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Characterising Stencil Printing of Surface Mount and Conductive Adhesives

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ABSTRACT

The increasing need for high-speed deposition of surface mount (SM) and conductive adhesive has generated an interest in stencil printing these materials as an alternative to the traditional dispensing method. The fine pitch printing performance of isotropic conductive adhesives (ICA), and the dot printing of surface mount adhesive (SMA) using both enclosed print head and metal squeegees are investigated here. This study evaluated a number of key aspects of printing with these materials whose material properties are significantly different of solder pastes. Stencil printing parameters were investigated and characterised. The benefit of using enclosed print heads was evaluated and found to be helpful when solvent loss was an issue. Different stencils were assessed for both for fine pitch printing and thick stencils for printing typical SMA dot deposits.

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1 Introduction

NPL has run a series of projects characterising stencil printing of solder paste. Typically adhesives are dispensed, but today adhesives are also commonly printed. The capability to stencil print isotropic conductive adhesives (ICA) and surface mount adhesives (SMA) has occurred to meet high-throughput assembly. The dispensing method has a number of advantages, which include easy control of deposit volume and easy maintenance and control of the rheological properties. The adhesive in dispensing is contained in a syringe, significantly reducing environmental degradation. However, when a high number of dots need to be placed there are good arguments for switching to a stencil printing process. The material requirements for stencil printing are different to dispensing. In printing the adhesive is required to roll on the stencil, fill the apertures under low pressure, and release cleanly from the aperture walls as the board drops. This presents a challenge to the material supplier who must balance the adhesive and cohesive forces in the adhesive to best match the printing requirements.

Previous work with solder paste characterised typical performance both with an enclosed print head and normal squeegee blades(1,2). This work will evaluate the printing properties of adhesives with both methods. The properties of adhesive require a different set-up and management of the process on the printer compared to solder pastes. In this work adhesives were assessed in two scenarios, one as a solder replacement with fine pitch stencil printing performance of ICAs through QFP type apertures, and secondly the printing through round apertures, dot type prints, with SMAs, were both investigated. Both materials were printed with an enclosed print head and normal metal squeegees. The evaluation includes assessments using different separation and print speeds, internal cartridge pressures, stencil thickness and environment conditions.

2 Experimental

2.1 Evaluation of print deposits

2.1.1 Isotropic conductive adhesives

A special fine pitch (down to 300 µm pitch) printed circuit board and stencil, TB37, were designed to evaluate fine pitch printing performance of ICA. Three stainless steel stencils, 75, 100, and 125 µm thick and laser cut were used. The aperture arrays were in orthogonal axis, with one axis aligned with the print direction. Figure 1 shows the board and stencil design. The design comprises five aperture group arrays that are in different columns and each of these comprises three sets of apertures of different pitches and two orientations. Each aperture group array comprises three aperture arrays of 0.4, 0.35 and 0.3 mm pitch in two orientations. The aperture group arrays are repeated in five columns to give a 1 X 5 pattern, and differ by increasing individual apertures by 5µm, between each group array. This was done to allow accurate matching of the stencil and pad apertures. The stencil does not have the surrounding dots around each aperture array; these dots were used as a reference for paste deposit measurements, and only appear on the PCBs.

A laser scanning profiler (UBM with a triangulation sensor) was used to measure the ICA deposits. Because ICA have higher adhesive forces than solder paste the release process tends to create “dog-ears” (extended cusps) on the print deposit. The size, numbers and positions of the “dog-ears” vary with stencil aperture size, thickness and separation speed. This distorted shape proved difficult to analyse and produce a shape factor, *wall-angle,* by the PVO programme(3). Only print volume was selected to characterise the print deposit (3). Print volume is given as a ratio to the stencil aperture volume. A microscope was used to show the shape of deposits, and check the adhesive left on the stencil after the printing.

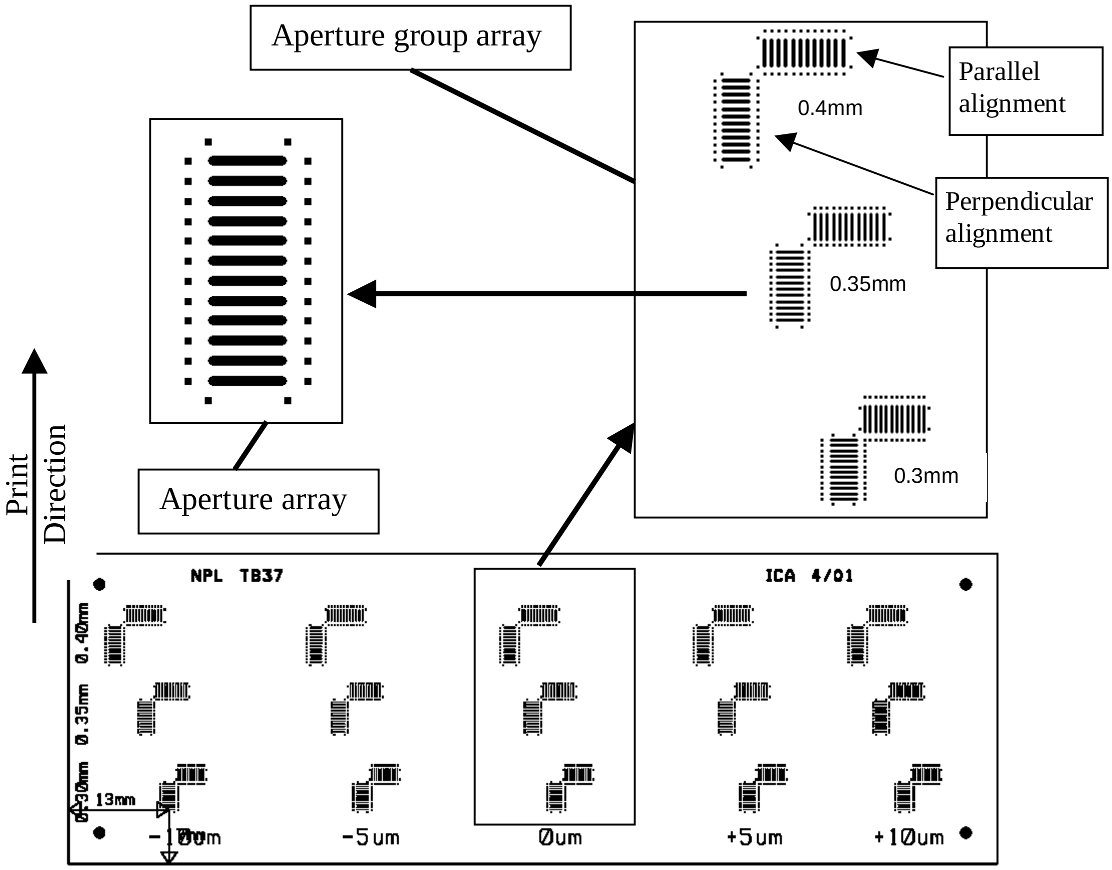


Figure 1: Test board and stencil design for conductive adhesives

2.1.2 Surface mount adhesives

Two stencils, TBa and TBb, were used for SMT adhesive printing. TBa is a 150 µm thick laser cut stencil contains three 0.45mm round apertures. TBb is a 1000 µm thick polymer stencil designed with a range of round apertures, which range from 0.6mm to 2.0 mm in 0.2 increments, as shown in Figure 2. The adhesives were printed on FR4 copper foil boards.

A laser scanning profiler (UBM with a auto-focus sensor) was used to measure the SMA deposits. Because the SMA poorly reflects light, a thin layer of gloss white paint was sprayed over the print deposits and board to increase reflection, as shown in Figure 3. Dot volume and height were selected to characterise the print deposit (3). The dot volume is given as a ratio of stencil aperture volume. The dot height is the maximum height of adhesive deposit, shown in Figure 3.

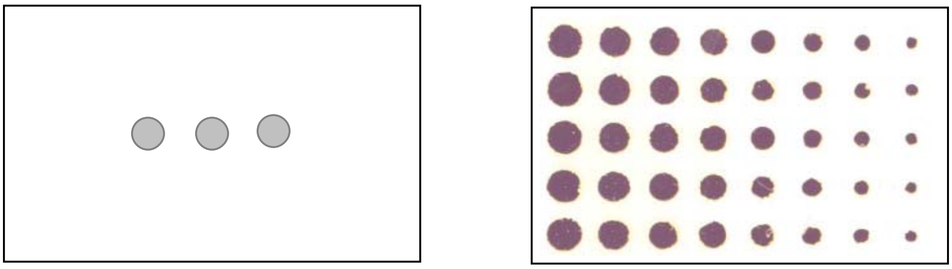


Figure 2: The stencils TBa and TBb.

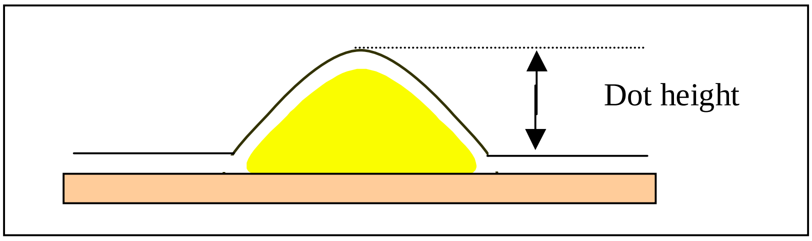


Figure 3: The dot height of SMT adhesive

2.2 *The stencil printing of adhesives*

2.2.1 Printer and adhesives description

All the printing reported here was conducted on DEK 265 GSX printer. Both an enclosed print head and normal squeegee blades were used for the printing. The enclosed print head was DEK ProFlow 265 GSX, and the squeegee was 60° permalex metal squeegee. The enclosed print head had 300mm working length, and metal squeegee had 170mm working length. Two commercial ICAs, A and B, and two SMA, C and D were printed. A and B are both epoxy, silver filled isotropic conductive adhesives, and A was supplied in pot form, and B was supplied in a syringe, both for the squeegee printing. The epoxy adhesives, C and D, were both supplied in cartridges for the enclosed print head printing. For the squeegee trials of C and D material was removed from the cartridge. The materials were provided by and Emerson & Cuming, Heraeus, Kester Solder and Loctite.

2.2.2 Printing at different print and separation speed with various stencils

The first assessment was with ICA A and this was printed using stencil TB37, with metal squeegees, at different separation speeds, 0.1, 1, 5 and 20 mm/sec. For each print setting the deposit was photographed using a microscope. The print separation speed was critical for adhesive printing, and the slow speed was selected as this generally gave the best performance and was used to evaluate the other print parameters. The printer parameter settings and the stencil used for the printing using the print head and squeegees for each adhesive are listed in Table 1. The parameters in bold in each section indicate the variable under investigation.

Table 1: Experimental conditions for adhesive evaluation

Print speed (mm/sec)	Print load (Kg) (squeegees) / Internal cartridge pressure (bar)	Stencil thickness (µm)	Separation speed (mm/sec)
Conductive adhesive **A** using stencil **TB37** with **squeegees**			
50	2.0	100	0.1
75	2.8		
100	3.4		
50	2.0	**75**	
		100	
		125	
50	2.0	100	**0.1**
			1
			5
			20
Conductive adhesive **A** using stencil **TB37** with **enclosed print head**			
50	2.0	100	0.1
75			
100			
50	2.0	**75**	
		100	
		125	
Conductive adhesive **B** using stencil **TB37** with **squeegees**			
50	1.0	75	0.1
150	1.0		
Surface mount adhesive **C** and **D** using stencil **TBa** with **squeegees**			
50	2.6	150	0.1
75	3.2		
100	3.8		
Surface mount adhesive **C** and **D** using stencil **TBa** with **enclosed print head**			
50	2.0	150	0.1
75			
100			
Conductive adhesive **C** using stencil **TBb** with **enclosed print head**			
50	2.0	1000	0.1
75			
100			
50	**1.5**	1000	0.1
	2.0		
	2.5		

All printing was conducted at 22°C/40% RH. ICA A was printed using stencil TB37 with both the enclosed print head and metal squeegees at different print speeds and stencil thicknesses. Eight prints were printed for each print speed and stencil thickness. The deposits measured were from perpendicularly aligned apertures, 400, 350 and 300 µm pitch in the middle column of the aperture group array. The results taken for all set ups were the average from the 6th and 8th boards. ICA B was printed using metal squeegees with stencil TB37 at 50 and 150 mm/sec print speeds. The print deposits were also inspected under a microscope. SMA C and D were printed onto a plain copper foiled FR4 board using stencil TBa with the both enclosed print head and metal squeegees at different print speeds. Adhesive C was also printed using the thick polymer stencil TBb with the enclosed print head at different print speeds and internal cartridge pressures. Eight prints were printed for each speed and pressure.

Measured deposits: The deposits measured for the printing with stencil TBa were three 0.45 mm dots. The deposits measured for the printing with the stencil TBb were five dots for each diameter aperture. The average of 10 dots for each aperture size was taken. To avoid stringing when printing with the thick 1000 µm polymer stencil TBb, a 1 mm gap between the board and stencil was set.

2.2.3 Printing with different environment conditions

To asses the stencil life of ICA A and SMA C and D, these materials were printed under the harsh environment condition of 28°C/75%RH, using both the enclosed print head and conventional metal squeegees. ICA A was also printed at 22°C/75%RH using metal squeegees. The printing parameter settings, environment conditions and stencil used for the printing are listed in Table2.

Table2: Experimental conditions for environmental evaluation

	Adhesive	Printing environ-ment	Print time (hour)	Print load (Kg)	Print Speed (mm/sec)	Stencil & thickness (µm)	Separation speed (mm/sec)
Squeegee	A	22°C/75%	0	2.0	50	100 (TB37)	0.1
			2	2.0			
			4	2.6			
			6	3.4			
		28°C/75%	0	2.0			
			2	3.0			
			4	4.2			
			6	No printing, adhesive became solid			
	C	28°C/75%	0-6	3.2	50	150 (TBa)	0.1
	D		0-6	3.2			
Enclosed print head	Adhesive	Printing condition	Internal cartridge pressure (bar)		Print Speed (mm/sec)	Stencil thickness (µm)	Separation speed (mm/sec)
	A	28°C/75%	2.0		50	100 (TB37)	0.1
	C					150 (TBa)	
	D						

The adhesives were continually printed over a 6 hour period. Eight prints were printed at 0, 2, 4 and 6 hours after the start of printing. The deposits measured are the same as those described in 2.2.2. In between taking sample prints, adhesive was conditioned by moving the adhesive backwards and forwards on a blank area of the stencil, as shown in Figure 4. it was found necessary to increase the print load for the squeegee with conductive adhesive A so as to maintain a clean stencil, since during a 6 hour period the adhesive became harder due to curing and solvent loss.

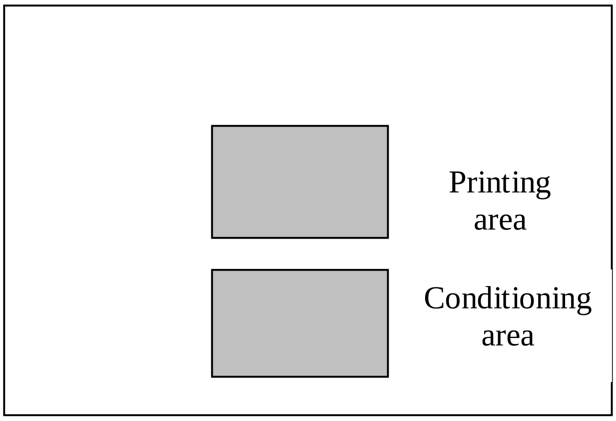


Figure 4: Printing and conditioning areas on the stencil

3 Results and Discussion

3.1 The effect of separation speed on printing ICA

The printed ICA A deposits through the 0.35 mm aperture with different board separation speeds are shown in Figure 5, and clearly show dramatic effects of board separation speed on the print deposit shape. Increasing separation speed from 0.1 to 20 mm/sec, the “dog-ear” deposit increases in size with print deterioration. The lowest separation speed, 0.1 mm/sec, produced the most consistent deposit, and was therefore was used for the print speed and stencil thickness study.

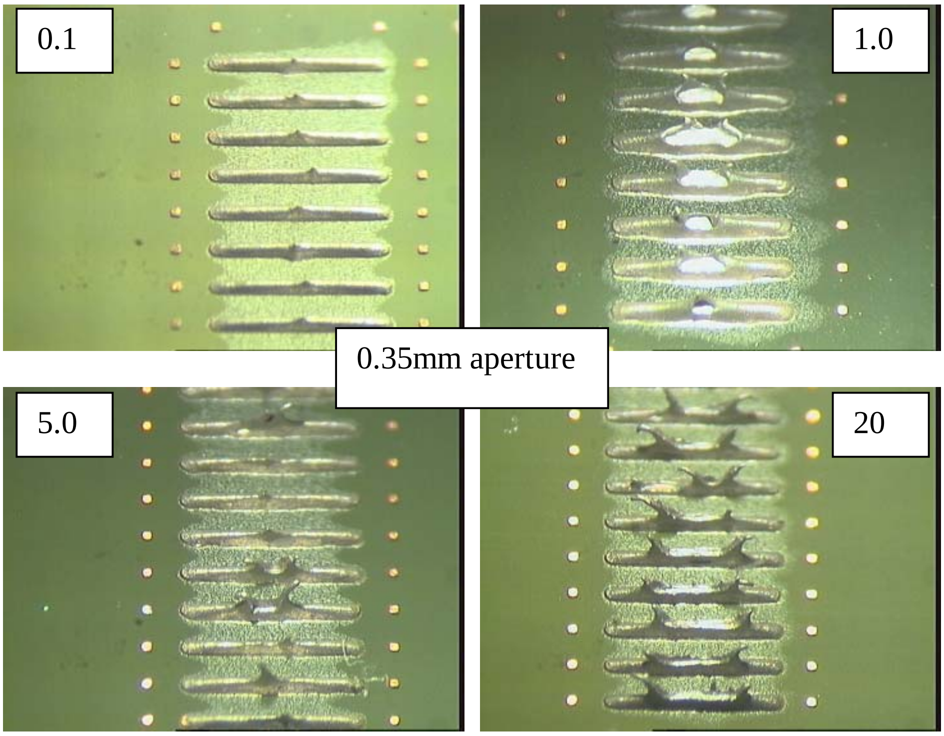


Figure 5: The print deposits with different separation speeds for IC adhesive A

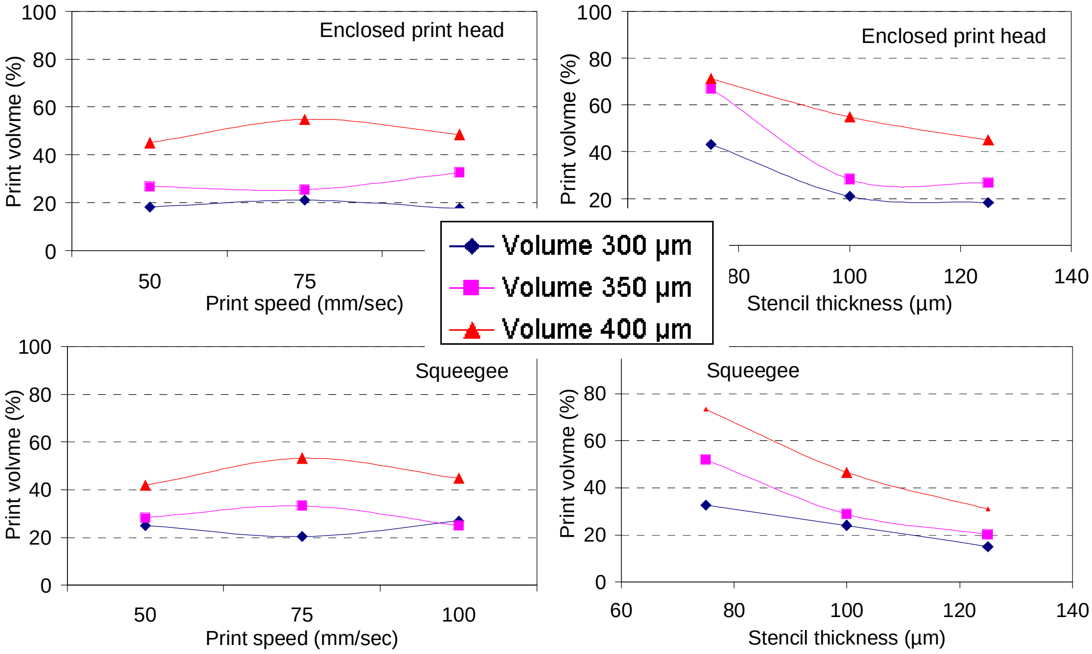
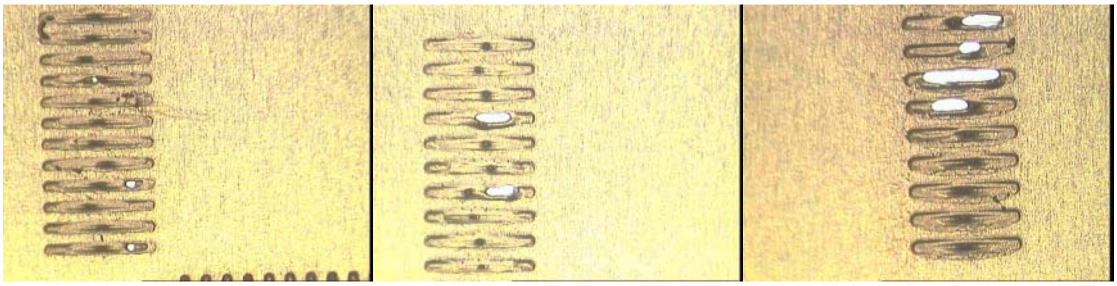


Figure 6: Print volume with print speed and stencil thickness for conductive adhesive A

3.2 The effect of print speed and stencil thickness on printing ICA.

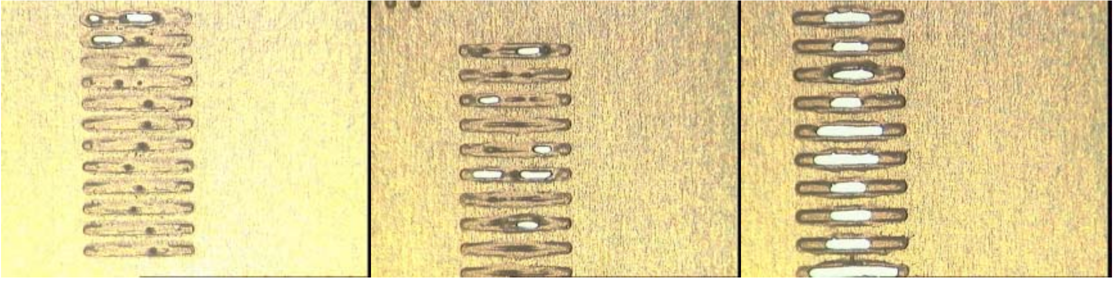
The effect of print speed and stencil thickness on the printed volume of ICA A using enclosed print head and metal squeegees are plotted in Figure 6, and the important points are :

- Both enclosed print head and metal squeegees showed similar printing performance for conductive adhesive A.
- Print speed did not affect the print volume.
- However the fractional volume significantly dropped with stencil thickness increase and the stencil aperture decrease.
- The print volume was much lower compared with solder paste printing(1), particularly on fine pitch apertures, 350 and 300 µm, with thick stencils, 100 and 125µm.



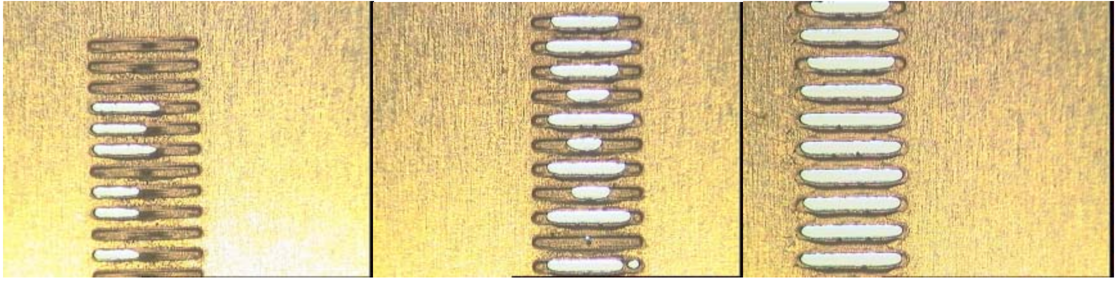
300µm 350µm 400µm

(125µm stencil)



300µm 350µm 400µm

(100µm stencil)



300µm 350µm 400µm

(75µm stencil)

Figure 7: Pictures of the stencil apertures after 8 prints for conductive adhesive A

The differences between the material characteristics of adhesives and solder pastes are now considered. In both systems the interplay between the cohesive and adhesive forces are critical to performance. In both systems the magnitude of the two forces will change broadly in line with each other. Hence, the adhesive will have higher adhesive and cohesive forces than solder paste. During board separation there is an interplay between various forces, there are the interfacial adhesive forces between the board and the aperture walls, there are the cohesive forces maintaining deposit continuity, and gravity. A set of images in Figure 7 shows the degree of aperture blocking as the aperture and stencil dimensions are varied. The images are arranged on a 3x3 array of increasing aperture size and increasing stencil thickness. Crossing the matrix at 45° the level of blocking changes, being most open at the bottom-right, the widest aperture and thinnest stencil, and blocked at the top-left corner, the narrowest aperture and thickest stencil. Clearly the ratio of the aperture wall area to the aperture opening area for the apertures is going to be important in the relative balance between the adhesive forces between the deposit and the pad and the deposit and the aperture wall. The ratio of aperture wall area to the aperture opening area (Wall / Open), for the three aperture and stencil sizes, are shown in Figure 8.

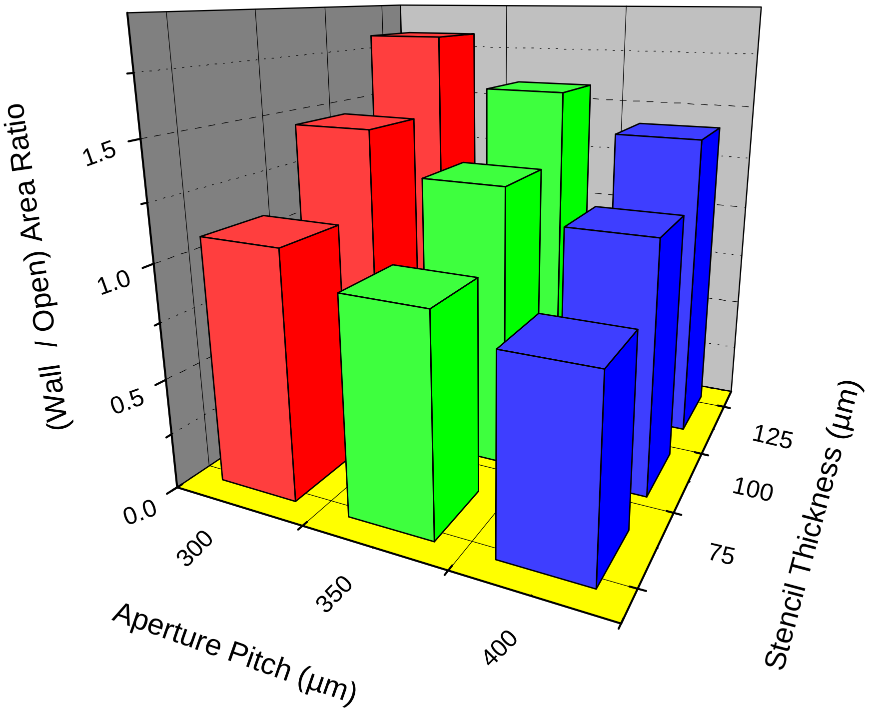


Figure 8: The ratio of aperture wall area to the aperture opening area for the range of apertures and stencils

Figure 8 clearly shows that there is a factor of 2 between the extremes, and hence with materials with high adhesive forces this ratio will be important. With the high wall/open ratio of the 300µm aperture in the 125µm stencil, the much larger aperture wall area provides significant contact area for the adhesive to adhere to, and this is much higher than for the pad contact area on the board. There clearly is a connection between the blocking of the apertures seen in Figure 7 and the aperture wall/open ratio, shown in Figure 8. This is quantified in Figure 9 where this ratio is plotted against the blocked percentage for each aperture. The results show there is a clear trend between these two variables, and that for good printing and no blocking of the apertures the ratio should be less than 0.8. The results also support the concept of aperture wall/open ratio approach but the precise values will depend on the adhesive forces of the material and the aperture shape. Clearly with solder pastes apertures will not normally block until this ratio is much higher, probably in the region of 4. A family of curves such as that in Figure 8 could be generated for materials using different aperture designs and stencil thickness, and hence a performance map could be created.

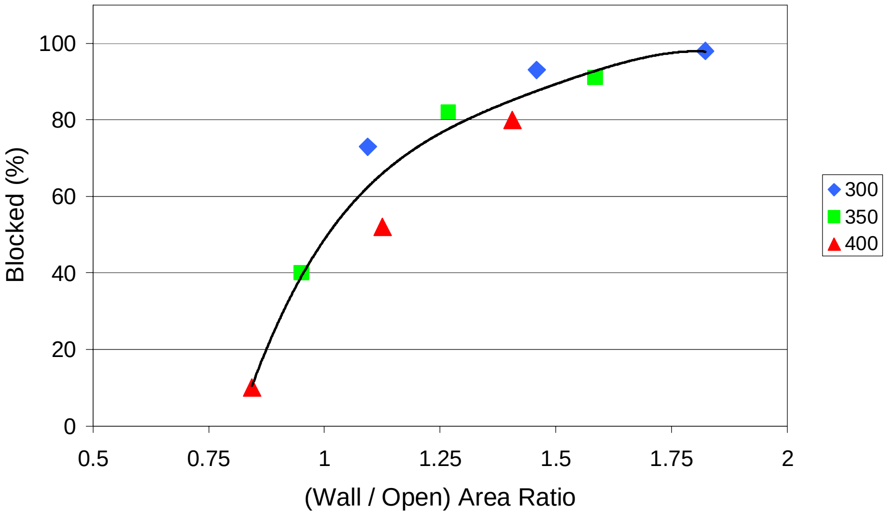


Figure 9: Aperture blocking with ICA A as a function of aperture wall/open ratio

Inspection of the print deposits on the boards and the degree of aperture blocking seen in Figure 7, reveals similarities with the pump printing process. The prints on the boards and a view of the apertures are shown in Figure 10, where also a schematic of the adhesive release from the aperture is shown.

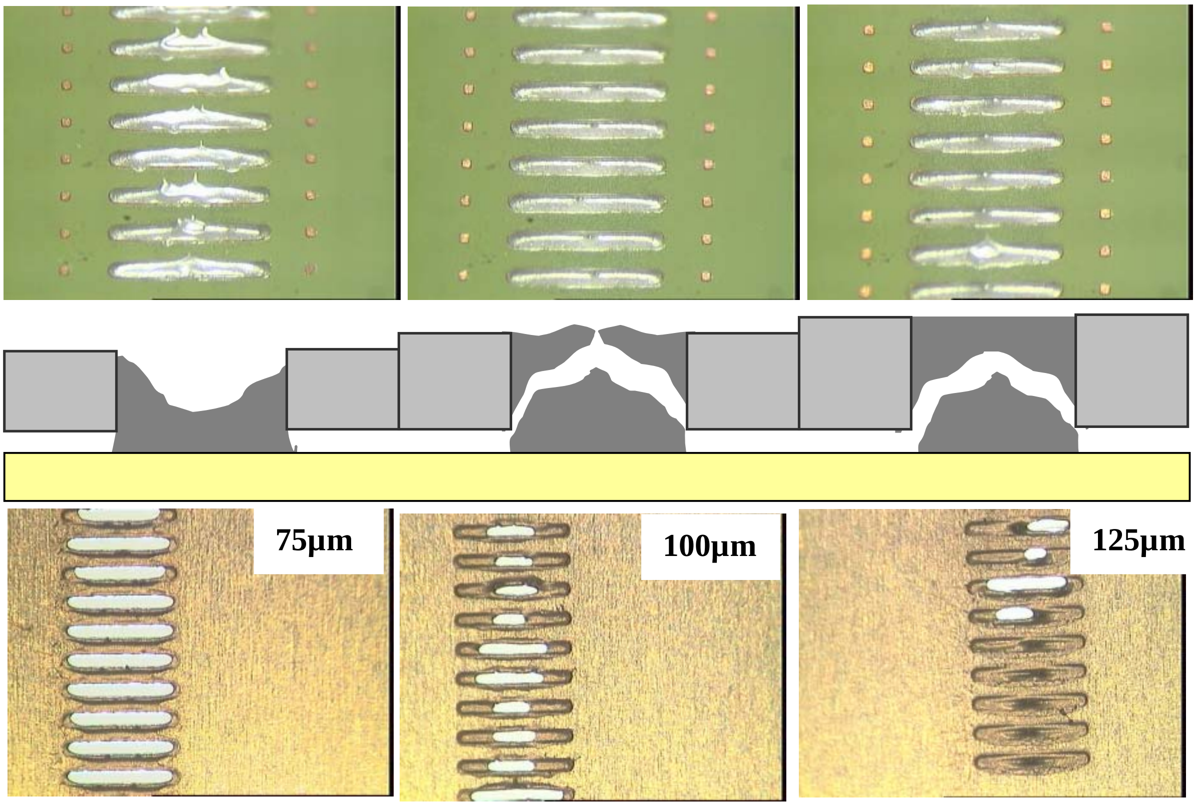
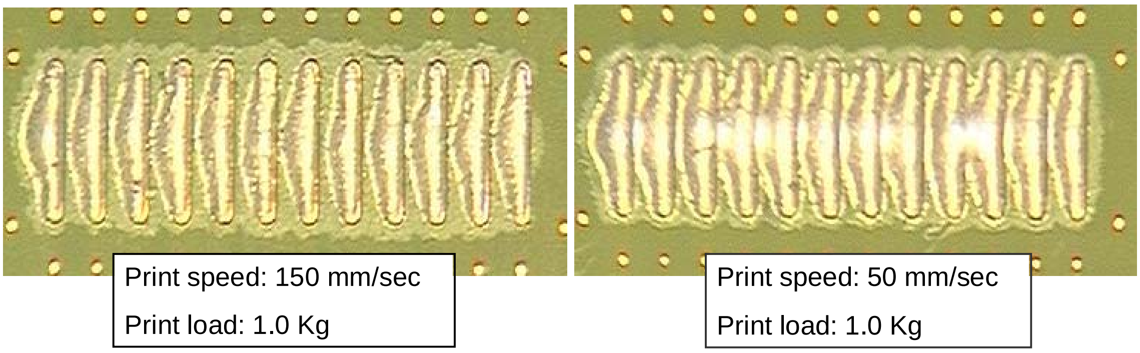


Figure 10: The release process (400µm pitch aperture)

The schematic in Figure 10 is consistent with both the reduced fractional print volume, as measured in Figure 6, and that printing continues even with blocked apertures, particularly for the thicker stencil. The diagram clearly indicates that the cohesive force in the adhesive is insufficient to retain integrity of the deposit, with the presence of the strong adhesive force exerted from the aperture wall. For the 125µm aperture the adhesive passes through the aperture in a two stage process: first the ICA fills the half empty aperture, pushing the existing adhesive down to the bottom of the aperture, then during the next print the adhesive is only lost from the lower half of the aperture, and then our adhesive is then pushed to the bottom of the aperture with the next stroke of the squeegee blade for printing onto the board. The trend seen in Figure 10 indicates that to achieve higher volumes on the board the aperture size should be increased rather than the stencil at these critical aperture sizes.

IC adhesive B was also printed with different print speeds using 100µm stencil and the metal squeegees. It was difficult to achieve quality fine pitch printing for this adhesive, as shown in Figure 11. The print deposit was badly slumped. The viscosity of the adhesive A and B were measured, adhesive B was 766 cps, much lower than that of adhesive A at 45,000cps. These results confirm that for a printable ICA the viscosity needs to be much higher than that of a dispensable ICA.


Print speed: 150 mm/sec
Print load: 1.0 Kg

Print speed: 50 mm/sec
Print load: 1.0 Kg

Figure 11: The print deposits for IC adhesive B with different print speeds

3.3 *The effect of print speed with SMA*

3.3.1 Standard stencil investigation

The dot height and volume were measured for SMA C and D as a function of print speed using both enclosed print head and squeegees, and the results are plotted in Figure 12. The salient points are:

- For the same SMA the dot height and volume were similar for both the enclosed print head and squeegee printing.
- Print speed did not affect the dot height and volume.
- Although both SMAs, C and D, had similar dot volume, the dot height of adhesive D was much higher than adhesive C.

The dot height is very material dependent and for the same stencil two dot heights were observed, and we can see from Figure 12. The dot heights for SMA could be above or below the stencil thickness. Typical PVO height profiles for these two adhesives are shown in Figure 13. The dot shape and height are significantly different between the two adhesives. This difference can be attributed to their respective yield points and release characteristics from the aperture. Yield point plays an important role in determining whether a dot will tend to string and form a peak or collapse (slump)⁽⁷⁾. This performance is important as dot height is a critical parameter in SMA performance.

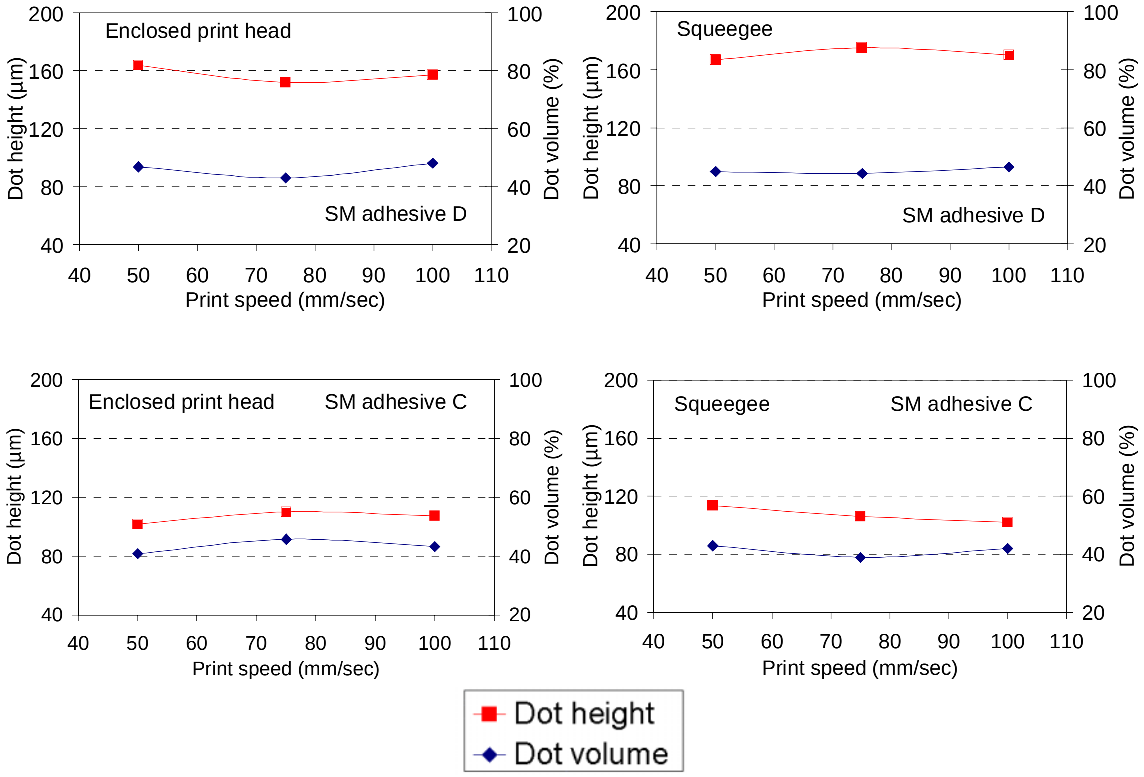


Figure 12: Dot height and volume with print speed for two SMAs

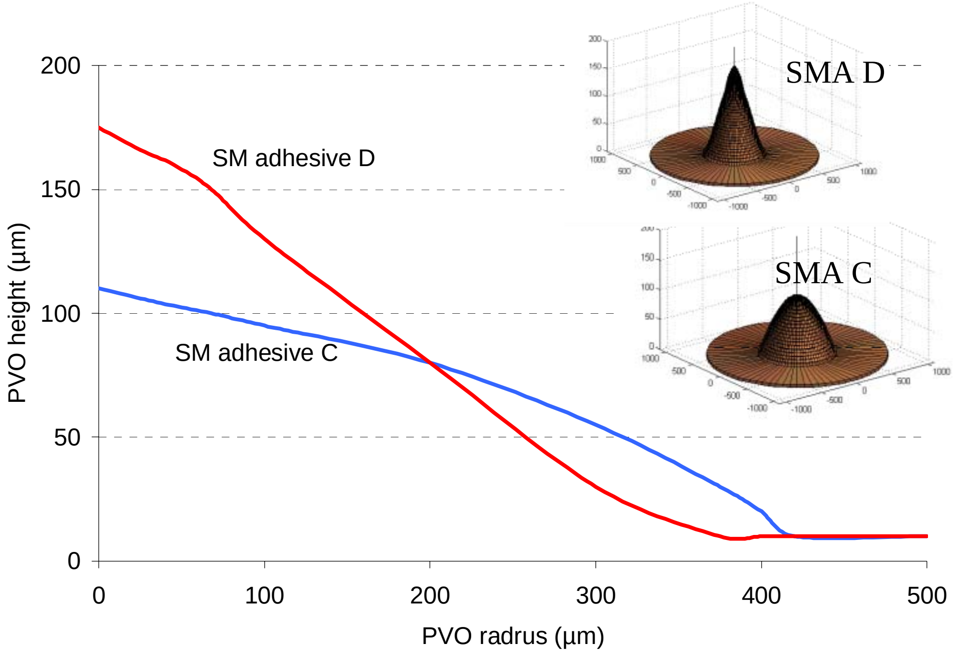
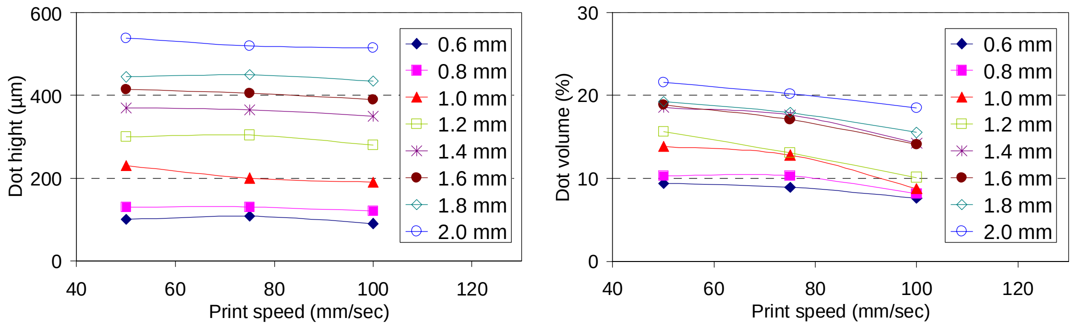


Figure 13: Typical PVO profiles for SMA C and D

3.3.2 Thick polymer stencil investigation

SMA C was printed using a thick polymer stencil using an enclosed print head. The stencil was manufactured from a 1mm thick nylon type material and comprised a range of circular apertures, from 0.6 to 2.0mm. The dot height and volume with print speed and internal cartridge pressure are plotted in Figure 14. The internal cartridge pressure for the print speed tests was 2.0bar, and the print speed was 50mm/sec for the internal cartridge pressure evaluation. Dot volume decreased with print speed, but increased with internal cartridge pressure. However, dot height was not affected by print speed or internal cartridge pressure. This implies that the aperture filling is more critical with a thick polymer stencil, than with conventional metal stencils, typically in the range of 100-200 µm. Lower print speed and high internal cartridge pressure significantly improve the aperture filling for the thick polymer stencil, and increase the dot volume. However the dot height was dependent on the individual adhesive, not the print speed and pressure.



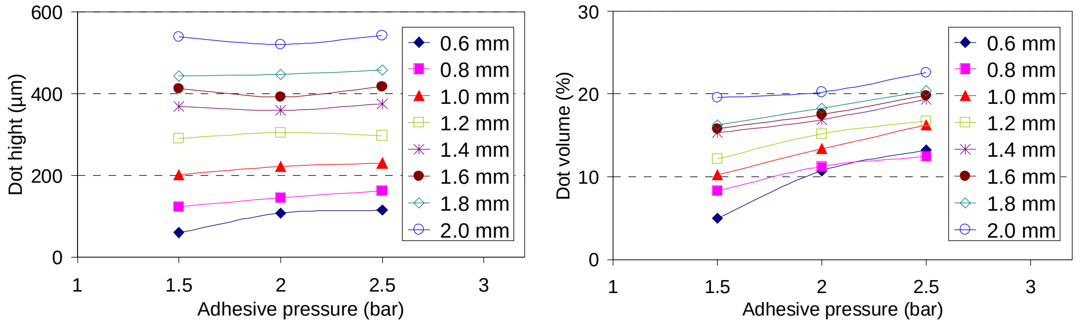


Figure 14: Dot height and volume with print speed and internal cartridge pressure for SMA C

Figure 15 shows that dot height and volume increase linearly with aperture size. Therefore, using a single thick polymer stencil, it is possible to deposit different dot heights by the controlling the aperture size. This phenomenon of being able to print multiple dots of various heights simultaneously makes stencil printing of SMA an attractive alternative to dispensing.

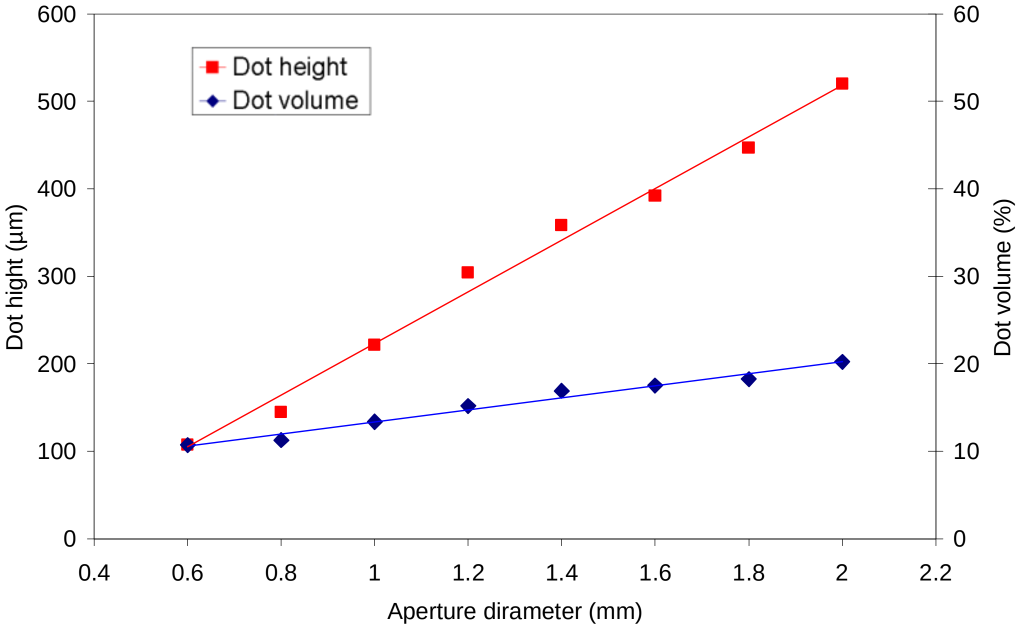


Figure 15: Dot height and volume of SMA C with aperture diameter

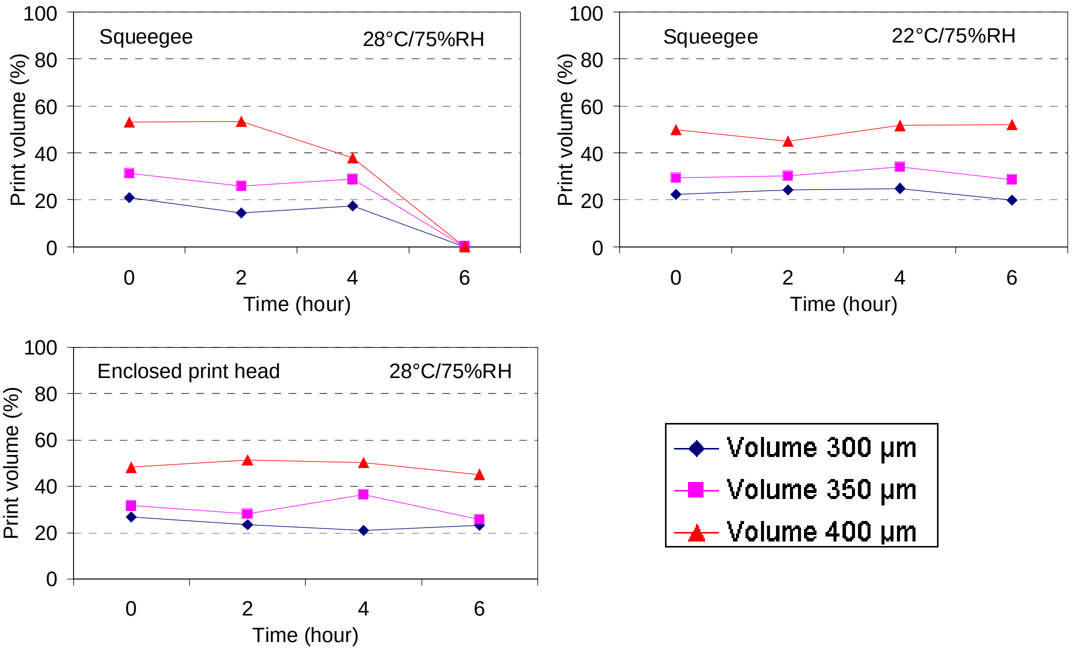


Figure 16: The effect of environment conditions on print volume for ICA A with an enclosed print head and metal squeegees over extended printing period

3.4 *The effect of environmental conditions on stencil printing of ICA and SMA*

3.4.1 ICA

Figure 16 reveals the impact of environmental conditions on print volume over a 6 hour period, for ICA A using an enclosed print head and metal squeegees. High humidity is known to be more detrimental to print systems than higher temperatures; hence the study here is just for high humidities. The squeegee results show after 4 hours at 28°C/75%RH printing ceases, but for 22°C/75%RH printing is still fine. Printing stopped as the adhesive became stiff and no longer rolled, and print volume was dramatically dropped. By contrast with the enclosed print head the print volume was constant during the 6 hours of printing at the same environmental condition. Reducing the environment temperature to 22°C for squeegee printing implies that degradation of the adhesive is caused by solvent loss, and hence at the higher temperature solvent loss is accelerated. The enclosed print head limits ICA degradation by preventing solvent loss, and prolong the stencil life of the adhesive. However, using an ICA in an enclosed print head may not be a practical consideration, unless high volume usage is anticipated. These materials must be stored at –40°C to avoid any curing. Generally, at room temperature the ICA will have less than 12 hours stencil life due to curing.

3.4.2 SMT adhesives

Figure 17 presents the results for print volume with time for SMA C and D using both the enclosed print head and metal squeegees at 28°C/75%RH. The results clearly reveal that for both techniques consistent printing, with no particular change in terms of dot height and volume, over the 6-hour period was obtained. These results confirm these materials have a long stencil life, in excess of 6 hours.

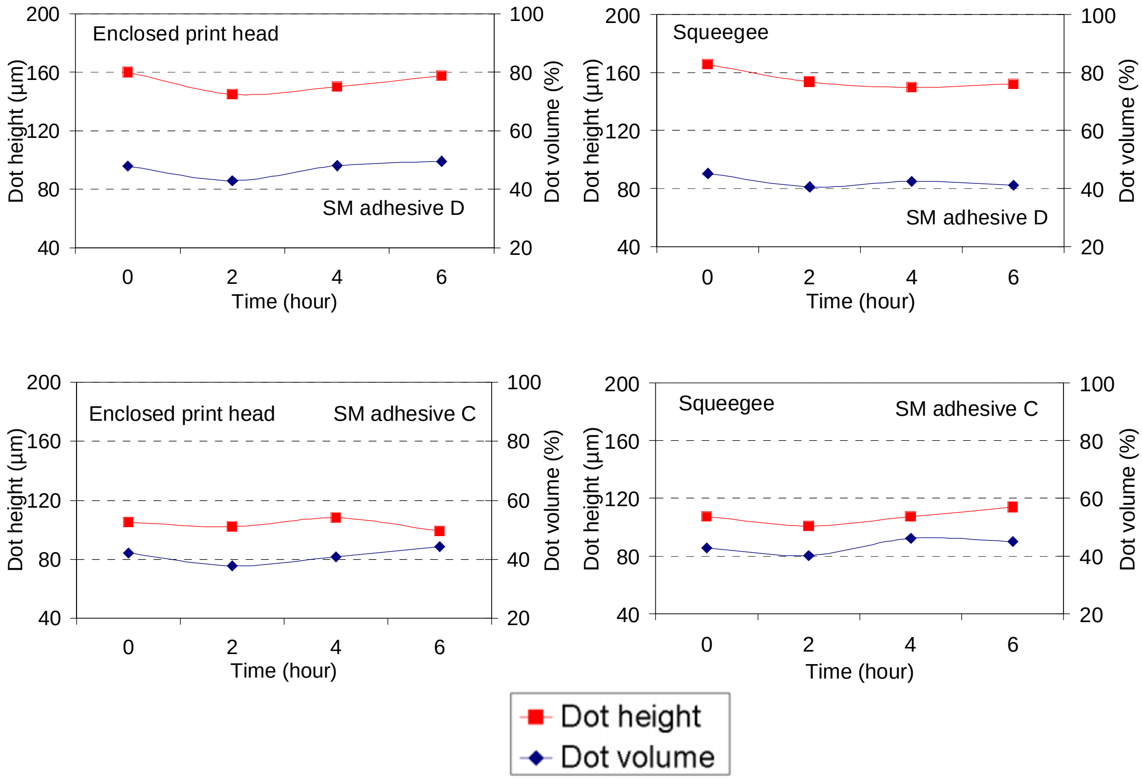


Figure 17: The effect of environment conditions on print volume for SMA C and D with an enclosed print head and metal squeegees over extended printing period at 28°C/75%RH

4 Conclusions

This work has shown that ICAs and SMAs can be successfully stencil printed, both with squeegee and enclosed print head systems. The SMAs proved to be very robust materials and stencil print under a wide range of conditions. The ICAs proved to have limitations with fine pitch printing, which has implications as a solder replacement.

- Under elevated temperature and humidity conditions the two types of materials behaved differently. The SMAs proved to have long stencil lives and the extra protection from the enclosed print head did not offer any superior performance. However, with the ICA materials tested here curing and solvent loss were an issue and the enclosed print head did confer useful benefits, particularly in limiting solvent loss.

Isotropic conductive adhesives:

- Fine pitch printing of ICA is unlike solder paste printing. Material release from the stencil aperture is more of an issue with the higher adhesive forces. Hence the print volume is much lower than with solder paste.
- Print volume was dependent on aperture size and stencil thickness, but not print speed. The fractional printed volume dramatically drops with stencil thickness

increase. It is necessary to maintain a sufficiently low aperture wall / open ratio that allows clean material release without aperture blocking.
- Where apertures are tending to block it is more important to increase the aperture size, rather than the stencil thickness, to increase print volume.
- Separation speed between the printed board and stencil significantly affects the print quality when the material has high adhesive forces, in which case slow speeds are more advantageous.
- Successful printing of ICAs does require the adhesive have a high viscosity.

Surface mount adhesives:

- Printing SMA dots with a conventional metal stencil, the print speed does not affect the dot height and volume. However, the dot height is very dependent on the material rheology properties. The printed dots can be higher or lower than the stencil thickness.
- For thick polymer stencil, low print speed and high internal cartridge pressure significantly improve the aperture filling, and increase dot volume, but not dot height. A single stencil thickness can produce multiple dot height by varying the aperture size. This phenomenon of thick polymer stencil printing makes the stencil printing of SMA attractive, as multiple dots of varying height can be printed simultaneously.

5 Acknowledgements

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