The Effect of Metal Content and Flux Chemistry on Fine Pitch Stencil Printing Performance Using an Enclosed Print Head

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ABSTRACT

Stencil printing is widely used in the electronics industry, and recently enclosed print head systems have been introduced as an improvement on the traditionally used squeegee methods for printing. As part of a programme to assess the performance of the enclosed print head system this work was undertaken to investigate aspects of the process. Particular emphasis was placed on the printing performance through fine pitch (0.3mm) apertures of pastes with different metal contents and flux chemistries, and as functions of print runs and paste print pressures. Major findings of this limited study are:

(i) Printing with the enclosed print heads is confirmed as a robust process, performing well under a range of printing conditions.
(ii) With appropriate selection of paste and optimised printing conditions acceptable print quality can be obtained for demanding fine pitch (0.3mm) applications.
(iii) Printing through fine pitch apertures is more sensitive to paste choice, metal content and print pressure than is printing through larger apertures. Although the high print pressure improves the aperture filling, it can cause bridging particularly for pastes with a low metal content.
(iv) The process performs best using pastes with a higher metal content e.g. 90 wt% for SnPbAg pastes and 89 wt% for SnAgCu pastes.
(v) The paste print pressure is critical when using low metal content pastes.
(vi) The printing performance did not vary with the two flux vehicles tested.

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. Paste printing is a process depending on many interacting variables. Fine pitch solder paste (1), and fine pitch stencil printing with normal squeegees (2,3), are now well understood. Recently, to improve on the print performance with squeegee printing, DEK pioneered the development of enclosed print heads. This technology has been widely adopted throughout the industry, and work undertaken to evaluate some aspects of the process has been reported previously (4). However, the printing parameter settings for these new systems are different to those for squeegee printing, and their dependence on paste, environment, and machine factors will vary. This paper evaluates the fine pitch printing performance of pastes with different metal contents and flux chemistries on fine pitch stencil-printing performance. It includes a study of the dependence of printing parameter settings for the specific pastes trialed here.

2. Experimental

2.1. Evaluation of printing deposit

For this evaluation the specially designed test board and stencil used in the previous study (4), were again employed. The stencil was made from stainless steel 100µm thick and laser cut with apertures arranged on orthogonal axes. Figure 1 shows the board and stencil design. The design comprises an aperture array that is repeated in many locations, with three different pitches and two orientations. An aperture group array comprised three sets (each of 0.4, 0.35 and 0.3 mm pitch) of aperture arrays, plus the 0.4 mm apertures repeated but turned through 90°. The aperture group arrays are repeated to give a 3 X 3 pattern across the PCB, which then provides the board aperture arrangement. The stencil does not have the surrounding dots around each aperture array; these dots were used as a reference for paste deposit measurements.

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 (5).

Print volume in this work is given as a ratio of the stencil aperture volume. For quality printing the paste volume should be greater than 60%, and less than 90%. If the printing volume is less than 60%, there is insufficient paste, and there is an increasing possibility of skipping in the paste deposit occurring. If the paste volume is greater than 90%, there may be some excess paste deposited non-uniformly, e.g. "dog ears" on QFP type pads. It is critical to deposit the correct amounts of paste cleanly onto the substrate, to form a reliable solder joint. The **wall angle** is a representation of the shape of the printed deposit. The larger the wall angle of the solder deposit, the sharper the edge of the solder deposit. The wall angle 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 Ref(5).

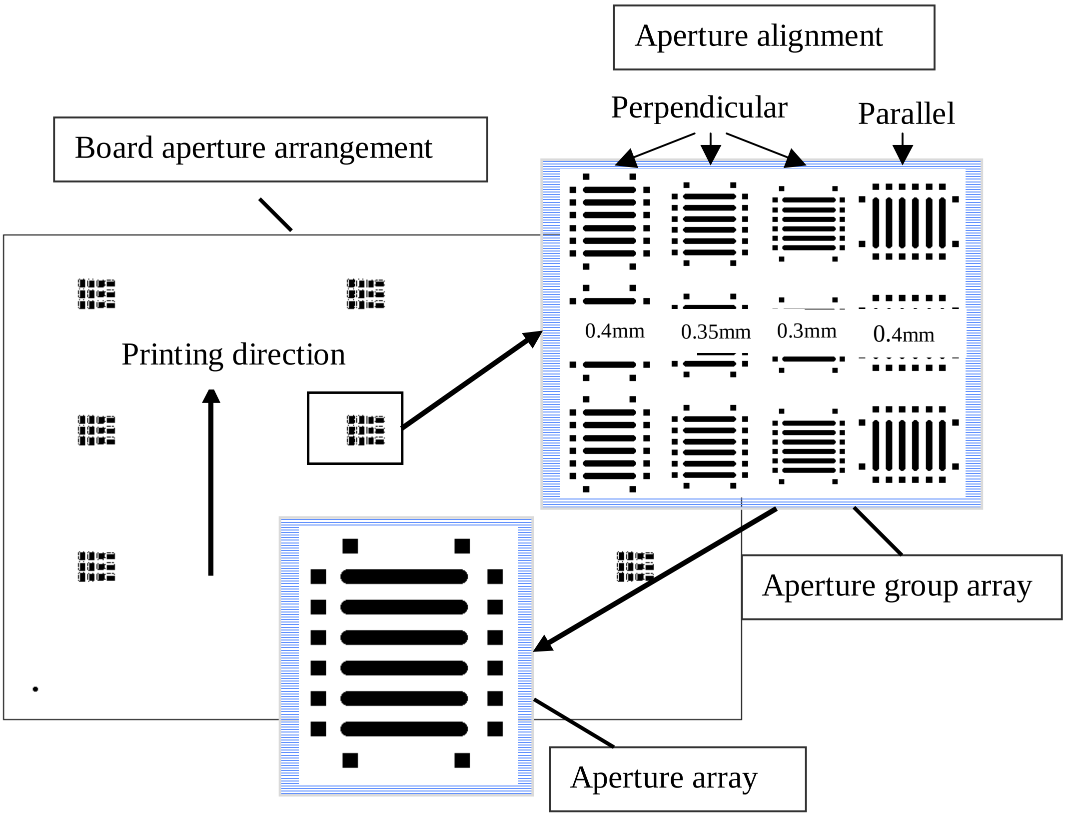

Figure 1: The test board and stencil design

2.2. *Printing paste and printer parameter settings*

The printing was conducted on DEK 265 GSX printer. Stencil printing processes with an enclosed print head are different from those using normal squeegees. There is only one pressure applied to squeegees during stencil printing, but there are two pressures for enclosed print heads, as shown in Figure 2. For all enclosed print head systems the head is held down on the stencil by the print load, and a second internal pressure dispenses the solder paste. Within the print head this “paste” pressure is exerted to push the paste out through the bottom. Retaining wipers or squeegees constrain the paste to hold it inside the print head and on the stencil as the print load or board height is altered. The printing load should not significantly affect printing performance with an enclosed print heads, provided the stencil is wiped clean and good gasketing is achieved between stencil and blades of the enclosed head. However, the pressure applied to the solder paste reservoir to push the paste through the stencil apertures is critical. In this work the paste pressure was varied from 1.4 bar to 2.0 bar, and the printing load and printing speed were keep constant for all the pastes. The printing parameters are shown in Table 1.

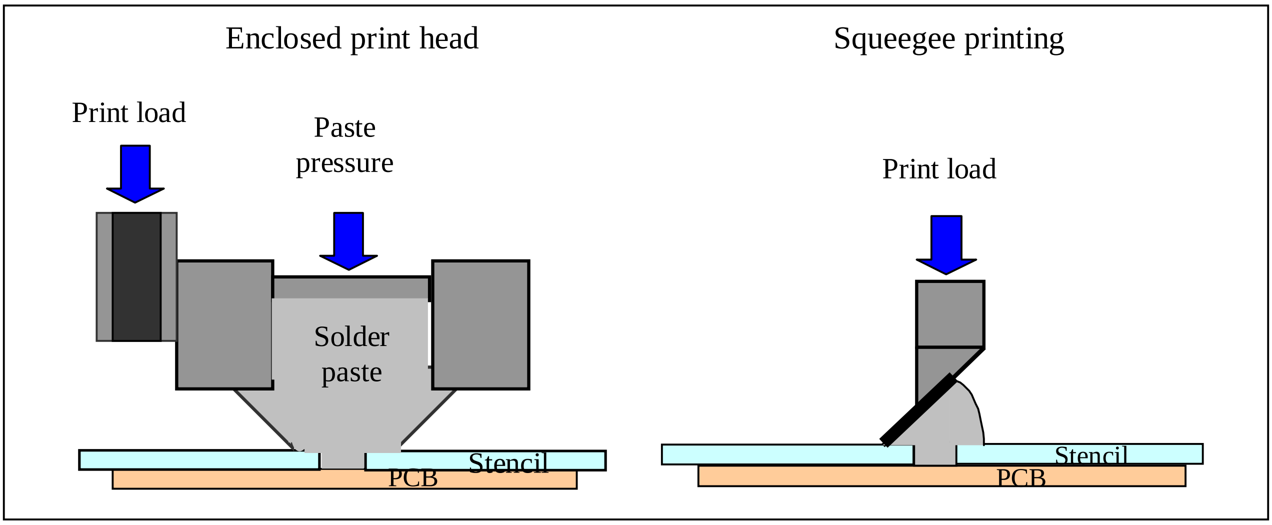

Figure 2: Schematic of enclosed print head and normal squeegee

Table 1: Printing parameter settings

Printing load on 300 mm head (Kg)	Printing speed (mm/sec)	Paste pressure (bar)		
2.0	90	1.4	1.7	2.0

For the investigation of different flux chemistries two pastes, A and B, were used. They were both Sn/Pb/Ag alloy pastes, with the same metal content, but different flux chemistries, as shown in Table 2. The effect of metal content with two pastes, B and C, were evaluated for three metal levels. B was a Sn/Pb/Ag, and C was a Sn/Ag/Cu alloy paste. Details are summarised in Table 3. Since the alloy is different in the B and C pastes, a different flux chemistry is used.

Table 2: Pastes with different flux chemistries

Paste	Flux	Metal content (wt%)	Type
Paste A	Flux A	90.0	Sn/Pb/Ag
Paste B	Flux B		

Each paste was printed using three paste pressures and ten prints were printed at each pressure. The 1st, 5th and 10th prints were measured using the laser scanning profiler. The prints measured were the perpendicularly aligned, 0.4, 0.35 and 0.3 mm pitch in the middle row of the *aperture group array*, and the middle position of the *board aperture arrangement*.

Table 3: Pastes with different metal contents

Paste	Type	Metal content (wt%)		
Paste B	Sn/Pb/Ag	89.5	90.0	90.5
Paste C	Sn/Ag/Cu	88.0	88.5	89.0

3. Results and Discussion

3.1. The effect of paste metal content on fine pitch printing performance

3.1.1. Paste B

The results for print volume and wall angle for this paste are shown in Figures 3, 4 and 5 respectively as a function of paste pressure. The salient points are:

- At the lowest pressure (1.4 bar) for the fine pitch aperture (0.3mm) and for the lowest metal content (see Figure 3), the print volume remained at unacceptable levels (<60%) even after 10 print runs
- When the paste pressure was increased to 1.7 bar the aperture filling was significantly improved, with the print volume exceeding the acceptable level (see Figure 3) after the first print run.
- However, with increasing print pressure the wall angle decreased, and in the case of the fine pitch (0.3mm) aperture reached the unacceptable 20° value after five print runs. Visual inspection of the deposits printed at the higher pressures confirmed the presence of bridging.
- Hence for this low metal content paste, the enclosed print head was not capable of producing good quality deposits with fine pitch (0.3mm) apertures.
- The overall quality of the print deposits was increased when the metal content was raised (see Figures 4 and 5). Although the print volumes at the various print pressures gave similar results to those for the lowest metal content paste, the wall angles improved significantly with the increased metal content, and in all cases exceeded the 20° limit.

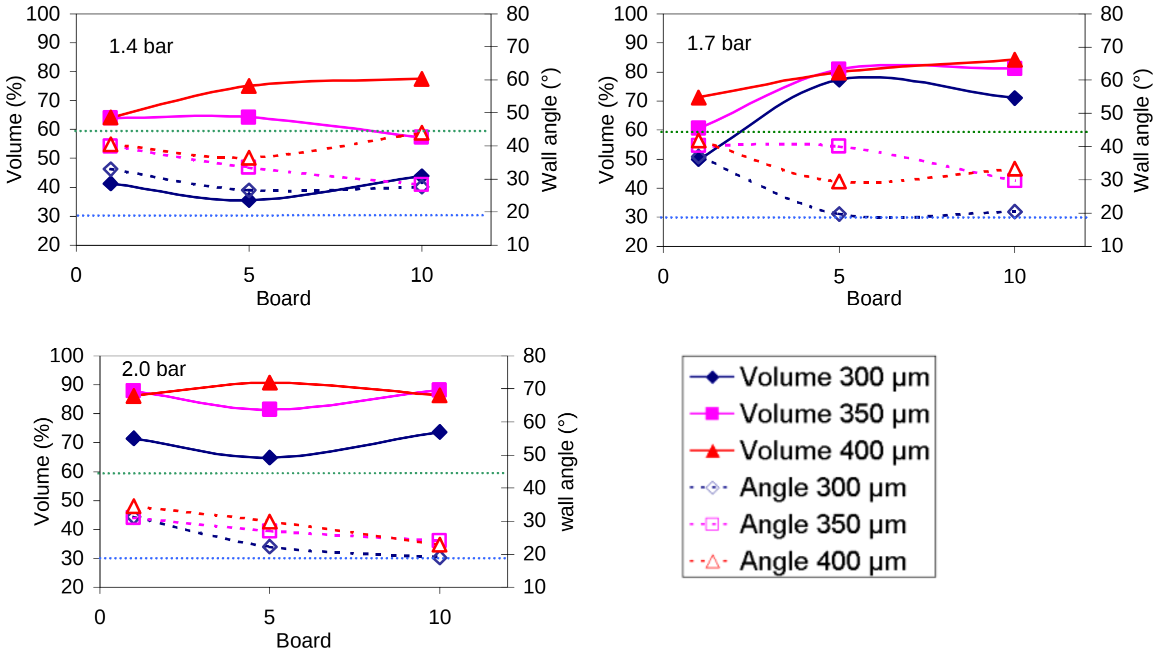

Figure 3: Print volume and wall angle of 1st, 5th and 10th prints
for paste B with low metal content

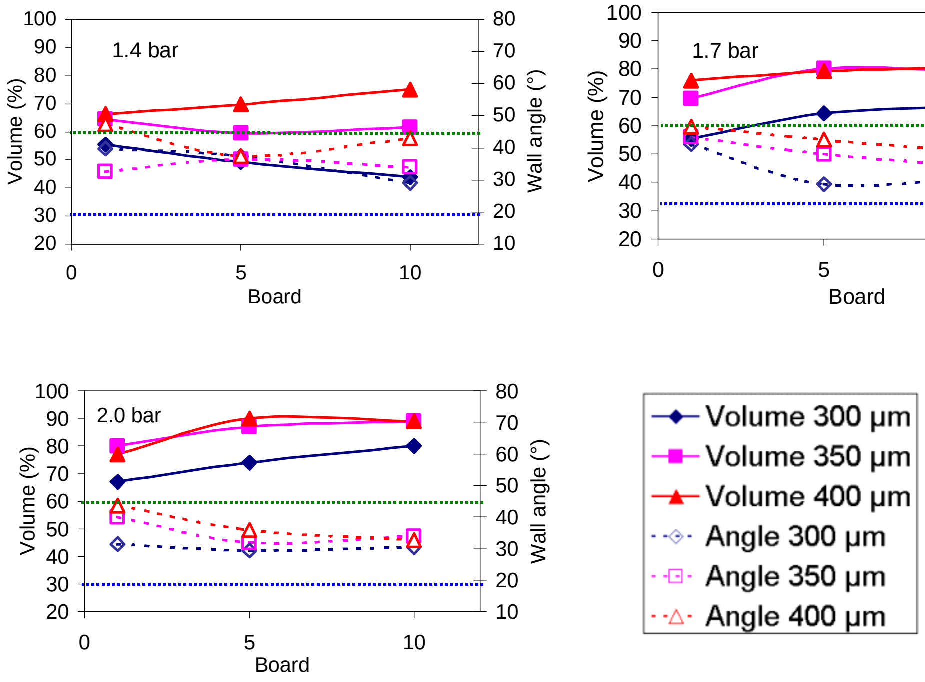

Figure 4: Print volume and wall angle of 1st, 5th and 10th prints for paste B with medium metal content

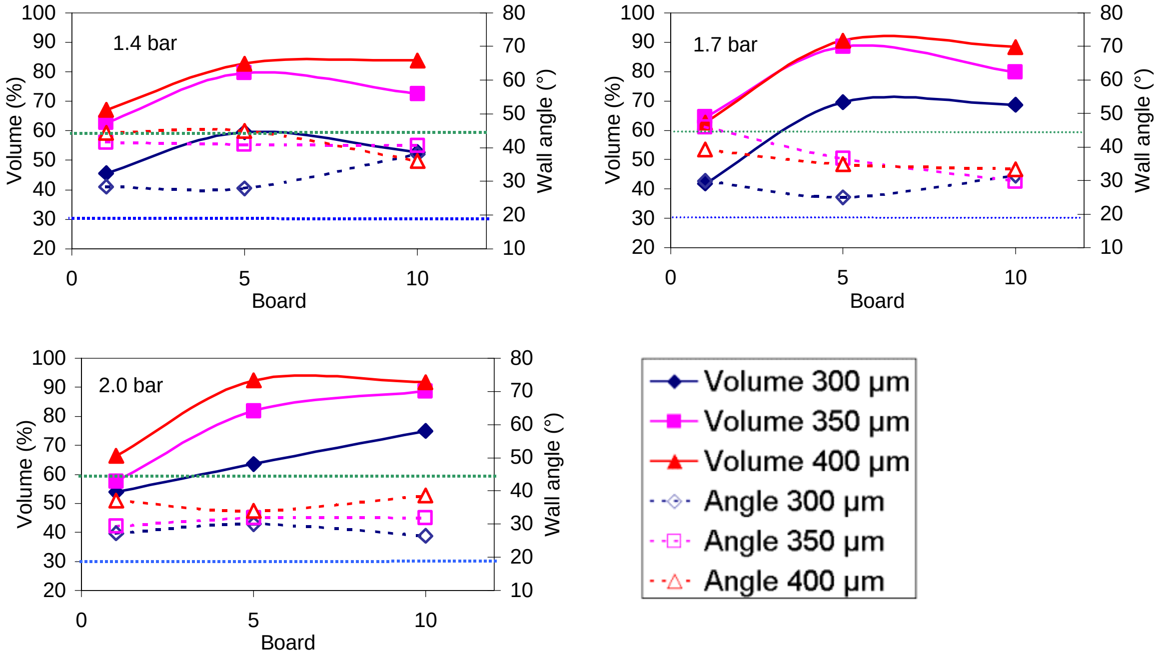

Figure 5: Print volume and wall angle of 1st, 5th and 10th prints for paste B with high metal content

Of particular interest is the printing performance at fine pitch (0.3mm) in comparison with the larger pitches (0.35 and 0.4mm):

- It appears to be more sensitive to the metal contents and paste pressures.
- The printing volume after the first print run was always lower
- The wall angle was invariably higher with the higher pitches
- The printing became reasonably stable after five print runs.

In Figure 6 the print volume and wall angle for the tenth print run using the fine pitch stencil are plotted as a function of print pressure.

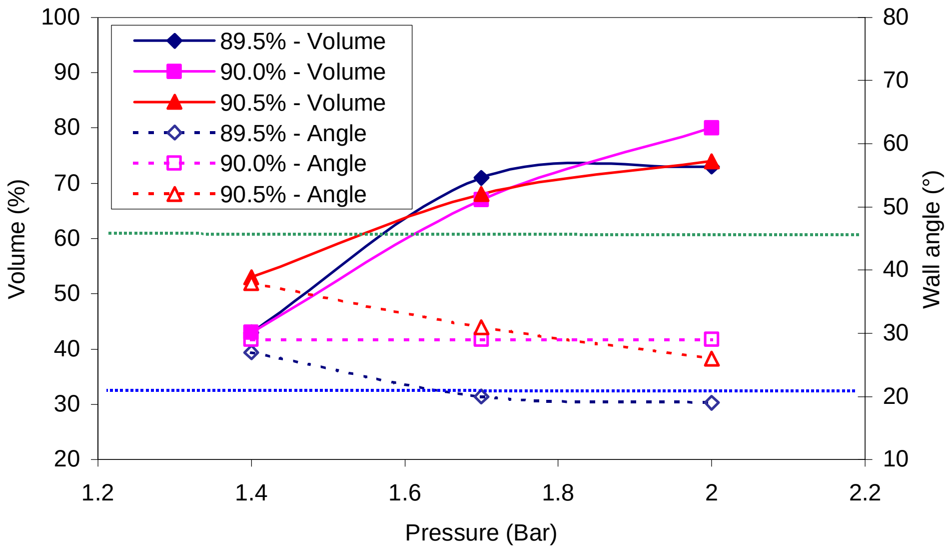

Figure 6: Print volume and wall angle with different paste pressures for paste B with different metal content pastes

The effects of metal content on solder paste fine pitch printing performance are mixed. The wall angle deteriorated with increasing print pressure, and for low metal content (89.5 wt%) paste was unacceptable for pressures of 1.7 bar and above. Hence the metal content needs to be higher than 89.5 wt% to achieve good printing. At the lowest print pressure (1.4 bar) only the highest metal content (90.5 wt%) paste gave a wall angle of above 30^{O}, producing good shaped prints. In terms of print volume it is clear that this parameter is sharply dependent on the print pressure for all the metal contents studied. The deposits printed at the lowest pressure (for all metal contents) all gave unacceptable results (i.e. <60%)., and the print pressure had to be raised to at least 1.6 bar to achieve an acceptable print volume of >60%.

There is therefore an apparent conflict as the pitch approaches 0.3mm. Although the high print pressures produces acceptable print volumes, they confer a tendency to slump and bridge. Under these conditions the viscosity is critical, and any reduction in viscosity can lead to a critical loss of printing performance through bridging.

3.1.2. Paste C

The results for print volume and wall angle for this paste are shown in Figures 7, 8 and 9 respectively as a function of paste pressure. (NB. The metal content in wt% for this paste is lower than that for paste B, owing to the lower density of this lead-free paste). The salient points are:

- For the lowest metal content (88 wt%) the print volume is acceptable at all print pressures, (see Figure 7).
- However, as the print pressure is increased the wall angle deteriorates significantly becoming unacceptable at 1.7 bar for the fine pitch (0.3mm) aperture after three print runs, at 2.0 bar for the 0.35mm aperture after five print runs, and at 2.0 bar for the 0.4mm aperture after ten print runs.
- Increasing the metal content (to 88.5 and 89.0 wt%) improves the wall angle with acceptable values being obtained under all conditions studied. There was a concomitant increase in the print volume (see Figures 8 and 9) with acceptable values of >60% being obtained after the first print run in all cases.
- In terms of fine pitch printing, the process is more sensitive to metal content and paste pressures than when using the larger apertures. Acceptable print volumes were obtained for all the combinations studied after the first print run. But probably the best condition was the combination of high metal content and 1.7 bar for which the print volume was essentially constant throughout the ten print runs (see Figure 9).
- Hence when using the enclosed print head process, increasing paste metal content widens the process window.

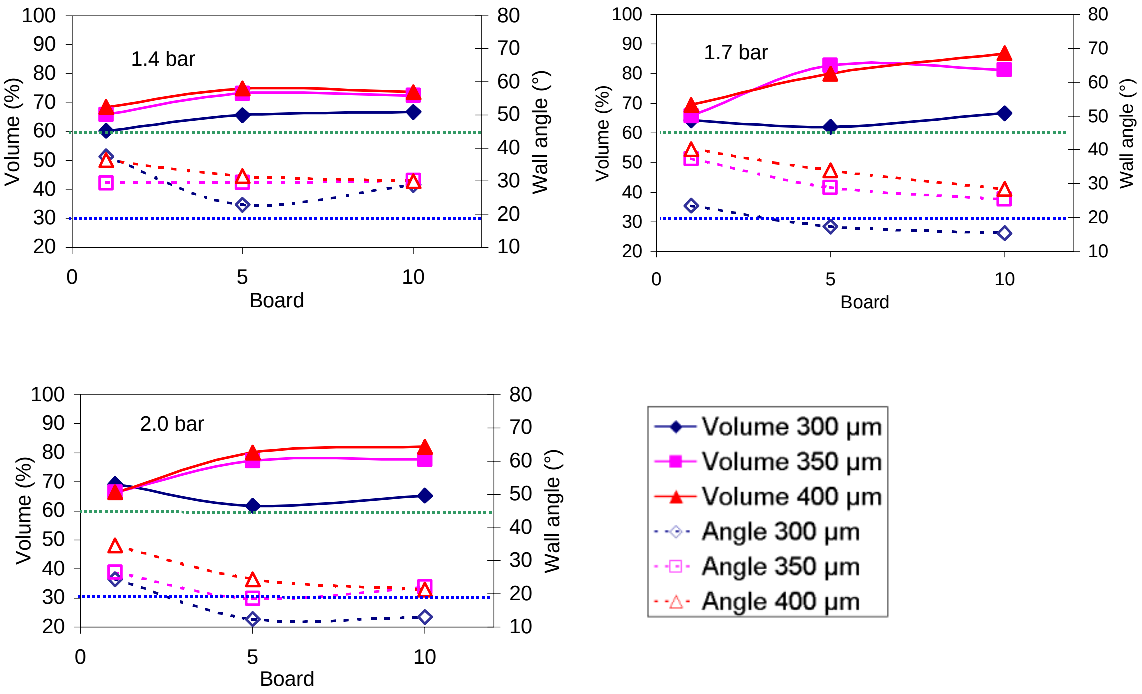

Figure 7: Print volume and wall angle of 1st, 5th and 10th prints for paste C with low metal content

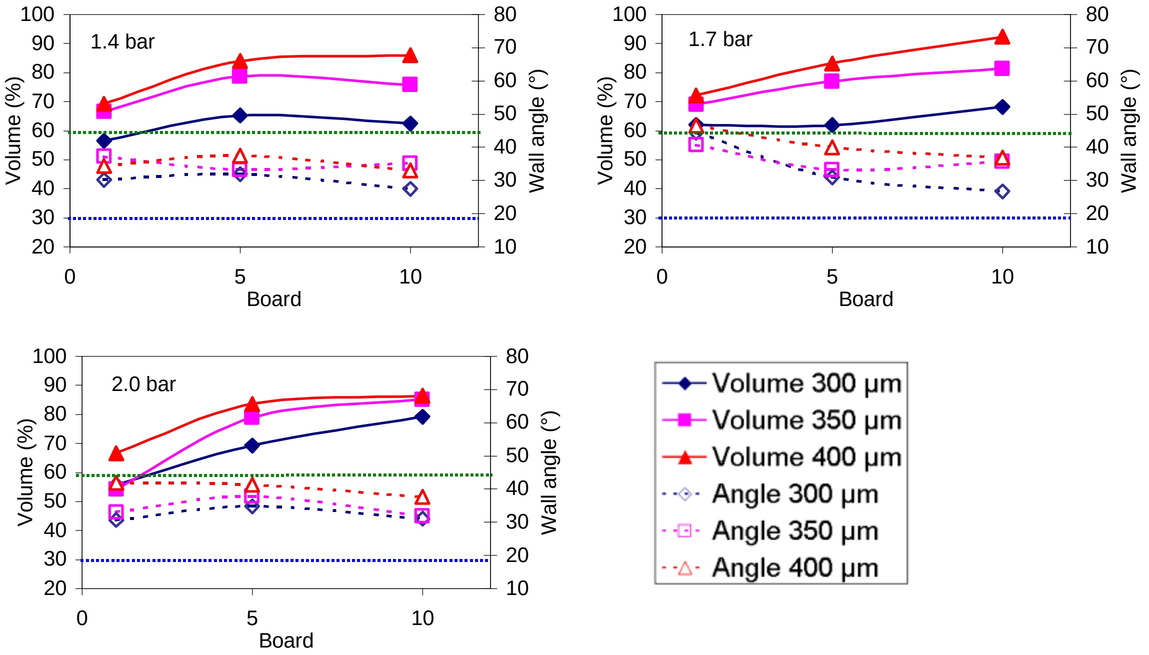

Figure 8: Print volume and wall angle of 1st, 5th and 10th prints for paste C with medium metal content

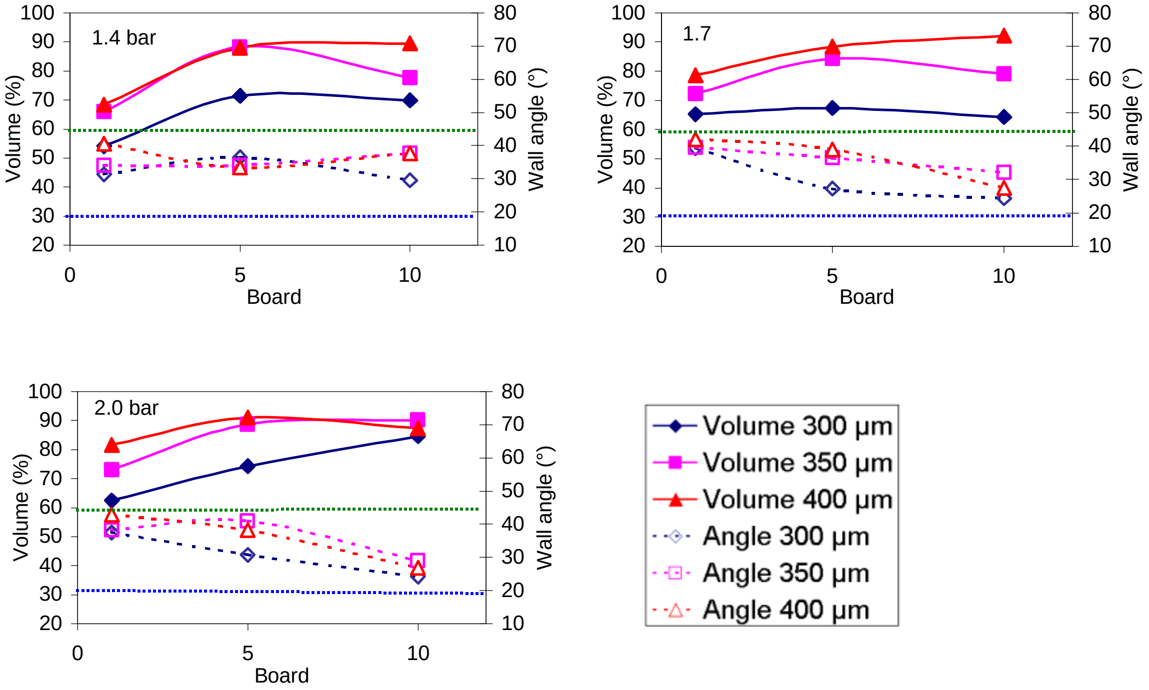

Figure 9: Print volume and wall angle of 1st, 5th and 10th prints for paste C with high metal content

The fine pitch printing performance of paste C using the enclosed print head system is summarised in Figure 10.

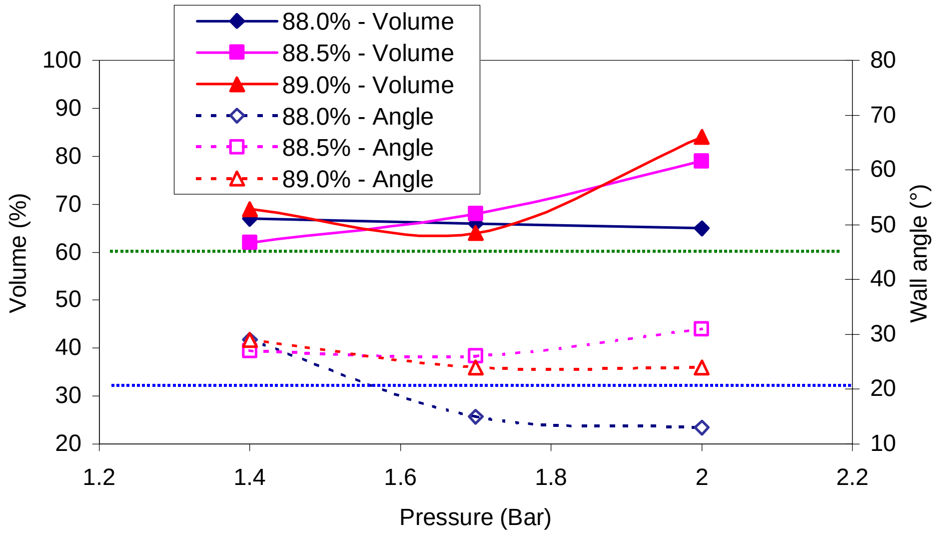

Figure 10: Print volume and wall angle with different paste pressures for paste C with different metal contents using a fine (0.3mm) aperture

It is evident that acceptable quality printing can be obtained even with 88.5 wt% metal content (compared with paste B the metal content needed to be at least 89.5 wt%) – both the print volumes and wall angles were within acceptable limits. In general, high print pressure gives improved aperture filling and hence paste volume, but it may also cause bridging for fine apertures, typically 0.3mm. Paste B, with a low metal content, was prone to bridging using the enclosed print head and fine apertures, and this was again the case with paste C.

The lowest metal content (88.0 wt%) gave unacceptable wall angle values for print pressures in excess of 1.5 bar (see Figure 10). This indicates that using a paste with this metal content narrows the process window, with the paste pressure setting becoming critical.

From this work it appears that the enclosed print head system works best with a metal content around 90 wt% for SnPbAg pastes and 89 wt% for SnAgCu pastes.

3.2. The effect of flux chemistry on fine pitch printing performance

The printing performance of pastes with different fluxes was studied using pastes A and B, with different paste pressures, as shown in Figure 11. Although these two pastes have different flux chemistries, the printing performances and print windows were similar. They both showed high quality printing, even for the very fine pitch aperture, with a paste pressure range from 1.7-2.0 bar. Therefore printing performance with the enclosed print head does not appear to be critically dependent on these two flux chemistries.

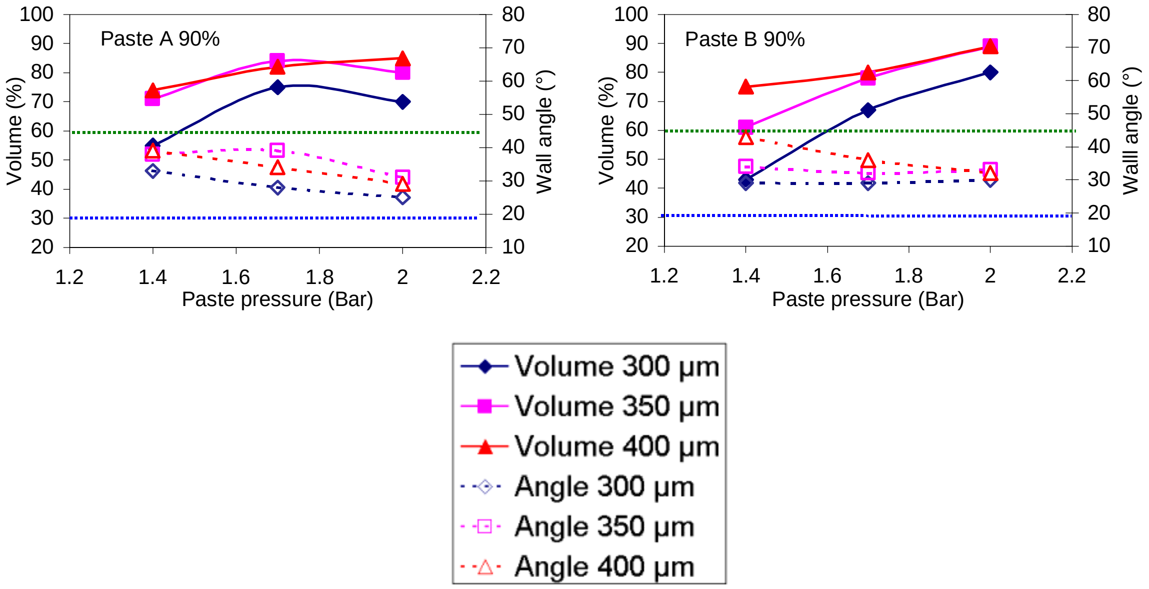

Figure 11: Print volume and wall angle with different paste pressures for two pastes with different fluxes

4. Conclusions

From this limited study it is possible to make the following points:

- The enclosed print head system is capable of producing good quality printing over a range of printing conditions. With appropriate selection of paste and optimised printing conditions acceptable print quality can be obtained for demanding fine pitch (0.3mm) applications.

- For enclosed print head system, although the metal content of the paste plays an important role in fine pitch printing performance, other factors are also important such as the solder alloy, print pressure used, and the number of print runs. For the middle and high metal content pastes tested in this work the printing performances were generally similar, and not particularly sensitive to print pressure. Print volumes were typically acceptable after the first print run, and stabilised after five print runs. There was a tendency for the wall angle to show a small but steady decrease with increasing print runs, and increasing print pressure, which in some cases led to unacceptable values (<20°), particularly at 0.3mm pitch. Bridging could result if under-screen wiping were not used.

- Printing through fine pitch apertures is more sensitive to metal content and print pressure than is printing through larger apertures. The paste metal content and print pressure should therefore be chosen carefully when printing using the enclosed print head system. In general, although the high print pressure improves the aperture filling, it can cause bridging particularly for pastes with a low metal content.

- The printing performance using the enclosed print head (and the same solder alloy) did not vary between the two flux vehicles tested.

- The enclosed print head system works best with pastes having a metal content around 90 wt% for SnPbAg pastes and 89 wt% for SnAgCu pastes.

5. Acknowledgements

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