Performance of Kapton Stencils vs Stainless Steel Stencils for Prototype Printing Volumes Processes

Hung Hoang
BEST Inc
Rolling Meadows IL
hhoang@solder.net

Bob Wettermann
BEST Inc
Rolling Meadows IL
bwet@solder.net

ABSTRACT

It has been demonstrated in numerous pieces of work that stencil printing, one of the most complex PCB assembly processes, is one of the largest contributors to defects (Revelino et el). This complexity extends to prototype builds where a small number of boards need to be assembled quickly and reliably. Stencil printing is becoming increasingly challenging as packages shrink in size, increase in lead count and require closer lead spacing (finer pitch). Prototype SMT assembly can be further divided between industrial and commercial work and the DIYer, hobbyist or researcher groups. This second group is highly price sensitive when it comes to the materials used for the board assembly as their funds are sourced from personal or research monies as opposed to company funds. This has led to development of a lower cost SMT printing stencil made from plastic film as opposed to the more traditional stainless steel stencil used by industrial and commercial users. This study compares the performance of these two traditional materials and their respective impact on solder paste printing including efficiency and print quality.

BACKGROUND

For some time there have been options in terms of the SMT stencil material for SMT prototype assembly. The most popular options, namely stainless steel and its derivatives, and mylar and its derivatives, are being used in printing solder paste for prototype and pilot production runs. While these are the most popular options for the prototyping market, a direct comparison of their printing performance has not been reported on. The work herein describes the outcomes of using these material types in SMT printing comparing their performance in the hand printing of solder paste, the release characteristics from the apertures and any geometric limitations based on SPI measurements.
Stainless steel and various derivatives used in SMT stencil printing is the most common commercial stencil materials. PHD material, one of the derivatives, is a high nickel content, small grain boundary material which has excellent release properties and is dimensionally stable meaning the apertures are not deformed during cutting. The smaller grain structure yields several benefits to the printing operation. These benefits include better release properties as the aperture walls are smoother. This surface also presents a cleaner surface for the paste to roll over and less places that the paste will remain once the paste is released. -

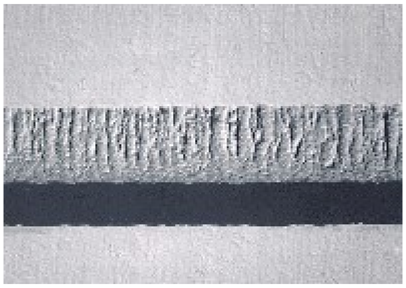

Figure -Smooth PHD sidewall

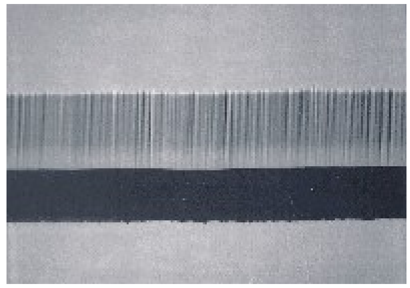

Figure -Typical stainless steel side wall

The other common materials used in prototype SMT stencil fabrication are polyimide and its derivatives. Kapton™, a DuPont derivative of the polyimide family, has very good heat withstand properties as well as strong dimensional stability, making it ideally suited for stencil printing applications. The laser will not heat up and distort the apertures; and the flatness of the printing surface to the PCB will not be impacted by the heat-producing laser aperture cutting process.

The SMT solder printing process takes on a variety of methods for new product introduction or prototyping where only a handful of boards need to be built. At one end of the spectrum is the same printing process in use for the alpha production run as will be used for production volume. This means using a fully automated stencil printing machine along with a framed metal stencil. On the other end of the spectrum a simple foil only, with no frames for tensioning or any fiducials for board alignment, is the simplest stencil set up. In this case the stencil is simply affixed to a flat surface where the printing will occur (usually with tape) and the board is visually aligned to foil typically using a corner of the board as a reference. After this is in place, a manual squeegee rolls solder paste through the apertures of the stencil with the "snap off", squeegee pressure, angle of squeegee impingement and other variables controlled manually. This is common practice for low volume PCB assembly.

TEST VEHICLE

The test vehicle used was a 6 layer test PCB having an immersion silver finish with an Enthone USR-7G *S* solder mask populated with a variety of SMT patterns. The device locations were chosen such that a variety of pitches in a variety of locations on the PCB would be evaluated in terms of the solder paste volume deposited on the pads. The device locations were as follows:

U6 80 pin QFP 0.80mm pitch
U13 44 pin QFP 1.00mm pitch
U19 20 pin SOIC 1.00mm pitch
U23 14 pin SOIC 1.00mm pitch

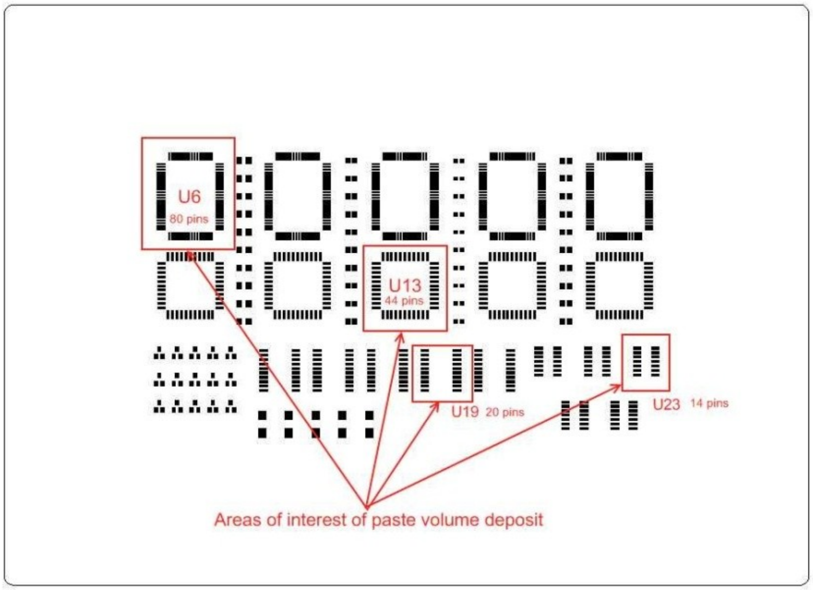

Figure -Location designators where solder paste volume measured with SPI

LASER CUT Kapton™ STENCILS

The Kapton™ used to fabricate the stencils was a type FPC as it has appropriate properties for stencil usage including the ability to withstand extreme heat as well as good dimensional stability. During the laser cutting process heat is generated locally which can cause the stencil material to deform and become non-planar near the wall edges. Dimensional stability is important so that after laser drilling of the stencil the hole dimensions and tolerances are held. Both of these phenomenon reduce the transfer efficiency of the solder paste being rolled through the apertures of a plastic stencil. Alternatively, Mylar is also being marketed as a stencil material. This material is not well-suited for stencil printing because during stencil cuts this material creates "ridges" around the apertures thereby reducing the co-planarity between the stencil and the PCB leading to smearing.

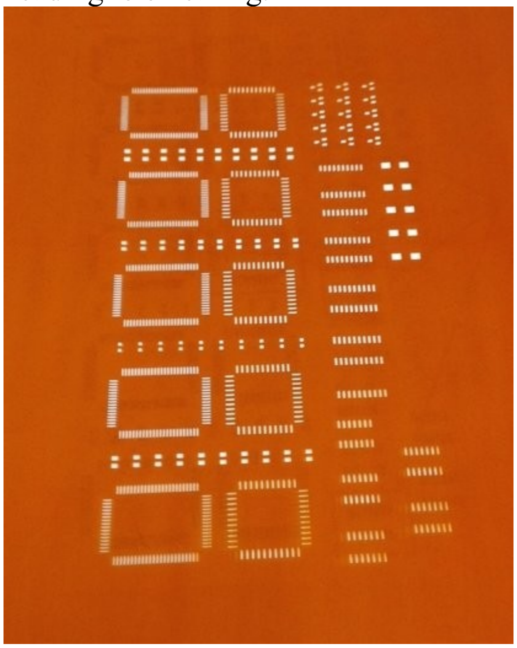

Figure Kapton(TM) Stencil

LASER CUT PHD STAINLESS STEEL STENCILS

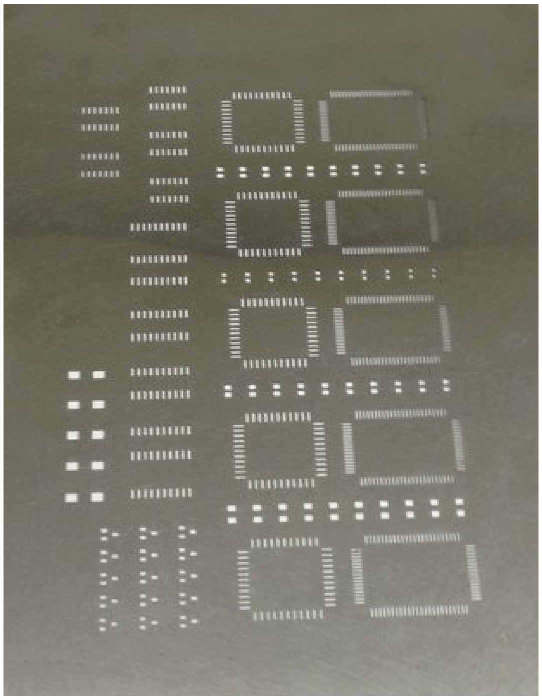

Figure -PHD stainless steel stencil

The type of stainless steel derivative used in this study was a high nickel content PHD stainless steel material.

EQUIPMENT AND CONSUMMABLES

The following equipment and materials were used in this study:

Solder paste-Qualitek 691A Type 4 no clean, set up at 24.4 degrees C, 71% RH
PCBs-BEST Inc solder training board, silver finish, 0.042" thickness
Manual squeegee-12" in length, stainless steel construction
SPI machine ASC VisionPro AP500.
PHD stainless steel YAG laser cut metal stencil, 5 mils in thickness
Dupont Kapton™ YAG laser cut stencil , 5 mils in thickness
Mitituyo Toolmaker's microscope TM-505/510 Series 176

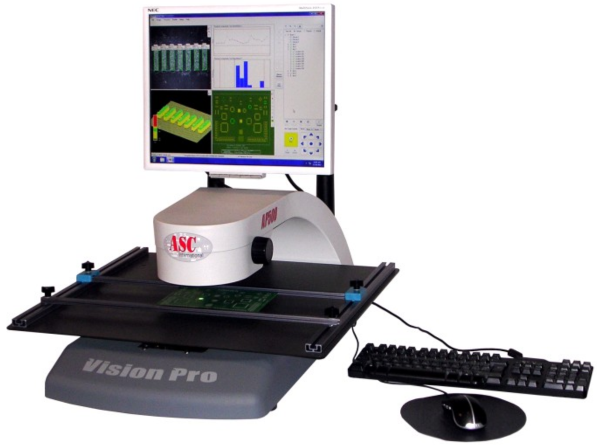

Figure -ASC Vision Pro 5000 used for SPI measurements

Experimental Procedure

Each of the stencils was cut using the same modified Gerber files. The GERBERS were modified based on a combination of the IPC-7525 recommended modifications as well as on CAD operator experience. The metal stencil was cut on an LPKF 355nm YAG source laser and the Kapton™ stencil on a Coherent Nd YAG laser operating at 355nm. The stencils, after being labeled for the correct position on the PCB, were measured with a toolmakers microscope. Measurements were also made on the PCB to confirm pad size. Gerber aperture measurements were taken right from the design tool.

Various locations on the stencil were measured and the expected volume was determined by measuring the actual thickness of the stencil multiplied by the area calculated by measuring the "x" and "Y" dimensional openings of the stencils as indicated in Figure 7 below:

Source of Dimension	U6 Aperture Dimension (mm) Avg of 3 random locations	U13 Aperture Dimension (mm)	U19 Aperture Dimension (mm)	U23 Aperture Dimension (mm)
GERBER file dimension	2.13 x .45mm	2.23 x .52mm	2.15 x .57	2.15 x .57
PCB pad dimension	2.14 X .48	2.23 x .56	2.17 x 59	2.16 x .56
Actual aperture dimension-Kapton ™	2.11 x .44	2.20 x .48	2.15 x .56	2.14 x .55
Actual aperture dimension-PHD ™	2.10 x .43	2.21 x .516	2.14 x .56	2.14 x 56

Figure 7 Listing of pad dimension and aperture dimensions

Starting with the Kapton (TM) stencil, it was aligned to the test PCB by first placing the stencil on a flat surface and affixing it with tape. An "L" shaped corner holder made from FR-4 was used to align the PCB in the same spot each time. This allowed the apertures' of the stencil to be aligned with the pads of the test PCB. Once in place, solder paste, after being mixed with a stainless steel spatula, was rolled through the apertures by hand using a 12" wide stainless steel squeegee.

After each subsequent print, starting at print (1) through print (10) select measurements of solder paste volume on each one of the locations were measured using SPI for solder paste volume and recorded .

After each measurement the board was cleaned using a Kimwipe and alcohol. This eliminated the variance found in typical PCB board measurements. This same sequence of events was repeated using the stainless steel stencil at the exact same locations on the stencil and board. The results were then recorded and 3D graphs were created by the SPI machine software.

VISUAL OBSERVATIONS

The visually observed print quality of the solder paste was similar between the two stencil materials up and including 0.8mm pitch components. For pitches less than this amount the print quality of the Kapton™ printed boards was inferior. Specifically pads of the finer pitched components looked "worn out" after a few print cycles as they were exercised back and forth. The once crisp hard rectangles became rounded. All deposits left of the finer pitched components were quite uneven and lead in many cases to insufficients.

RESULTS AND DISCUSSION

After accumulating all of the measurements, the data was loaded in to a spreadsheet for further analysis. This data is enumerated below in Figures AA-FF. 3-dimensional graphs were also outputted for each of the measurements with select graphs included herein in figures 7-10. After entering the data in to the spreadsheets, the nominal values of solder paste volume for each of the pad sizes for each of the reference designators was determined. Using the measured values of the aperture openings (3 apertures measured and averaged) and the measured thickness of the stencil, the theoretical volume was calculated. A measure of the transfer efficiency was then compared the actual to this theoretical value to determine what percentage of the solder paste volume was pushed through the stencil onto the PCB. This resultant value was calculated and marked as the transfer efficiency. In each of the cases the transfer efficiency for the plastic stencils was less than that of the comparable metal stencil.

Solder paste volume measurements (mils3)											
Plastic Stencil				U19			2 pad locations had inconsistent results				
Trial #	Location1		Location3		Location4		Location1				
	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Avg		
1	9351	8403	9234	9644	8422	9750	9618	8470	9112		
2	10963	9364	9868	9574	10354	9206	9815	8574	9715		
3	10639	9115	9445	9745	9847	8310	9448	8420	9371		
4	10427	8792	9516	9216	10443	9021	9291	9100	9476		
5	10217	8931	9668	9986	10373	9288	9516	9251	9654		
8	10084	7855	8905	9310	10464	8753	9099	7188	8957		
10	8784	10841	8890	9255	10534	8698	9667	8903	9447		
							Overall	Averag	9390.1		
							Theoretical volu		9798		
Stainless Stencil							Txf Efficiency		96%		
Trial #	Location1		Location2		Location3		Location4		Location1		
	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Avg
1	11328	11470	9923	10696	10663	11749	11132	12018	10954	10998	11093
2	11111	11195	9428	9778	9910	11088	11186	11286	10613	10714	10631
3	10763	11358	9541	9158	10208	11295	11705	11023	10084	10030	10517
4	10707	10437	8708	9531	9857	11084	10802	11072	9994	9785	10198
5	11473	10877	10644	11185	10707	11491	10781	11961	14483	11279	11488
8	11601	11758	11471	10526	10872	11933	11314	11562	10829	10673	11254
10	11395	11185	10991	9976	11072	12094	12186	10713	11725	11431	11277
									Overall	Averag	######
									Theoretical volu		10615
									Txf Efficiency		97%

Figure -Solder paste volume, U19 (mils3)

Solder paste volume measurements (mils3)

Plastic Stencil

Trial #	Location3		Location4		Location6		Location7		Location8		
	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Average
1	8275	6753	7099	7856	6731	5950	7478	6834	8023	6565	7156.4
2	10013	8260	8620	8362	8374	7838	8304	8075	7887	9306	8503.9
3	7550	6768	7486	7794	8878	7998	9080	9951	9097	7613	8221.5
4	8077	6852	6797	7783	8220	7559	8062	8482	8766	7527	7812.5
5	8323	6821	7117	7593	9939	9350	9414	9610	8178	9908	8625.3
8	8344	6899	7265	6393	8738	7763	7994	7992	6090	7727	7520.5
10	8364	6924	7737	7600	23611	111	10426	11248	8918	11149	9608.8
								Overall	Average	8207.0	
								Theoretical		8495.4	
								Txf Efficiency		97%	

Stianless Stencil

	U6										
Trial #	Location2		Location4		Location7		Location8				
	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Pad1	Pad2	Average		
1	10134	10166	6875	7721	10629	13507	9773	8599	9675.5		
2	10164	10175	6596	7281	8083	8199	9083	8568	8518.625		
3	9695	9956	14074	12312	9375	8613	9095	10291	10426.38		
4	11165	10631	11148	13870	11365	16114	9884	11395	11946.5		
5	11053	10807	6692	7484	10428	10313	9771	8551	9387.375		
8	10548	10729	7197	7828	8453	8639	9251	8658	8912.875		
10	11497	11485	14372	13706	9344	10517	10501	11727	11643.63		
								Overall	Average	10073.0	
								Theoretical volume		10150	
								Txf Efficiency		99%	

Figure -Solder paste volume, U6 (mils3)

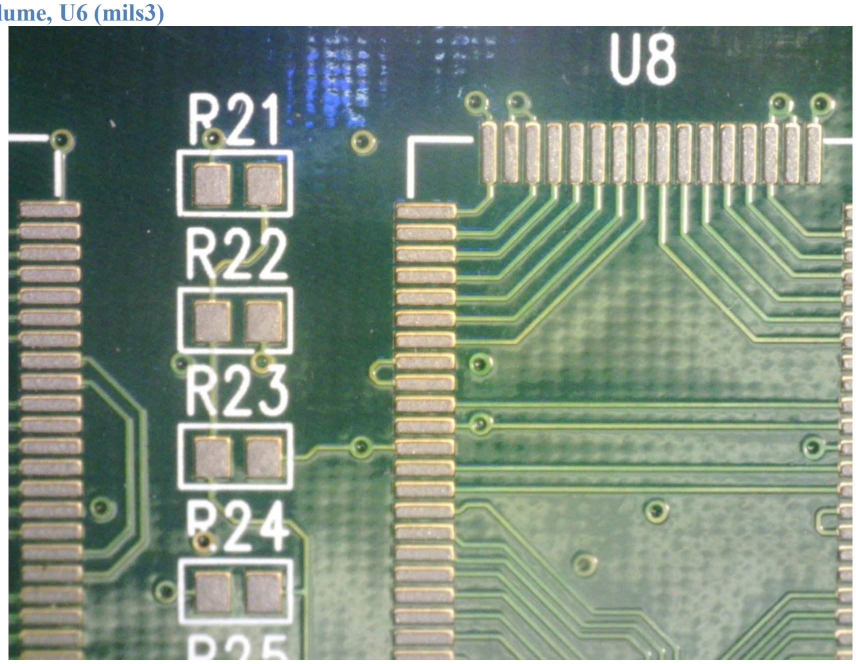

Figure -Stainless steel stencil print sample at U6

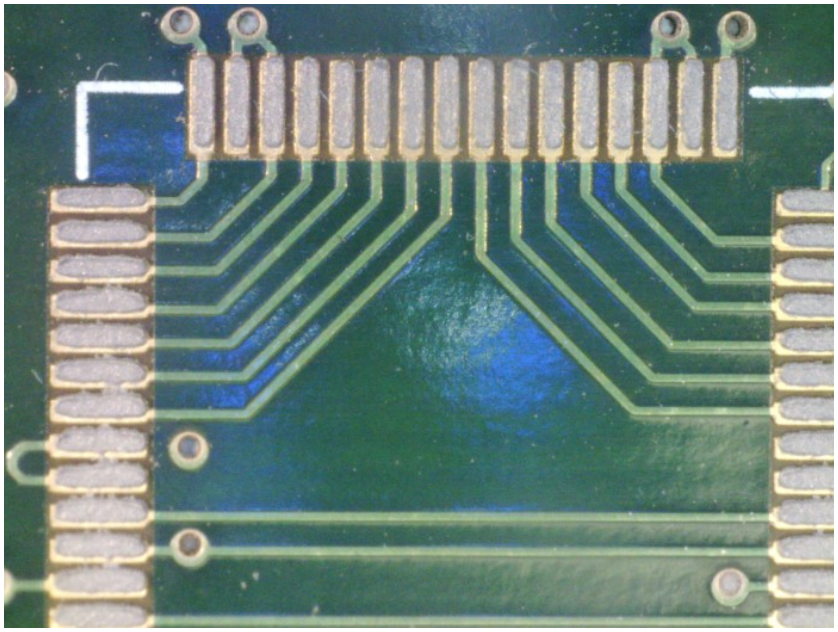

Figure -Kapton(TM) stencil print example showing smeared paste at U6

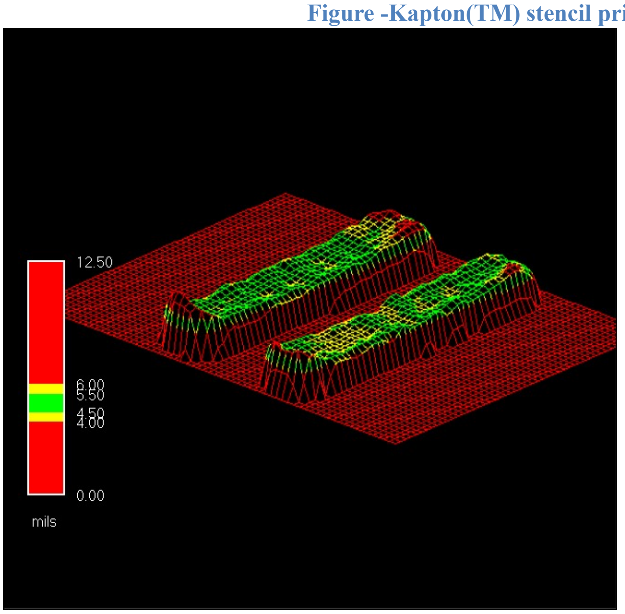

Figure -U6, Location 1 Showing "scooping" effect of Kapton™

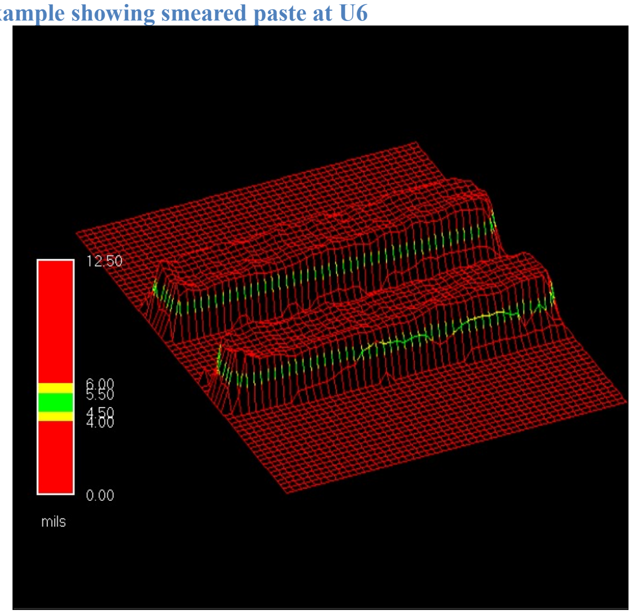

Figure - U6, Location 1 Stainless stencil

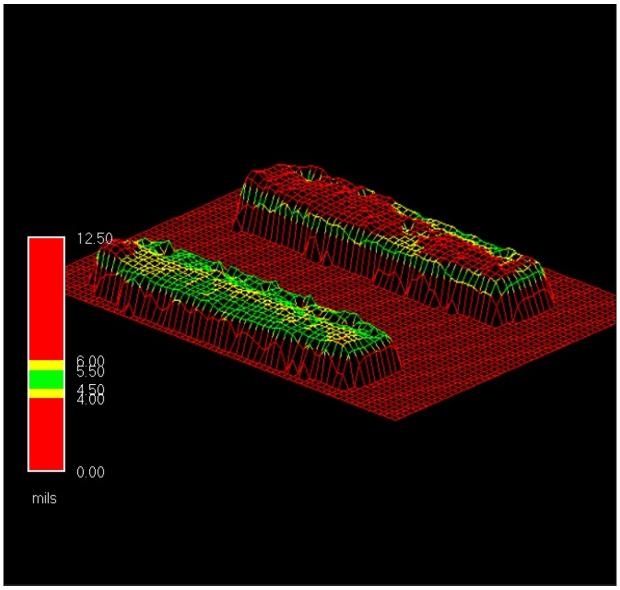

Figure -Kapton(TM) stencil "scooping' effect at U19, Location 3

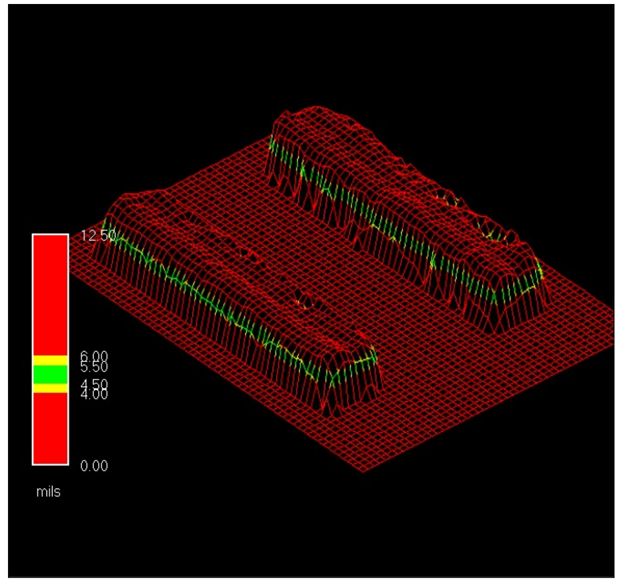

Figure - Stainless stencil U19, Location 3

Conclusions

For the hand printing of PCBs for low volume assembly there are very small differences between the results of paste printing 1.00 mm pitch and larger components using plastic Kapton™ and a high end PHD™ stainless steel stencils. Plastic stencils where the "scooping" of solder paste from the "softer" shore hardness Kapton stencils has a small but noticeable effect on solder paste volume (Figure 13-16). In addition, at these pitches, the detriments of the soft "webbing" between each of the SMT pads such as on a QFP do not deform the paste prints which can lead to paste "smearing". For pitches less than or equal to 0.80mm, both the "scooping" and the movement of the webbing phenomenon have a greater impact causing there to be a lower first pass print yield as the "smearing" of the solder paste becomes a more pronounced issue. The transfer efficiency of solder was in all cases less with the plastic. For the DIY developer, hobbyist or researcher the Kapton™ stencils provide adequate printing for SMT assembly stencils for the protype hand printing process.

Acknowledgements

Thanks to SPI vendor ASC and its applications engineer Steve Arneson who set up and operated the AP500 SPI solder paste inspection system to generate the data volume. A further thank you is order for EMS provider's BESTProto (Rolling Meadows, IL) Josh Husky who supplied his knowledge and skill in manual paste printing.

References:

1. Revelino, D. (1997). Achieving Single Digit DPMO in SMT Processes, Surface Mount International Proceedings, pp.697-702.

2. C. Ashmore, M. Whitmore, S. Clasper, "Optimizing the Print Process for Mixed Technology," SMTAI,October 2009.

3. IPC-7525, Stencil Design Guidelines.

5. G Burkhalter, E. Leak, C. Shea, R. Tripp, G.Wade,"Transfer Efficiencies in Stencil Printing" SMT May 2007.

6. Fleck, I., Chouta, P., "A New Dimension in Stencil Print Optimization," SMTA International, Rosemont,Ill., September, 2002.

7. W. Coleman, "Stencil Technology and Design Guidelines for Print Performance," Circuits Assembly, March, 2001.

8. Santos, D.L., et al. (1997). Defect Reduction in PCB Contract Manufacturing Operations. Computers and Industrial Engineering, 33(1-2), pp. 381-384.