

**Fine Pitch Stencil
Printing Using Enclosed
Printing Systems**

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CONTENTS

1. INTRODUCTION	1
2. EXPERIMENTAL.....	1
2.1. EVALUATION OF PRINTING DEPOSIT	1
2.2. FINE PITCH STENCIL PRINTING.....	2
2.3. FINE PITCH PRINTING UNDER DIFFERENT ENVIRONMENTAL CONDITIONS.....	2
2.3.1. One day continuous printing	3
2.3.2. Intermittent printing of solder paste using an enclosed print head.....	4
2.4. FINE PITCH PRINTING ONTO DISTORTED SUBSTRATES	4
3. RESULTS AND DISCUSSION	5
3.1. THE EFFECT OF DIFFERENT ENVIRONMENTAL CONDITIONS ON FINE PITCH PRINTING PERFORMANCE.	5
3.1.1. One day continuous printing	5
3.1.2. Intermittent printing with enclosed print head	7
3.2. FINE PITCH PRINTING ONTO DISTORTED SUBSTRATES	9
4. CONCLUSIONS.....	10
5. ACKNOWLEDGEMENTS.....	11
6. REFERENCES	11

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by

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ABSTRACT

Enclosed print heads have recently been developed as an improvement on the traditional squeegee methods for solder paste printing. They offer the opportunity of widening the printing process window and reducing process waste. Consequently this work was undertaken to evaluate some aspects of enclosed print head printing and to compare them with those of the squeegee method. The results are encouraging. Printing with the enclosed print heads has been shown to be a robust process, performing as well as, and sometime better than, its squeegee counterpart. Major findings of this investigation are:

- (i) Whilst printing at fine pitch (300 μm) was acceptable with both techniques, when the humidity was increased the enclosed head method out-performed squeegee printing. This superior performance is attributable to the head sealing the paste from the atmosphere.
- (ii) This factor also permitted successful intermittent printing using the enclosed print head technique over a 5 day period, requiring only the stencil to be cleaned between print runs.
- (iii) When printing at fine pitch and high temperatures, the enclosed print head method can encounter problems with some pastes; the lower paste viscosity at the high temperature sometimes leading to bridging. At larger pitches no problems were encountered.
- (iv) The enclosed print head method is much more tolerant to distorted substrates than some squeegee blades, and hence improves printing on non-planar surfaces.
- (v) The use of enclosed print heads may significantly reduce paste wastage by reducing paste degradation.

1. INTRODUCTION

Competitive pressures to reduce equipment size and to maximise circuit performance have resulted in new challenges for fine pitch solder paste printing. Achieving high quality and consistent fine pitch printing is increasingly the issue in today's electronics manufacture. Solder paste printing is an important first stage of assembly process of PCBs, and the complexity, of both the printing process and the solder paste material requires a great deal of attention to optimise this process. Fine pitch stencil printing with normal squeegees has been extensively studied ^(1, 2, 3). Recently, to improve the quality from squeegee printing DEK pioneered the development of enclosed print head printing. This technology has now been widely adopted throughout industry. Two of the aims of the design were to reduce paste wastage and improve printing consistency. This paper evaluates specific aspects of fine pitch printing performance with an enclosed print head and compares them to those obtained using normal squeegee blades. The evaluation includes printing under different environmental conditions, and onto distorted substrate.

2. EXPERIMENTAL

2.1. EVALUATION OF PRINTING DEPOSIT

A special fine pitch (down to 300 μm) printed circuit board and stencil were designed to evaluate fine pitch printing performance. The stencil was made from stainless steel 100 μm thick and laser cut with aperture arrays in orthogonal axes, with one axis aligned with the print direction. Figure 1 shows the board and stencil design. The design comprised an aperture array that was repeated in many locations, with three different pitches and two orientations. An aperture group array comprised three sets each of 400, 350 and 300 μm pitch aperture arrays, with the 400 μm array repeated but turned through 90°. The aperture group arrays were repeated to give a 3 X 3 pattern, which then gave the board aperture arrangement. The stencil did 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.

In this work a laser scanning profiler (UBM with a triangulation sensor) has been used to measure the print deposits. Two criteria were selected to characterise the printing deposit, print volume and wall angle ⁽⁴⁾. Print volume is given as a ratio of stencil aperture volume. For good quality printing the paste volume should be greater than 60%, and less than 90%. If the printing volume is less than 60%, the insufficient paste increases the possibility of skipping on the paste deposits. If the paste volume is greater than 90%, there may be some excess paste deposited non-uniformly, eg. "dog ears" on QFP type pads. It is critical to deposit the correct paste volume cleanly onto the substrate, to form reliable solder joints. The wall angle is an average, and is representative of deposit wall shape, and should be larger than 20° for good printing. A wall angle, smaller than 20°, will probably result in bridging. More details about this measurement technique, and the characterisation of printed solder paste can be found in Reference (4).

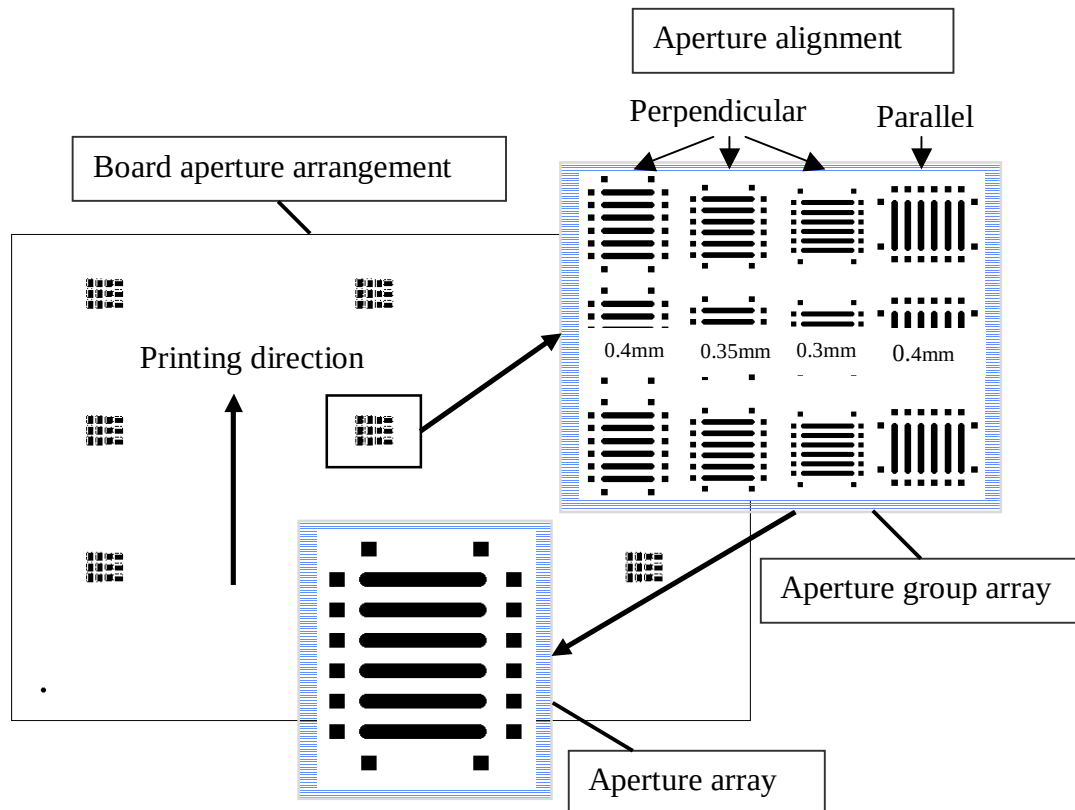


Figure 1: Test board and stencil design

2.2. FINE PITCH STENCIL PRINTING

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, 60° metal squeegee. Both the enclosed print head and metal squeegee had the same working length, 300 mm. The ProFlow used 250 mm blades with 14 mm unsupported, and the squeegee blades were 200 μ m thick with 6 mm unsupported. Two pastes, A and B, were printed. Both are fine pitch, fast printing, no-clean pastes. They were provided by Loctite Multicore and Alpha-Fry. They were supplied in pot form for the squeegee printing, and in cartridge for the enclosed print head printing.

2.3. FINE PITCH PRINTING UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

To assess the environmental effect on printing performance two approaches were adopted. One was a continuous one day printing using either an enclosed print head or normal squeegee blades under different environmental conditions. The second was to assess the ability of the enclosed print head to print intermittently over a five day period.

2.3.1. One day continuous printing

Pastes A and B were printed under different environmental conditions using both the enclosed print head and conventional metal squeegees. The printer parameter settings and printing conditions for the print head and squeegee are listed in Table 1. The paste pressure setting here was lower than conventional applied because the printing was at 400 μm pitch or less. Typically for 500 μm pitch and above the paste pressure would be set at or above 2.5 bars. The pressure was reduced to prevent bridging. Interestingly, with the high temperature conditions this pressure was reduced to 1 bar. The paste was continually printed over a 6 hour period. Six prints were taken at 0, 2, 4 and 6 hours. In between printing, the paste was conditioned by moving the paste backwards and forwards on a blank area of the stencil, as shown in Figure 2. The apertures measured for the sixth print using the laser scanning profiler were the apertures perpendicularly aligned, 400, 350 and 300 μm pitch in the middle row of the *aperture group array*, and for the *centre aperture group* array of the *board aperture arrangement*.

Table 1: The pastes, printing parameter settings and printing conditions

	Paste	Printing condition	Squeegee load (Kg)		Printing speed (mm/sec)	Separation speed (mm/sec)
Squeegee	Paste A	22°C/75%	5.2		90	1
		28°C/75%	3.6			
	Paste B	28°C/75%	3.6			
Enclosed Print head			Paste pressure (Bar)	System Load (Kg)		
	Paste A	22°C/40%	2.0	2	90	1
		22°C/75%	2.0			
		28°C/75%	1.0			
	Paste B	22°C/40%	2.0			
		28°C/75%	1.0			

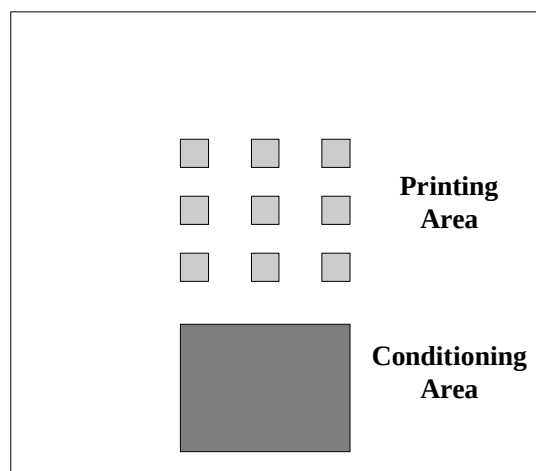


Figure 2: Printing and conditioning areas on the stencil

2.3.2. Intermittent printing of solder paste using an enclosed print head

Paste A was retained in the enclosed print head for five days at 22°C /40%RH on the printer. Six prints were taken every day, and the 1st, 3rd and 6th prints were measured using the laser scanning profiler. The stencil was cleaned after printing each day so that the aperture cleanliness was ensured. The printing parameter settings were the same as those used for the one day continuous printing.

2.4. FINE PITCH PRINTING ONTO DISTORTED SUBSTRATES

The two pastes were printed onto distorted substrates using both the enclosed print head and metal squeegees. The printing parameter settings were the same as those in the Table 1, and the printing was performed at 22°C/40%RH. The effect on printing performance of bending the substrate in two directions was tested, the substrate being bent perpendicular and parallel to the printing direction (as shown in Figure 3). The bend was achieved by placing a spacer underneath the board of the correct thickness, and restraining the edges of the board. This arrangement was then located within a carrier PCB. For the perpendicular bend the substrate was distorted from 0.1% to 0.4%, but for the parallel bend printing was only carried out on a 0.6% distorted substrate. The print deposit used for the measurements was that from the 400 µm pitch aperture in the middle line of aperture group array from each of the left, middle and right positions of the *board aperture arrangement*, for perpendicular bend, and the top, middle and bottom positions of the *board aperture arrangement* for the parallel bend, as shown in Figure 4.

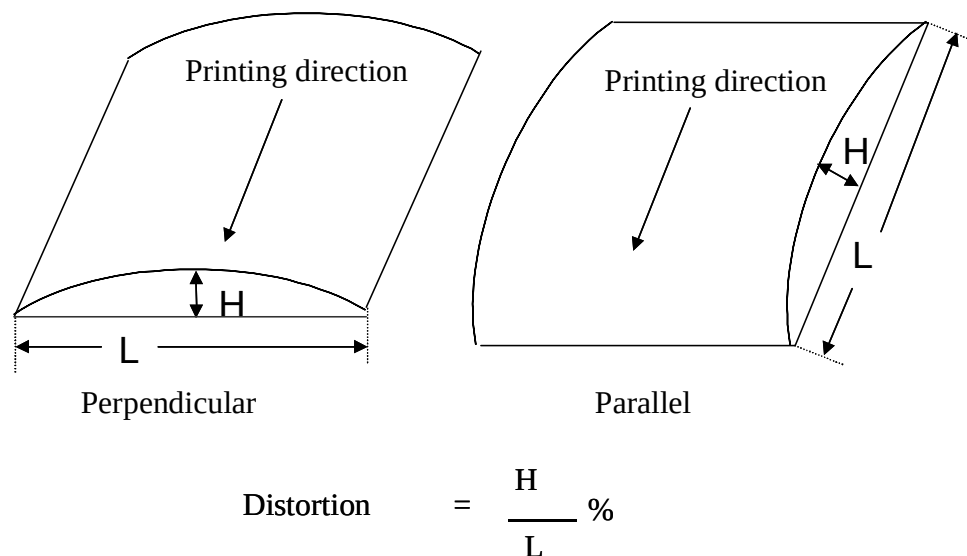


Figure 3: Board bend direction

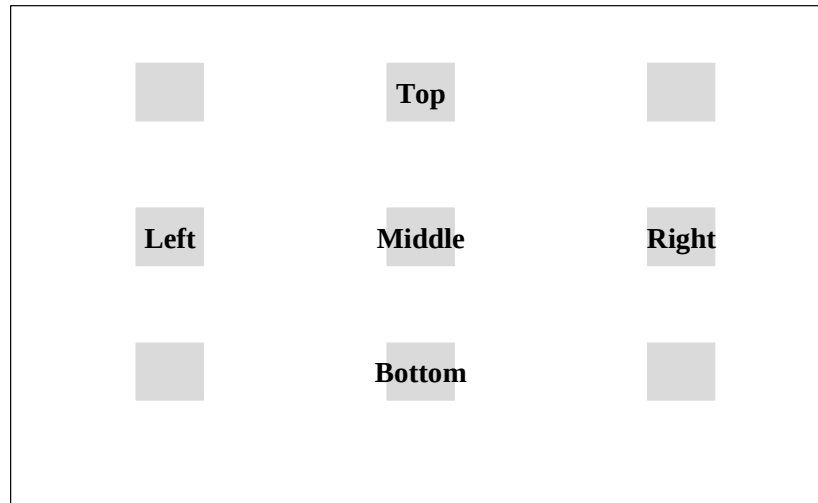


Figure 4: The positions of print deposit measured on board

3. RESULTS AND DISCUSSION

3.1. THE EFFECT OF DIFFERENT ENVIRONMENTAL CONDITIONS ON FINE PITCH PRINTING PERFORMANCE.

3.1.1. One day continuous printing

The printing volume and wall angle with printing time for paste A using metal squeegees and different environmental conditions are plotted in Figure 5. Similarly the results using the enclosed print head are presented in Figure 6. There are some important points to note from these two Figures. For paste A and squeegee printing the print quality deteriorated after 4 hours for both environmental conditions. The paste became stiff and did not roll at all, and the print volume was drastically reduced. By contrast, the print volume was constant with the enclosed head during the 6 hours of printing for all environmental conditions. However the enclosed print head did not perform very well for the very fine pitch, 300 μm aperture, and the high temperature condition. For the latter condition the paste pressure had to be re-optimised, and was reduced to 1.0 bar to prevent bridging. Without this adjustment the bridging and wall angle would have been considerably worse than the wall angle of just less than 20° actually measured. Visual inspection of the print deposit also confirmed that there was bridging on the 300 μm aperture deposit. At this combination of aperture pitch and environmental condition the printing with the squeegee performed well from the onset.

Generally with squeegee printing, paste deterioration is not as temperature sensitive, as it is to high humidity. This humidity sensitivity is due to the hygroscopic nature of the gel agents in

flux vehicles and their uptake of moisture. The enclosed print head can limit paste degradation, since it is a sealed system, protecting the paste reservoir.

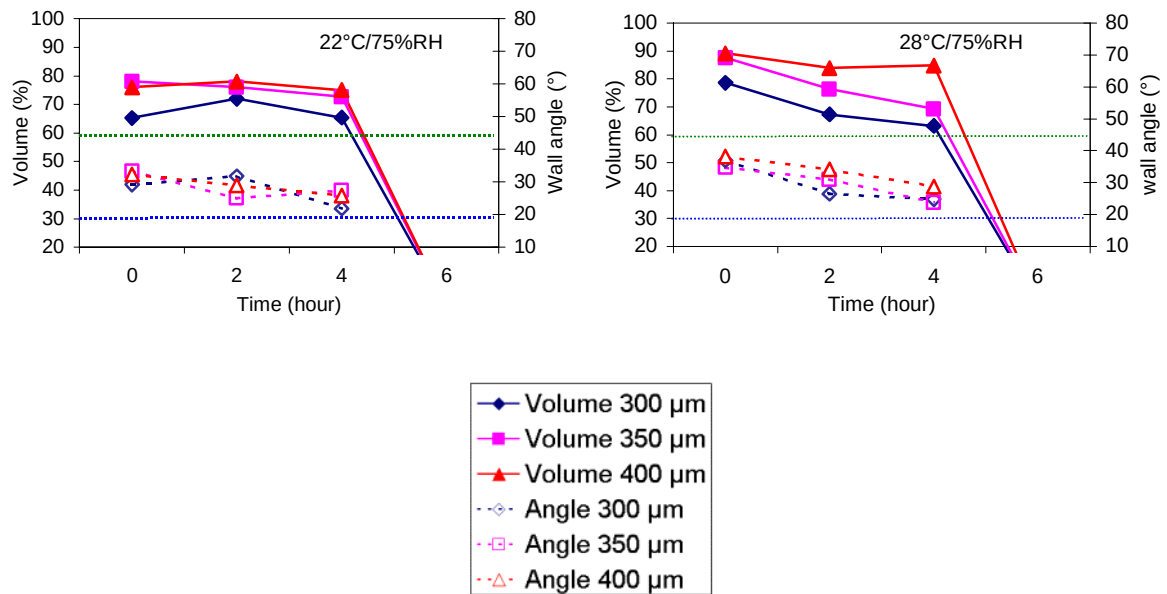


Figure 5: Print volume and wall angle with printing time for paste A using metal squeegees under different environmental conditions

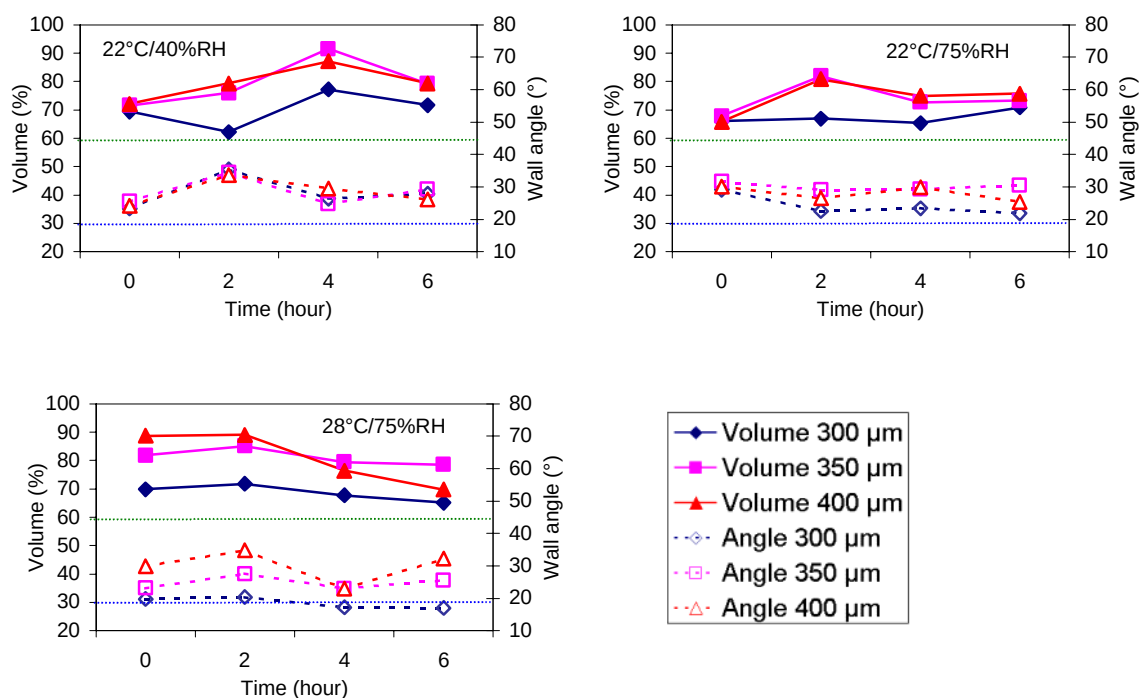


Figure 6: Print volume and wall angle with printing time for paste A using the enclosed print head under different environmental conditions

Printing with the print head is prone to bridging for very fine pitch applications, ($300\text{ }\mu\text{m}$) pitch, at the high temperature condition. Since the enclosed print head systems use a positive pressure to displace the solder paste, any reduction in paste viscosity could pose a potential problem. This was observed with this specific paste, and at elevated temperatures slumping and bridging were an issue with fine pitch. However, the system was resilient to increasing humidity, and the temperature control within the modern printer leads to a very robust system, minimising the occurrence of bridging.

The printing results for paste B using both the enclosed head and the normal squeegee method with different environmental conditions are shown in Figure 7. It can be clearly seen from Figure 7 that printing with squeegees during the 6 hours experiment at the high temperature and humidity condition, produces a print of reasonably consistent quality. This suggests that paste B has a longer stencil life than paste A. For paste B the enclosed print head did not show any particular change in performance in terms of printed volume between the two environmental conditions. At the finest pitch, $300\text{ }\mu\text{m}$, bridging at the high temperature was again observed for the enclosed print head, but at $350\text{ }\mu\text{m}$ printing was satisfactory. It is suggested that this problem can be prevented by suitable paste formulation.

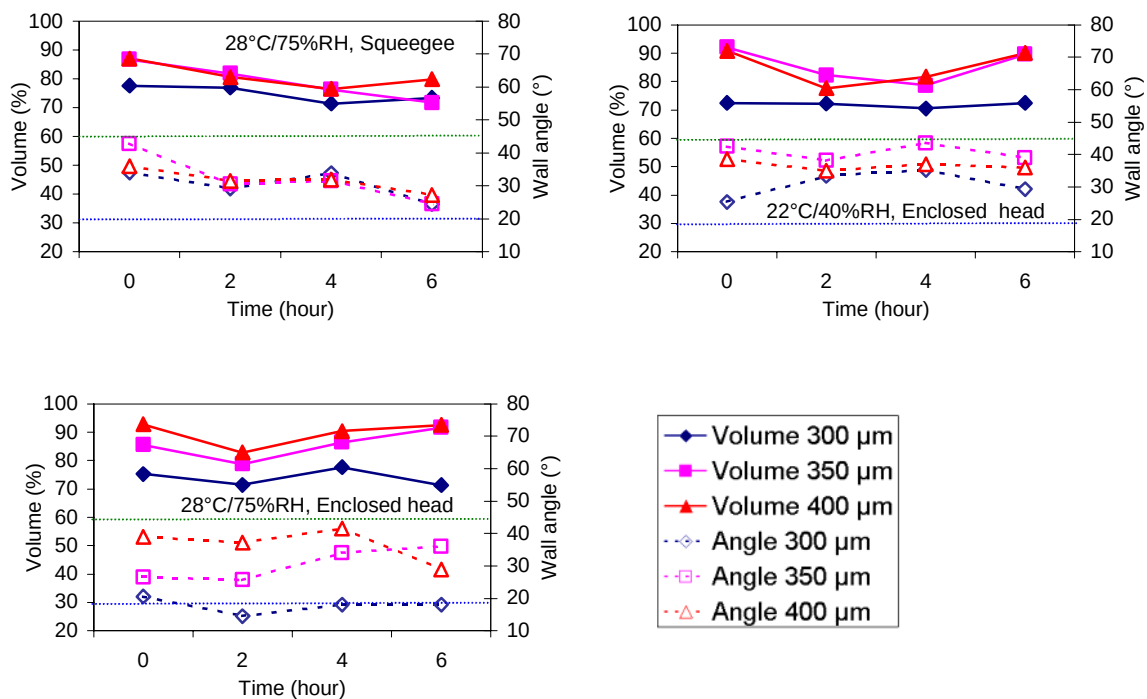


Figure 7: Print volume and wall angle with printing time for paste B using the enclosed print head and the squeegees under different environmental conditions

3.1.2. Intermittent printing with enclosed print head

Figure 8 presents the printing results during a five day period using the enclosed print head and paste A, and maintained at the at 22°C/40%RH condition. For these series of tests no preconditioning of the paste was used. For each trial the 1st, 3rd and 6th prints were measured.

During the wait period between prints the print head was left on the stencil, so the paste was not open to the atmosphere. Printing with squeegee blades the paste would normally require some preconditioning, and the paste would never be left open on the stencil for more than a shift. With respect to the quality of the prints made on an intermittent basis, the results clearly demonstrate the following points:

- For stencil apertures >0.4 mm, the enclosed print head can be used “from rest” to produce prints of acceptable quality
- For stencil apertures >0.3 mm, the enclosed print heads can be used to produce prints of acceptable quality, provided the first two prints are discarded. The third and sixth prints of the day were stable with time – the printed volume was always higher than 60%, even for the 0.3 mm pitch aperture.
- At the start of the day, acceptable prints were obtained only for the 0.4 and 0.35 mm pitch apertures, but both degraded with time - the printed volume falling below the 60% minimum acceptable level.

Although the print volume of the first print using the 0.3 mm apertures on the first day was just acceptable, it was unacceptable on subsequent days, gradually deteriorating to a value less than 20%. However, the print volume for the 0.3 mm aperture on the third and subsequent days was not only acceptable, but also consistent in the range 65 to 90%. It is believed that the constant deterioration in the first print is due to a progressive settling and solidification of the paste associated with the fact that with only six prints each day the paste will not be fully homogenised. Ageing, for example the formation of a skin of dried paste by solvent loss, is thought to have only a minor effect. For small volume manufacturers that require only infrequent board printing each day, the results are encouraging. They indicate that over a five-day period at least, only the stencil needs to be cleaned after each printing session. In these circumstances the use of an enclosed print head is very convenient and can significantly reduce paste wastage.

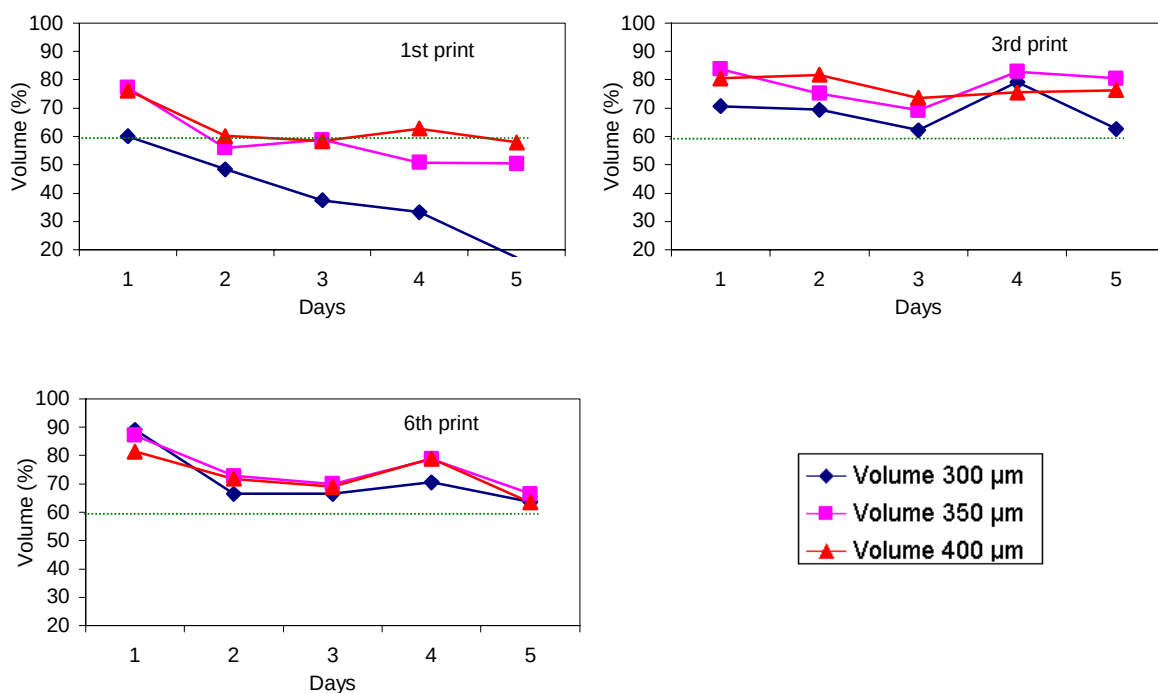


Figure 8: Print volume with printing time for paste A using the enclosed print head

3.2. FINE PITCH PRINTING ONTO DISTORTED SUBSTRATES

The results of the measurements of printed volume for various board distortions and different “aperture arrays” for the perpendicular bend (as defined in Figure 3) are presented in Figure 9. The data clearly demonstrate the following points:

- The printing performances of pastes A and B were similar.
- There was a significant difference between the prints produced from the enclosed print head and from the squeegee process. The enclosed print head method is more tolerant to printing on distorted substrates than the typical squeegee method used here. This is attributable to the more flexible blades employed in the enclosed print head, although squeegee blades with longer unsupported lengths would probably perform better than those used in this work.

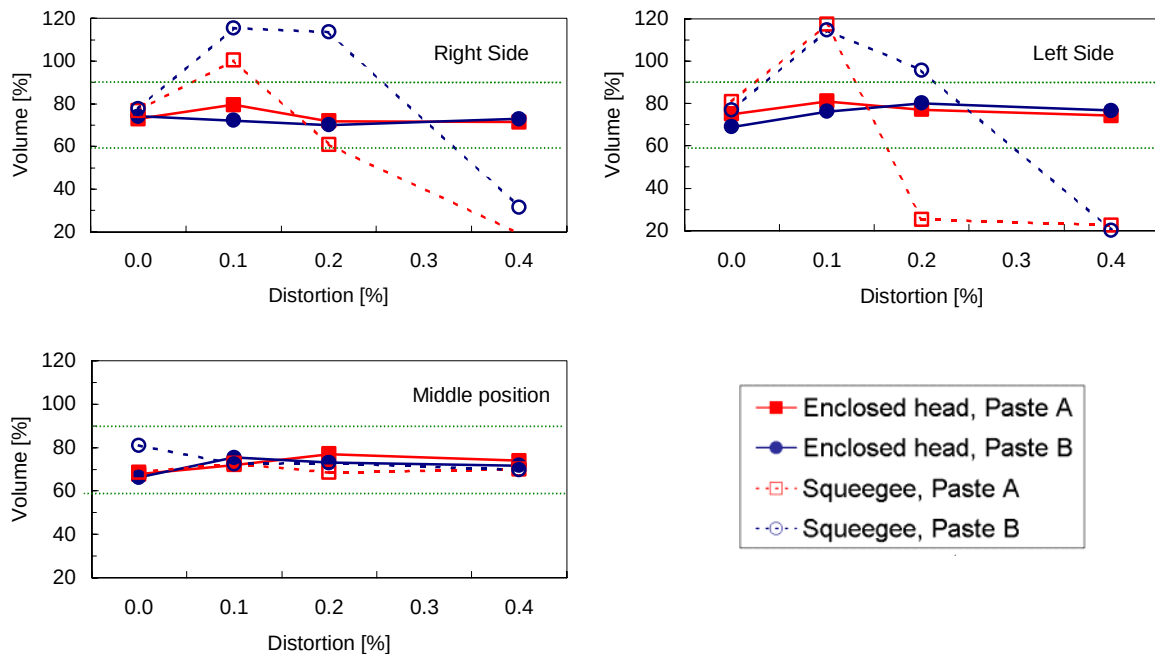


Figure 9: Print volume with board distortion on right, middle and left positions using the enclosed head and the squeegees for perpendicular board bend

- Printing using the squeegee blades produced variable and often unacceptable printed volumes on substrates having a distortion $>0.1\%$. The high printed volumes obtained for small (0.1%) distortions on the non-central locations, simply reflect the poor stencil and squeegee seal, and the occurrence of a paste film on the topside of the stencil. For small distortions this paste film contributes to the printed paste volume on the board. For larger distortions this paste film increases in thickness, and the squeegee no longer conforms to the board shape. Its action of pushing paste through the apertures is significantly reduced resulting in smaller paste volumes on the board.

- The inconsistency and non-uniformity of squeegee printing performance when the distortion of the substrate is larger than 0.1%, might potentially cause problems in terms of solder joint reliability.

Overall with the enclosed print head the volume was more consistent at the different aperture positions for all the board distortions evaluated, than the typical squeegee blades used here. Longer unsupported-length squeegee blades would perform better than the blades used here.

The effect of distorting the substrate in the parallel direction is shown in Figure 10. The print volumes were constant at different board positions for both the enclosed print head and the squeegee printing even with 0.6% board distortion. Hence both the enclosed print head and the squeegee blades are tolerant to board distortion of at least 0.6% for the parallel bend.

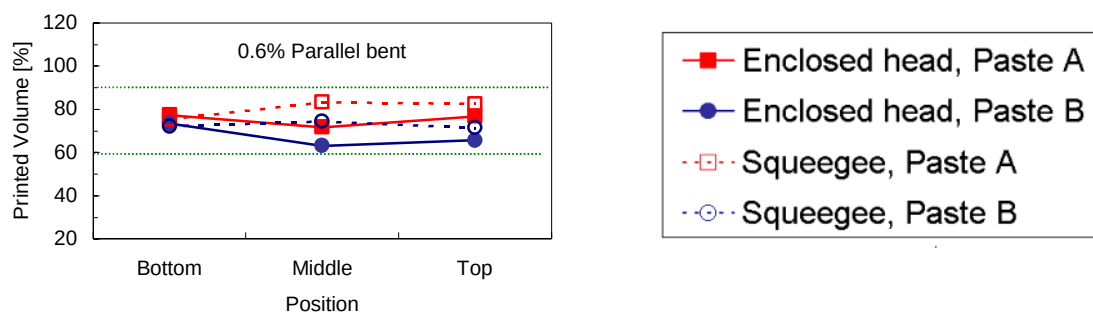


Figure 10: Print volume with board distortion at top, middle and bottom positions using both enclosed head and normal squeegee for parallel board bend

4. CONCLUSIONS

This work was carried out to evaluate the results of enclosed print head printing and to compare the results with those using the more traditional squeegee methods. The salient findings were:

- Printing with the enclosed print head has been shown to be a robust process, performing as well as, and sometimes better than, its more traditional counter-part.
- Printing at fine pitch (0.3 mm) was straightforward with both techniques, but when humidity was increased (to 75%) the enclosed print head out-performed squeegee printing, the latter producing unacceptable print volumes. This superior performance is due to the head sealing the paste from the atmosphere and hence minimising any deterioration of the paste.
- At high temperatures the enclosed print head method can encounter problems with some pastes for fine pitch printing. A lowering of the paste viscosity can cause a paste/flux bleed that leads to bridging. For printing at larger pitches more typical of current industrial practice (>0.35 mm), no problems were encountered at the higher temperatures.

- The enclosed print head method allowed successful intermittent printing over a 5-day period, requiring only the stencil to be cleaned between print runs. Again, the superior performance of the enclosed print head is due to a sealing of the paste reservoir.
- The wide flexible blades used in the specific enclosed print head, “ProFlow”, were excellent at accommodating distorted substrates, hence improving the ability to print on non-planar surfaces. High quality, acceptable, printing was achieved on substrates with at least 0.4% distortion, whereas under similar conditions squeegee printing was unable to cope with distortions as small as 0.1%.
- The use of enclosed print heads may significantly reduce paste wastage, by reducing atmospheric degradation of the paste.

5. ACKNOWLEDGEMENTS

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