)
9	C	E-form	1.33
10	C	Laser Cut 304 STAINLESS BASED FOIL	0.69
11	B	Laser Cut 304 STAINLESS BASED FOIL	.46

In addition to the Sa, potentially significant differences were noted during a visual review of the scans which cannot be expressed quantitatively. These included slag, different orientation of the roughness pattern and poor stencil thickness control.

Slag is formed during the laser cutting process. The molten metal solidifies on the sides of the apertures wall and bottom of the foil. Stencil vendors perform a post-cutting slag removal operation using abrasive material on the bottom of the foil, but it is generally a manual operation and the evidence in this and other studies shows that the removal can be inconsistent. It is believed, based on production experience, that this will prevent proper gasketing during screen printing. It also may also increase the effective thickness of the stencil.

Figure 7 shows a scan of a stencil with slag on both the aperture walls and the contact side of the stencil.



**Figure 7-Slag Evident on Stencil #10.**

(If available, can surface roughness scan images be supplied for all 11

Differences in the orientation, and concentration of roughness patterns were also noted. On Stencil 8, which was electroformed, the bumps are vertically oriented (see Figure 8 below). It seems likely that in this orientation the bumps is less likely to impede the flow of solder paste than if the bumps that are horizontally or randomly oriented such as in Stencil 1.

The thickness of both electroformed stencils was found to be significantly under the specified thickness of 0.127mm. Stencil 8 had an actual thickness of approximately 0.10mm and stencil 9 had a thickness of only 0.08mm.

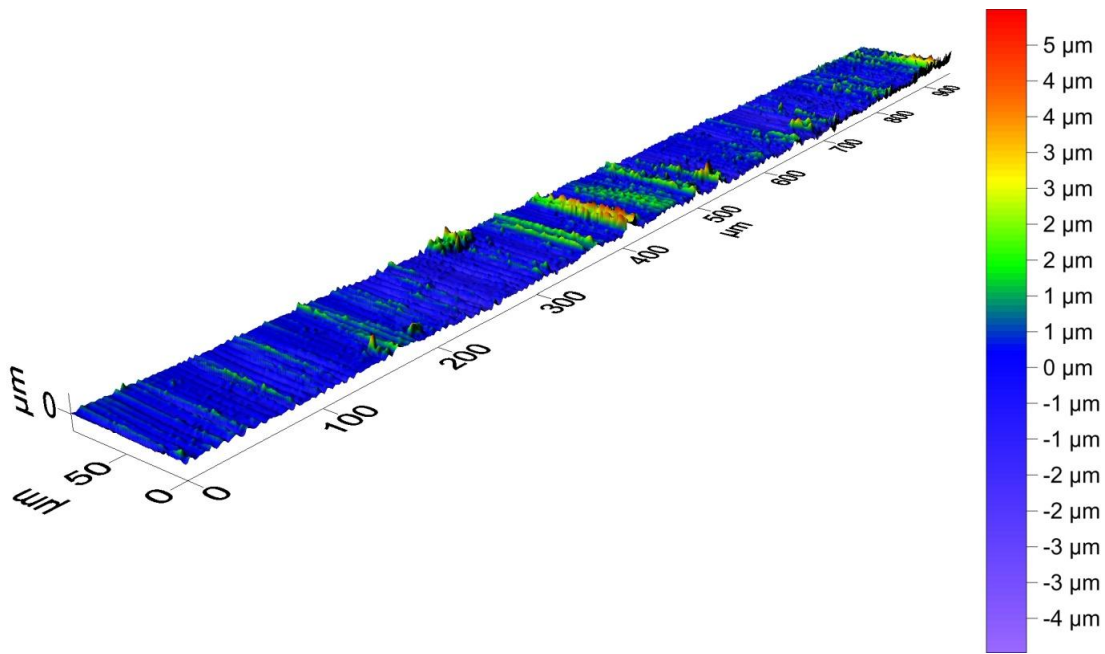


Figure 8-Electroform stencil #8

**Release data**

10 consecutive prints, with no wiping or cleaning between, were made with the 11 different stencils.

Initial review of the data, shown in figure 9, did not show a strong correlation between aperture wall quality and the volume of paste released.

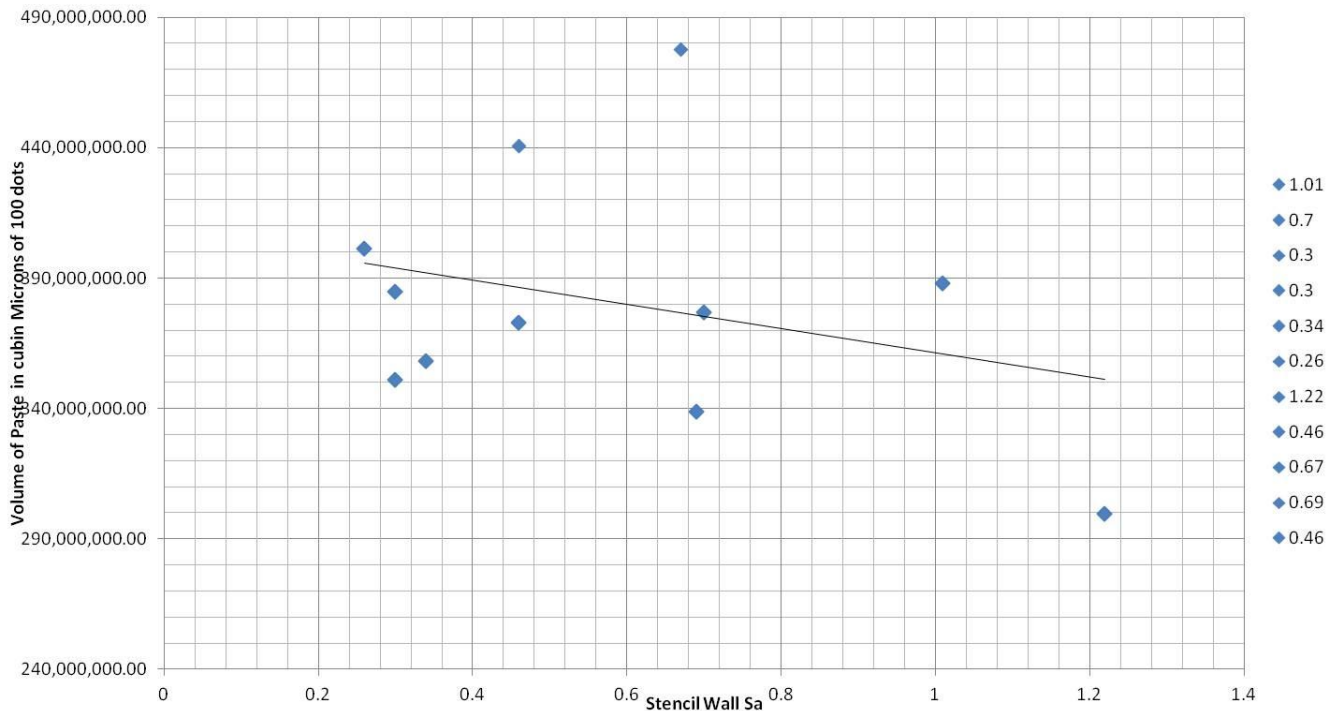


Figure 9 Paste Volume versus Sa

Further review of the best performing stencils, revealed them to be e-forms with thicknesses dramatically below specification. The thinner than specified thickness gives the e-forms stencil much more favorable area ratios. The area ratio of the 0.08mm stencil was 0.8 and the .10mm foil was 0.63. It appears that the better area ratios provided better release.

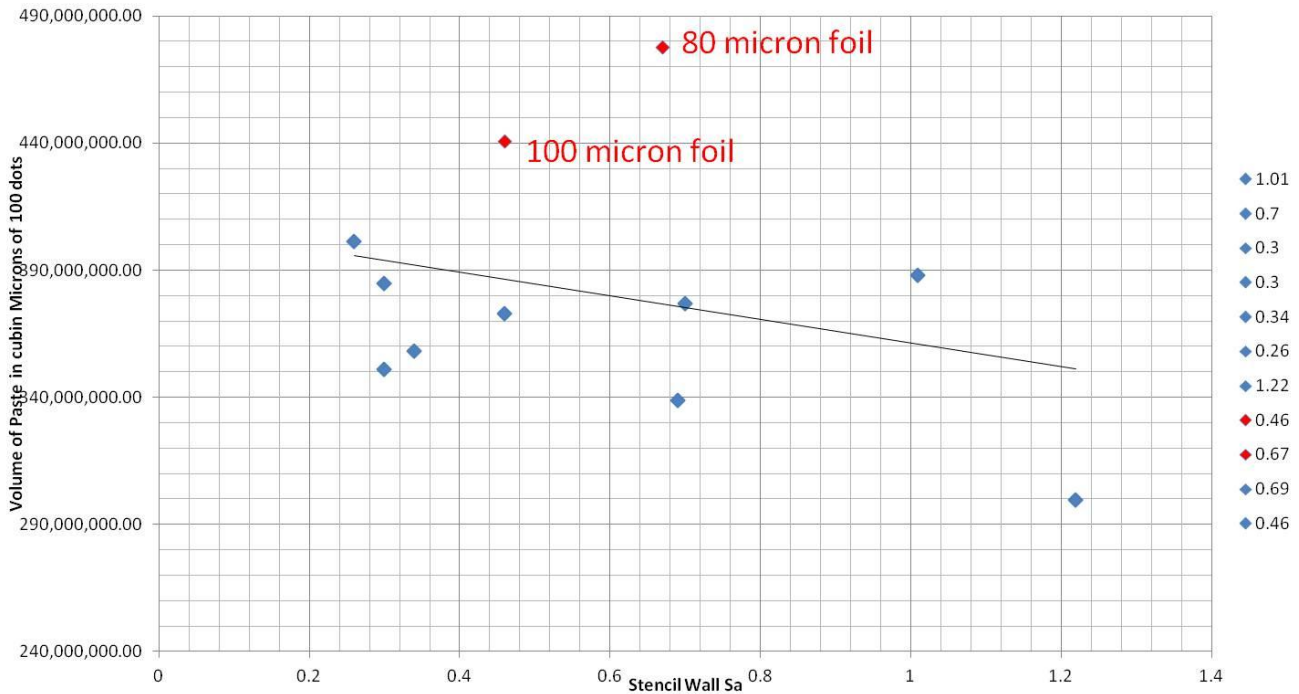


Figure 10 Paste Volume versus Sa with E-forms Highlighted

Removing the thin e-forms from the data strengthens the correlation, but two notably rough stencils still unexpectedly perform well. Both these stencil are from company A.

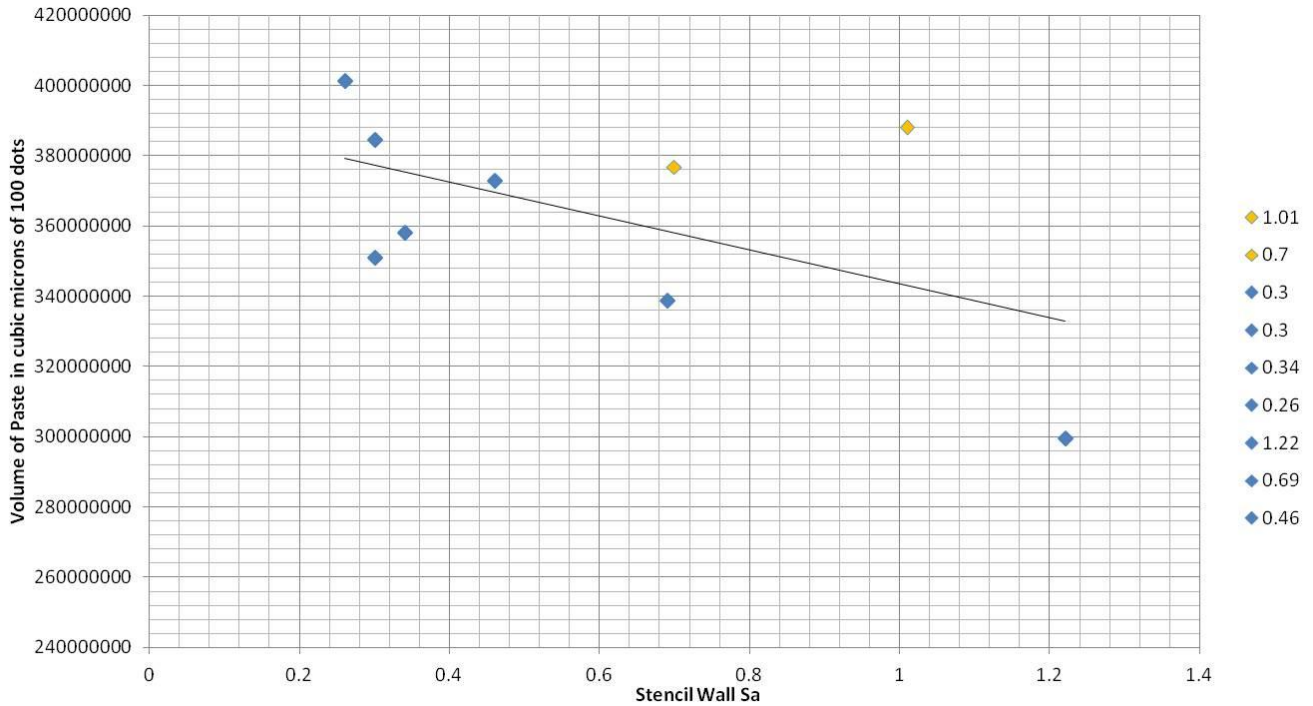


Figure 11 Paste Volume versus Sa with Company A Stencils Highlighted

We reviewed the data with company A. Not realizing that the coupon was meant to represent BGA wall aperture quality, they had not used the same laser settings on the coupons and cut the slots quickly, as they would on a 1206 resistor. Additionally, they believe the design of the coupon slot makes it impossible to cut with the same precision as a small BGA



aperture. Therefore, they stated that the aperture walls of the company A coupon slots would not be an accurate representation of the BGA aperture walls.

We cut out the BGA patterns and performed scanner sensor scans on the BGA aperture walls. A visual review of the scans confirms that the walls are much smoother than the coupon walls. It was not possible to accurately calculate the roughness because of the curved surface, small area and presence of debris. Figure 12 below shows a comparison of stencils 1, made by company A, and stencil 3, made by company B. The color scales are identical.

(Stencil Vendor A expressed concern that coupon aperture wall roughness does not represent BGA aperture wall roughness. Further analysis in Figure 12 confirmed this concern to be true. Can it be explained if the same concerns apply with Vendor B and C stencils.)

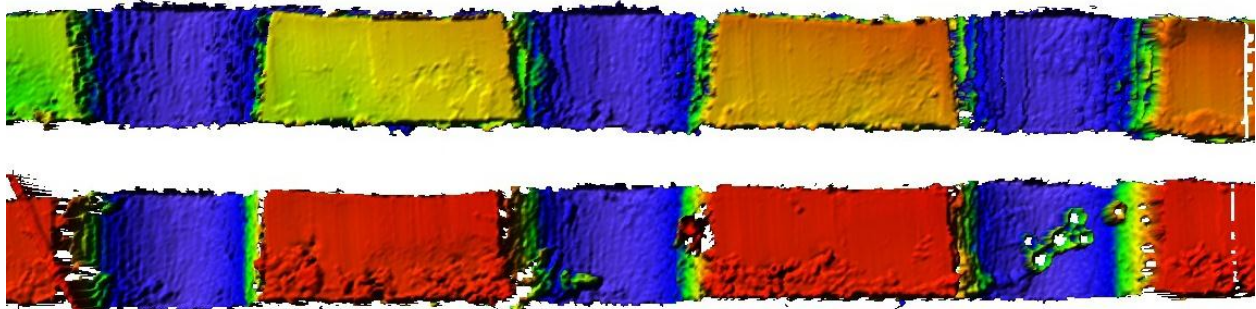


Figure 12 Comparison of BGA wall smoothness from Company A, Stencil 1 (top) and 3 (bottom)

When the data from company A is removed, there is a strong correlation between stencil wall roughness and the volume of paste release, which is directly related to transfer efficiency.

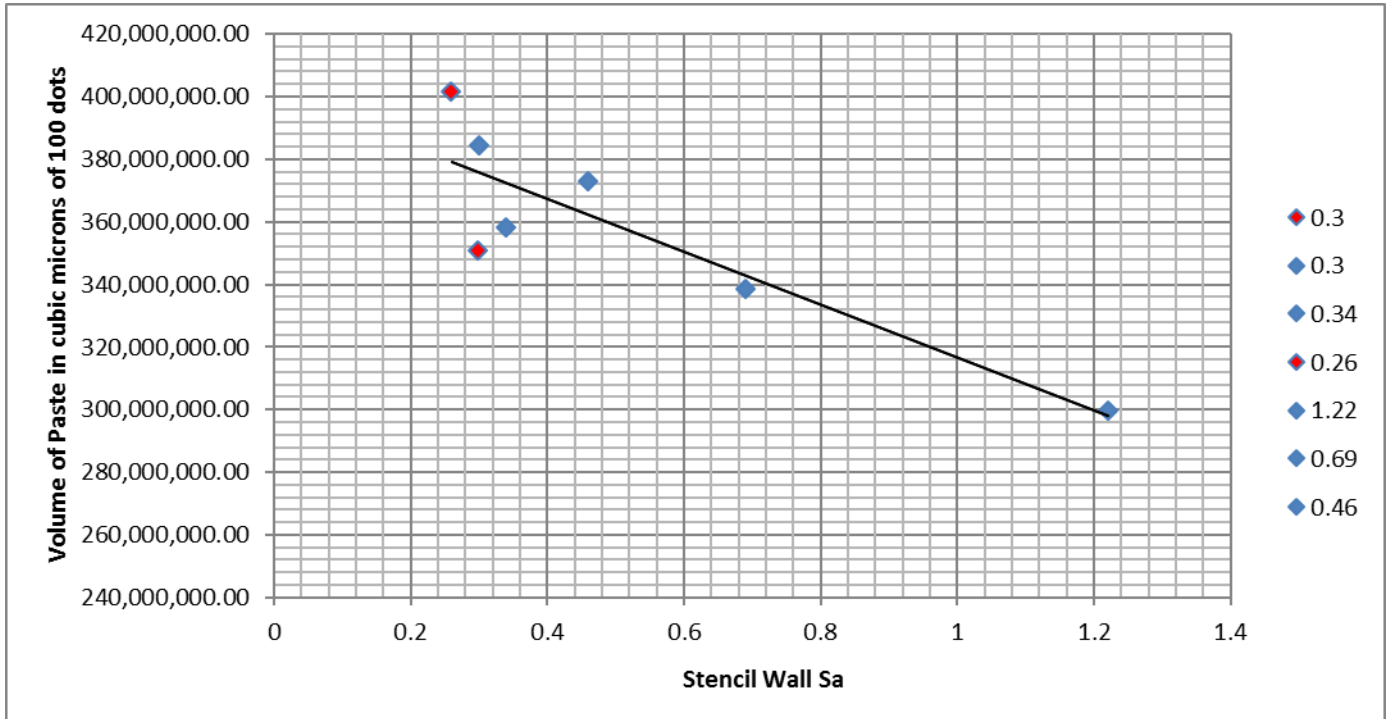


Figure 13 Graph of Paste Volume vs. Aperture Wall Roughness Nano Coated Stencils in red.

**Notes on nano coating**

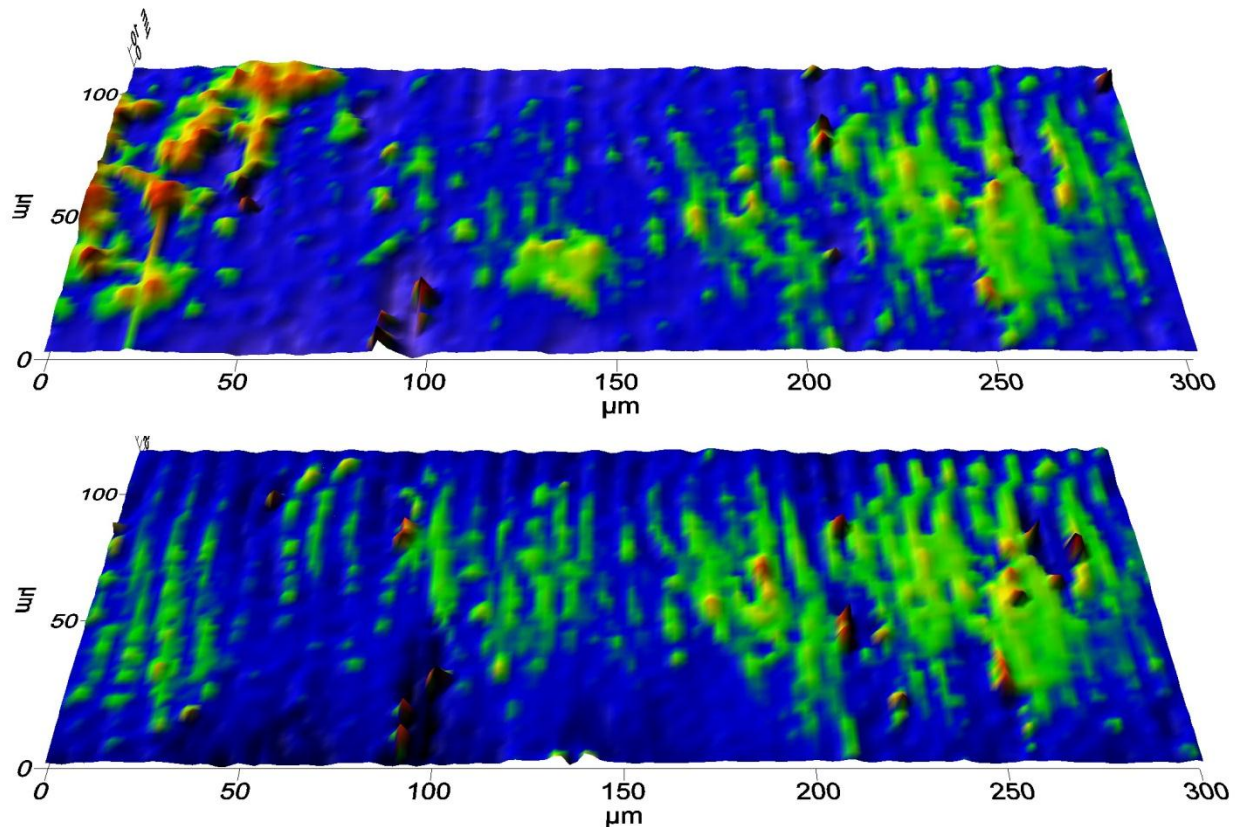
While the main goal of this study was to develop a method for the inspection of aperture walls, we were particularly interested in the impact of nano coating.

(It would be helpful to clarify the type of nanocoating used. Where applicable, can the nanocoating category be specified (i.e. wipe on, spray coat, plasma applied, other))

The impact of nano coating on aperture wall roughness or paste release was not clear. In some cases the nano coating does appear to fill in some of the valleys in the surface of the stencil wall. We also observed, on the stencil 1 coupon, the presence of large uneven deposits of nano coating appeared to actually increase Sa. Chemical removal of the nano coating using epoxy dissolver and rescan of the aperture wall showed an improvement of about 0.2 microns in Sa. Again, it is worth noting that company A was not aware of the purpose of the coupons and might have applied the nano coating to the coupon with less care than they used on the BGA apertures.

Figure 14 shows a comparison of the stencil #1 coupon wall with (top) and without (bottom) nano coating. Most noticeable are the large, uneven deposits of nano coating on the left side of the scan of the nano coated coupon. With the nano coating removed these large bumps are gone, but the groves caused by laser cutting are more evident. A relatively deep valley can be seen along the bottom at about the 100 micro mark which had apparently been filled with nano.

This stencil was coated with a hand wipe first generation nano coating. Results with newer material may be quite different.



**Figure 14-Stencil 3 coupon with and without nano coating.**

The impact of nano coating on paste release was also unclear. The two nano coated stencils shown in the final chart, perform roughly the same as non-coated stencils with similar Sa. The sample size was too small to make a conclusion on the impact of nano coating.

### Conclusions

Aperture wall roughness can be measured and quantified using this method. In addition to measuring the roughness over an area, stencil fabrication defects, such as out of spec thickness and slag are easily detected. There appears to be a significant correlation between the Sa of a stencil's aperture walls and release volumes based on the limited number of samples printed. While some additional work is needed in order to fine tune the design of the coupon, we believe this will prove helpful in determining the quality of stencils before printing.

The large variation in roughness for stencils cut with the same method indicates the quality of stencils cannot be predicted by specifying a certain fabrication method. For example, it is very clear that all laser cut stencils are not fabricated equally. In discussions with stencil vendors we found out that the type of laser used, the size of the beam, compressor type and cutting speed can greatly impact the quality of the aperture walls.

The manufacturing method and foil type appeared to have less of an impact on wall roughness than the cutting process. We found no evidence that there is any difference between Premium and less expensive 304 based foil stencils.

Electroformed stencils, based on this study and informal findings in production, are often thinner than specified. This may be more of a factor in aiding release than the quality of the stencil walls.

(The paper cites the 4 references below. Please number these references then also label in the body of the paper).

### **References.**

Chrys Shea and Quyen Chu et al “Quantitative Evaluation of New SMT Stencil Materials” IPC APEX/EXPO, Las Vegas, NV April 2011

Chrys Shea and Robert Farrel et al “Stencil Technology Evaluation For Miniaturized SMT Components” iMAPS New England Symposium and Expo 2013

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