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**Measuring the Effect on
Isotropic Electrically
Conductive Adhesive
Reliability of Joint Design
Characteristics**

**M Wickham, L Zou and
C P Hunt**

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Measuring the Effect on Isotropic Electrically Conductive Adhesive Reliability of Joint Design Characteristics

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ABSTRACT

As the transition away from lead-containing solders gathers momentum, isotropic conducting adhesives (ICAs) are being considered as possible replacements for conventional SnPb solder in certain applications. Consequently, the reliability of ICA joints is under scrutiny and in earlier work the effects of substrate and component finishes on ICA joint reliability were investigated. In this study the investigation has been extended to the effect of joint design on ICA reliability.

A range of test assemblies, manufactured using conductive adhesives, were subjected to 2000 hours damp heat stressing at 85°C/85%RH and assessed using a combination of visual inspection, micro-sectioning, shear testing and electrical continuity monitoring. The assemblies were built using a series of stencil patterns, stencils of two thicknesses (75 and 125 µm) and two ICA materials (both silver-loaded epoxy; one water-based and one solvent-based). Varying the stencil thickness produced little effect on the joint reliability. The stand-off of the components was dictated by the placement pressure rather than the stencil thickness, and the use of the thicker stencil (125 µm) did cause some bridging beneath R0603 components for larger area stencil aperture designs. The thicker stencil also gave higher shear strengths in the as-manufactured condition. Thinner stencils (75 µm) are likely to be more attractive as they use less ICA material, producing a lower cost manufacturing process.

Reducing the aperture opening was also studied, and assemblies using four different resistor and three SOIC stencil aperture designs were tested. Printed adhesive deposits covering the complete component pad, resulted in some bridging beneath R0603 components, particularly using the thicker stencil. However, there were few differences in the reliability performances of the joints made using the four resistor aperture designs. The aperture design using the least amount of material did show poorer reliability when printed using the thinner stencil, but there were few differences in reliability performance between the different SOIC aperture designs.

The positioning of smaller SOIC apertures did cause some concern. Since the position of the lead toe varies considerably between component suppliers, positioning of smaller gull-wing stencil apertures to ensure adequate bond area proved to be difficult. This will be of special interest for end-users who source the same component from a variety of suppliers.

The reliability trials of assemblies incorporating over-glueing and conformal coatings, showed some benefits to resistor joint reliability, but no advantages for SOICs. The benefits in reliability performance alone would not justify the additional costs of the material and its application, but over-glueing has benefit of significantly improving mechanical shock resistance.

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1 INTRODUCTION

Tin-lead solder has been used as the primary interconnection material by the electronics production industry for over 60 years. The introduction of European legislation in 2006 is forcing industry to change, by requiring the removal of lead from the solders used in the manufacture of a wide range of electronics goods. Replacement lead-free solder alloys are now available but they generally have a higher melting point than the alloys which they replace. This is expected to cause a number of end-user problems in the assembly of temperature sensitive components such as liquid crystal displays, electrolytic capacitors and optoelectronics. Electrically conductive adhesives could provide many users with an acceptable alternative to solder for the assembly of these types of components.

The restrictions on the use of lead in solders will also cause problems for those who use solder alloys which melt at different temperatures in sequential soldering operations. There are very few higher melting point alloys, which do not contain lead. However, electrically conductive adhesives could be used for initial soldering operations as they will not melt during later lead-free soldering. Indeed, conductive adhesives (CAs) are used extensively for component die-attach materials, which are subsequently soldered to electronic assemblies. CAs could also be used for the lower fabrication temperatures with lead-free solders being used for the initial operations.

Although many electrically conductive adhesives have been available for some time, the industry has perceived them as materials having low reliability, low mechanical strength and relatively high cost compared to solder. However, with the rising cost of assembly associated with the introduction of lead-free soldering, these materials have become more attractive. The potential use of these materials could be further boosted if the amount of adhesive printed could be reduced without affecting reliability. This could be achieved by reducing the printed area on the pad and/or reducing the stencil thickness. Both these aspects have been investigated in this project, utilising the reliability assessment methods developed in earlier phases of the project (References 1 and 2). In addition, this phase of the project has also investigated whether or not the use of conformal coatings or additional mechanical adhesives, could be used to improve the reliability of the conductive adhesive materials.

2 METHODOLOGY

2.1 TEST VEHICLE DESIGN AND DETAILS

A test vehicle, incorporating tin-finished R1206, R0603 and SOIC gull-wing lead formats, was designed and manufactured. A populated assembly is illustrated in Figure 1. The assembly utilises daisy-chain components to enable electrical continuity to be measured through assembled components via the edge connectors. The PCB was manufactured from double-sided FR4 laminate 1.6mm thick. The surface finish was immersion gold on electroless nickel (ENIG).

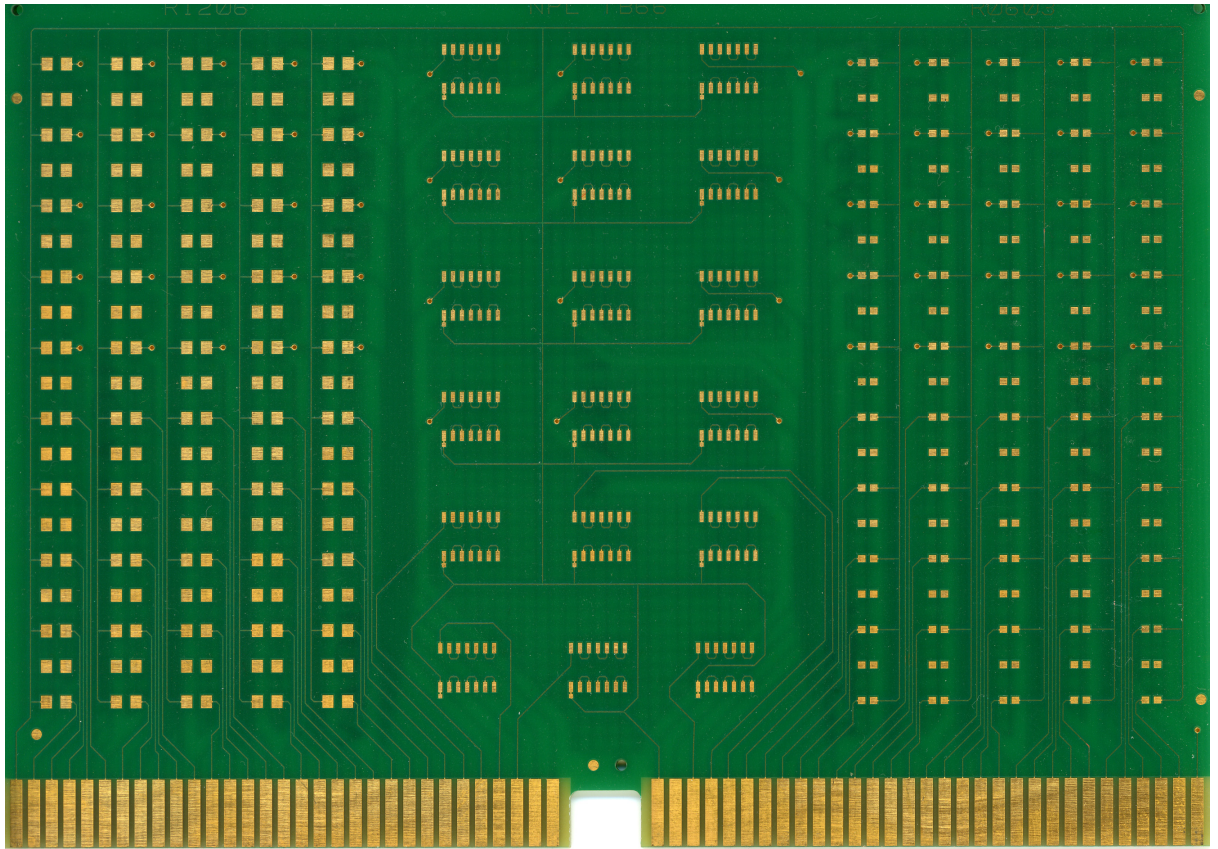


Figure 1 : Example of test substrate

2.2 STENCIL DESIGN

To determine how much adhesive is required to form a satisfactory joint, different stencil apertures were designed. These are shown in Figure 2 and Figure 3. Two different stencil thicknesses were also used (75 and 125 μm).

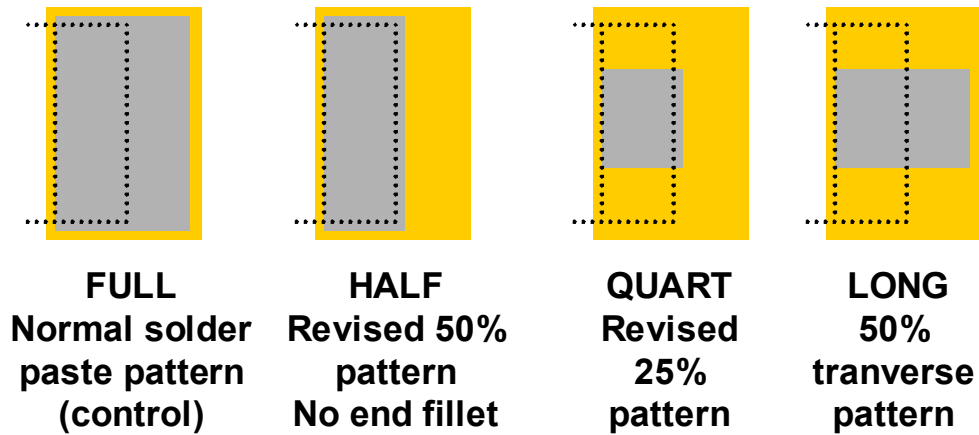


Figure 2 : Chip resistor ICA stencil patterns

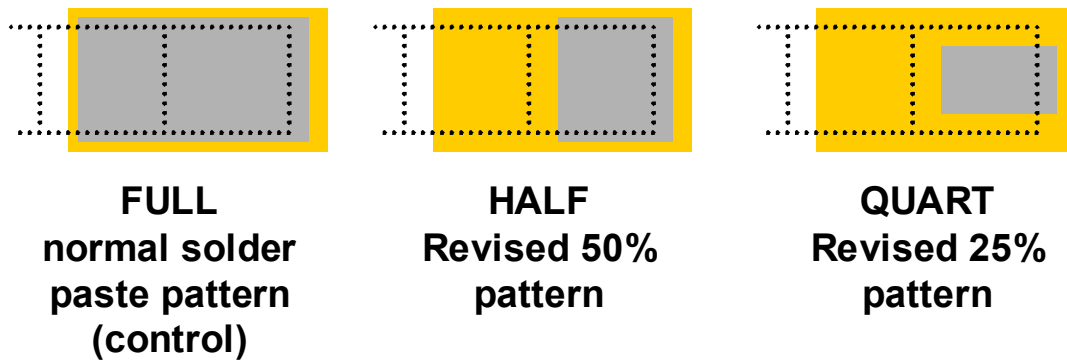


Figure 3 : SOIC ICA stencil patterns

2.3 ISOTROPIC CONDUCTIVE ADHESIVE DETAILS

Experimental work was undertaken using two representative commercially available isotropic conductive adhesives, both of which were single component, silver-loaded epoxy materials requiring storage at $-40\text{ }^{\circ}\text{C}$ to prevent cross-linking in the adhesives prior to assembly. The first of the materials was chosen as being suitable for curing in a reflow profile, and the second material was chosen for its longer cure schedule. The manufacturers' quoted data for the two materials are given in Table 1.

Table 1 : Comparison of manufacturers' quoted materials data

	Material A	Material B
% Ag Fill	Not Quoted	74%
Glass Transition Temperature	120 to 180 °C (cure dependent)	100°C
Volume Resisitivity	$<1 \times 10^{-4}$ Ohm.cm	7×10^{-4} Ohm.cm
Storage Life	12 months @ -40 °C	12 months @ -40 °C
Pot Life	24 hours	3 days
Cure Schedules	200 °C for 10 mins 180 °C for 15 mins 150 °C for 30 mins	150 °C for 3 mins (reflow) 125 °C for 5 mins (reflow) 150 °C for 5 mins (convection)

2.4 TEST VEHICLE ASSEMBLY

The conductive adhesives were applied to the PCBs in the same fashion as solder paste, using printing through 75 µm and 125 µm stainless steel laser-cut stencils. Normal 60° metal squeegees were utilised, and after stencil printing, the components were placed using an automatic placement system. Curing of material A was undertaken in an air-circulation oven for 30 minutes at 150 °C. Material B was cured in a 5-zone reflow oven using a modified SnPb reflow profile, for 5 minutes at 150 °C. The assembly route followed standard SM assembly practices.

After adhesive cure, some samples were conformally coated with either a solvent-based acrylic or a water-based acrylic.

For additional samples, wave-soldering adhesives were added on top of the solder joints on SOIC and chip resistor components (Figure 4). Previous work in this project (Reference 1) has shown that the use of such additional adhesives, significantly improves mechanical shock performance. In this work it was hoped to determine if the use of these materials could improve electrical performance.

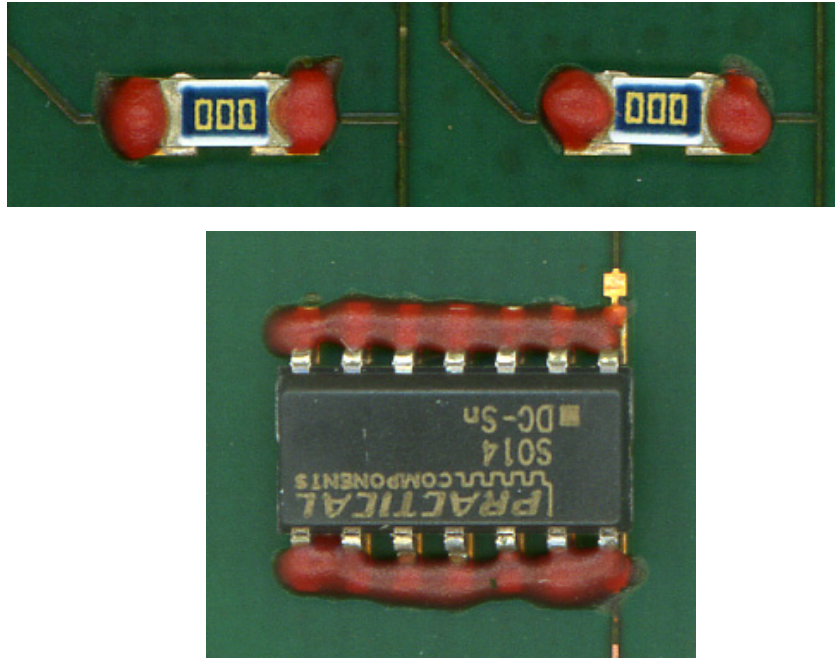


Figure 4 : Examples of application of wave soldering adhesives

2.5 SHEAR TESTING

Before stress screening, the joints of some resistor components were subjected to shear testing, to determine if the stencil aperture design had affected adhesion. Figure 5 illustrates a typical shear test. These tests were undertaken on a Dage Series-4000 modular multi-function bond-tester. The stand-off height of the tool was set equal to $h/2$ (typically $80\text{ }\mu\text{m}$), between the bottom of the shear tool and board surface (h is the stand-off height between the component and the board surface). During each test, the shear tool was moved forward at a defined speed ($200\text{ }\mu\text{m/s}$) against the test component, and the applied force increased until the attachment was broken.

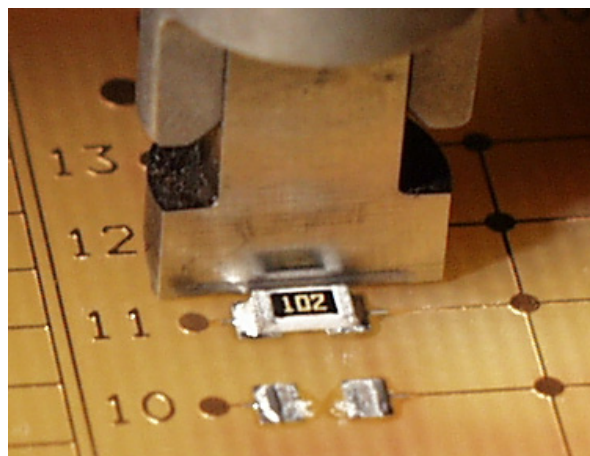


Figure 5 : Shear test jig and push-off tool before a shear test

2.6 STRESS SCREENING REGIMES

After manufacture, groups of assemblies were subjected to damp heat ageing at 85°C/85%RH for 2000 hours. This regime was found in phase 1 of this project (Reference 1) to be the most effective at increasing joint resistances.

2.7 ELECTRICAL CONTINUITY MONITORING

Three assemblies of each material were subjected to stress screening as detailed above for the full 2000 hours. After every 250 hours during stress screening, the samples were tested at room temperature and the resistance of each circuit on the assembly logged via a PC, DVM and programmable switching system.

3 RESULTS

3.1 MANUFACTURING CHARACTERISTICS

3.1.1 Bondline Thickness

Figure 6 and Figure 7 show micro-sections through two typical conductive adhesive joints formed using 75 and 125µm stencils respectively. These clearly demonstrate that the resulting bondline of the joints is largely independent of the stencil thickness, and hence it is the placement pressure of the placement system that is the deciding factor in determining bondline thickness.

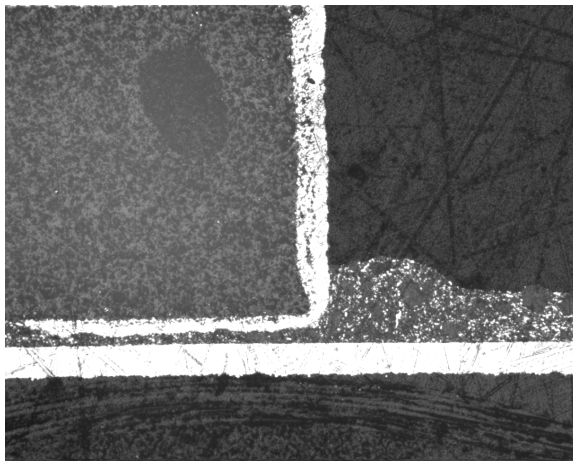


Figure 6 : Micro-section showing bondline thickness (75 µm stencil)

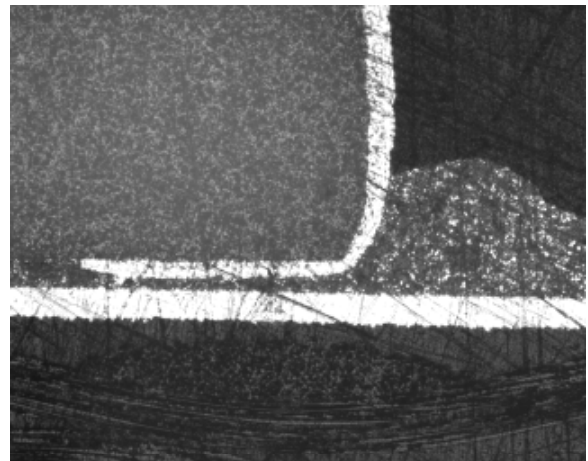


Figure 7 : Micro-section showing bondline thickness (125 µm stencil)

3.1.2 Joint Visual Appearance

The visual appearance of typical adhesive joints formed using adhesive B for R1206 and SOIC components are shown in Figures 8 to 11. Comparing the joints made using the thick and thin stencils, it can be noted that the conductive adhesive has generally been squeezed out more from the joint under the component, or termination, for the thicker stencil. The joints formed with material A exhibited a similar trend.

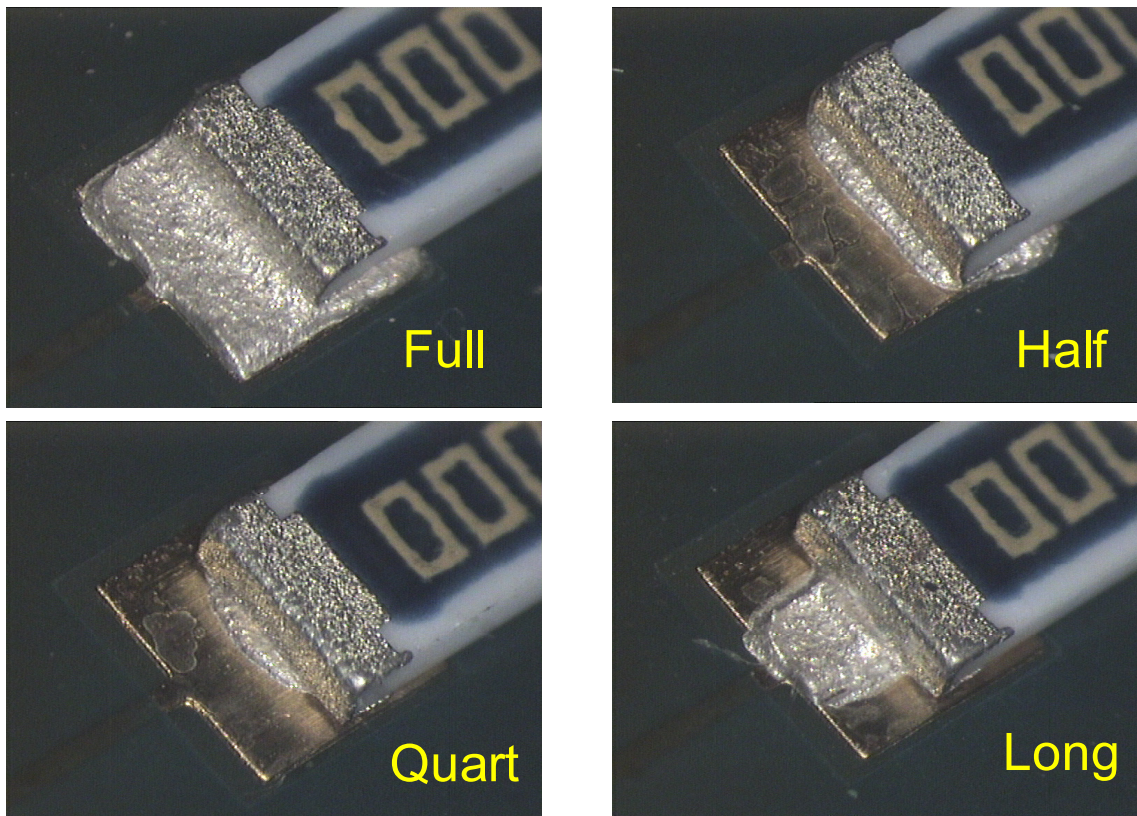


Figure 8 : Typical joints for material B for the four R1206 stencil aperture designs (75 µm thick stencil)

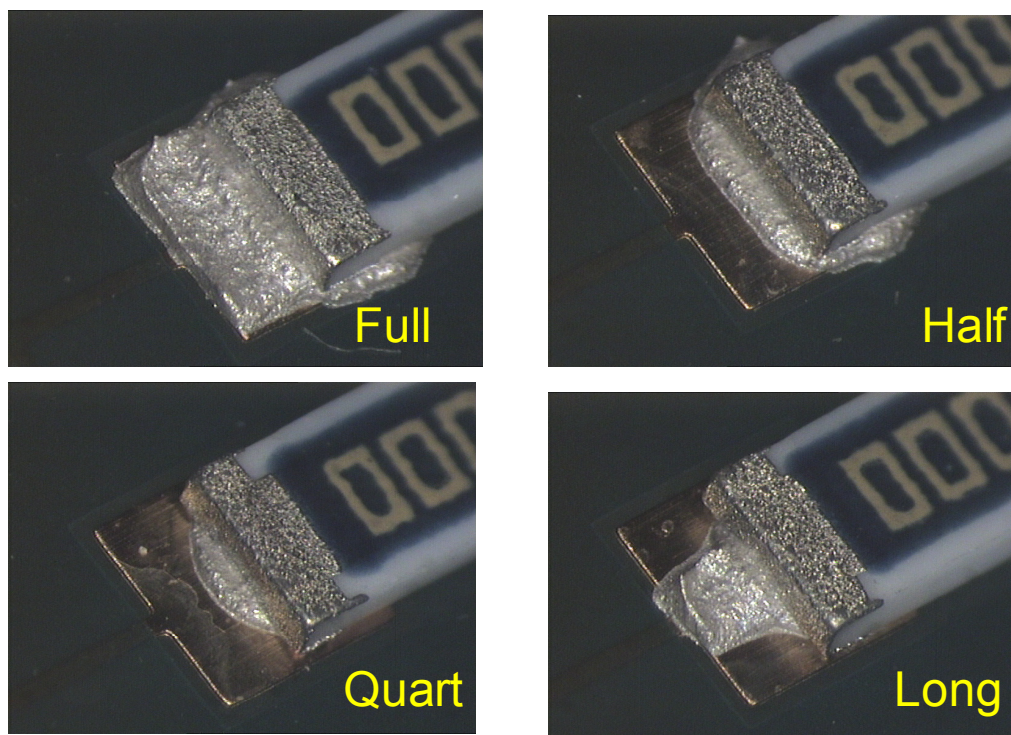


Figure 9 : Typical joints for material B for the four R1206 stencil aperture designs (125 µm thick stencil)

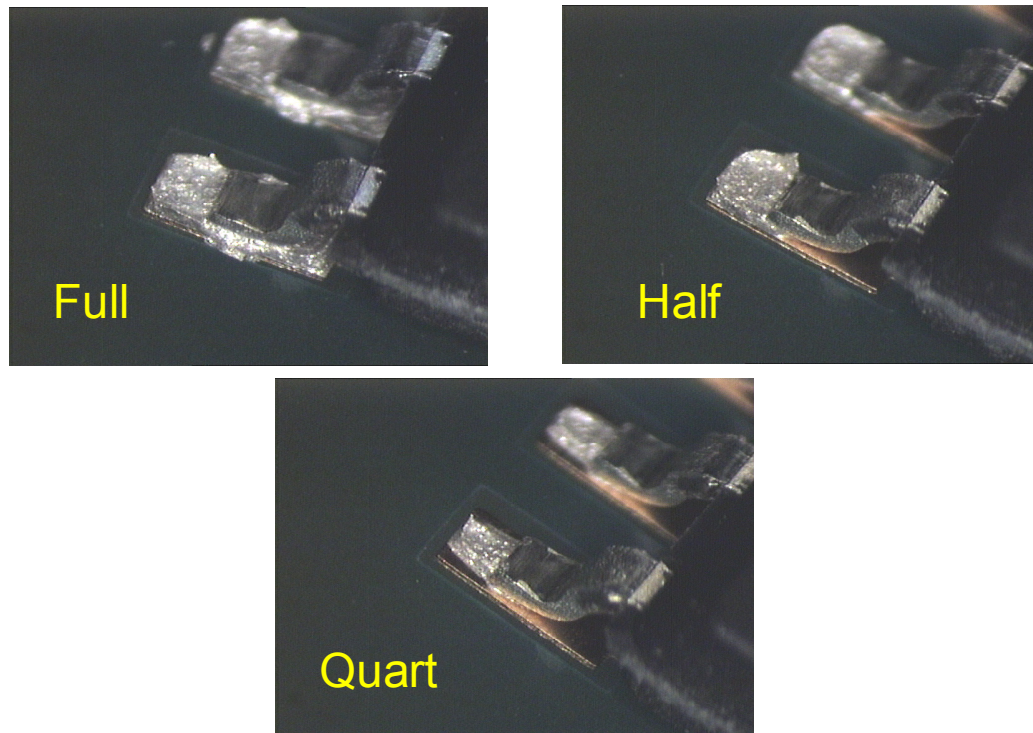


Figure 10 : Typical joints for material B for the three SOIC stencil Aperture designs (75 μm thick stencil)

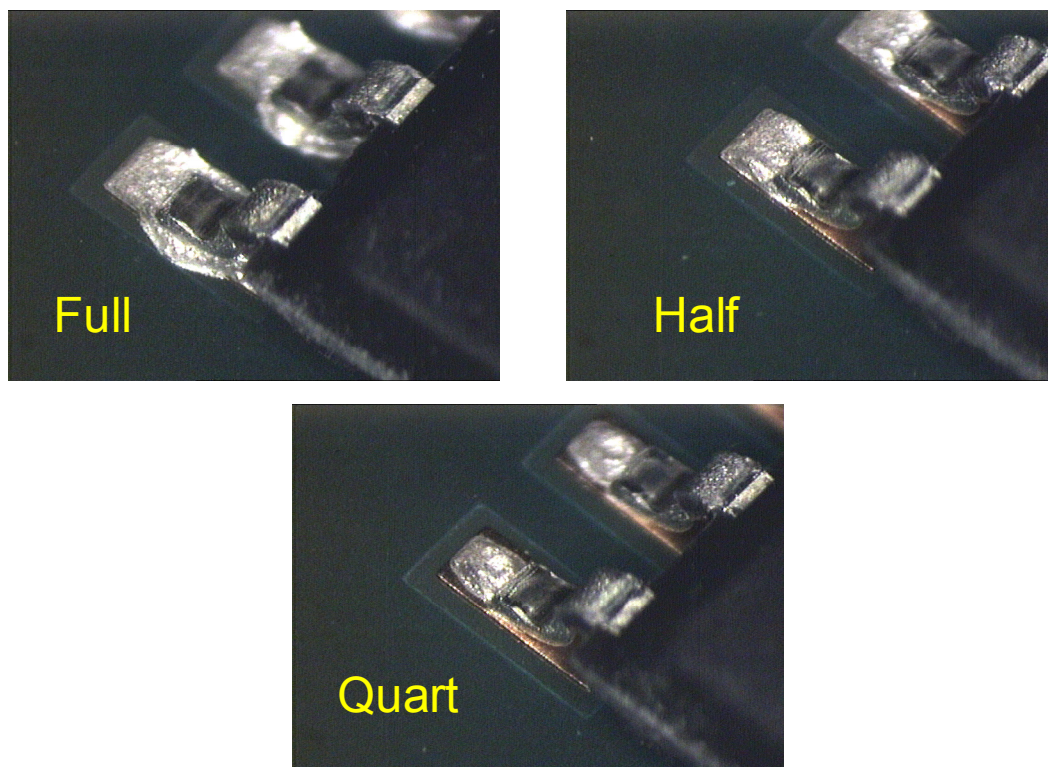


Figure 11 : Typical joints for material B for the three SOIC stencil aperture designs (125 μm thick stencil)

3.1.3 Shear Testing

The results for the shear strength measurements of joints made using both stencil thicknesses and both materials are summarised in Figures 12-15. The shear strengths of joints made using the full and half aperture designs are similar, with possibly more material being pushed up the sides of the component with the full stencil aperture design. This results in slightly higher shear strengths because of the greater bond area of the joint. For the other two stencil aperture designs (quart and long), the corresponding bond area of the joint is significantly less, resulting in lower shear strengths. Material B gave joints with higher shear strengths than did material A.

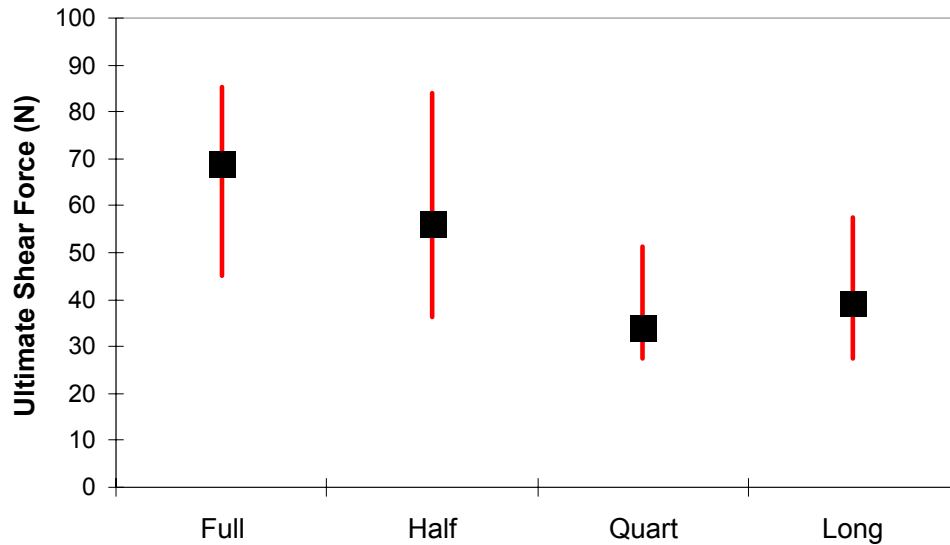


Figure 12 : R1206 shear test results for four stencil aperture designs (125µm stencil thickness for material A)

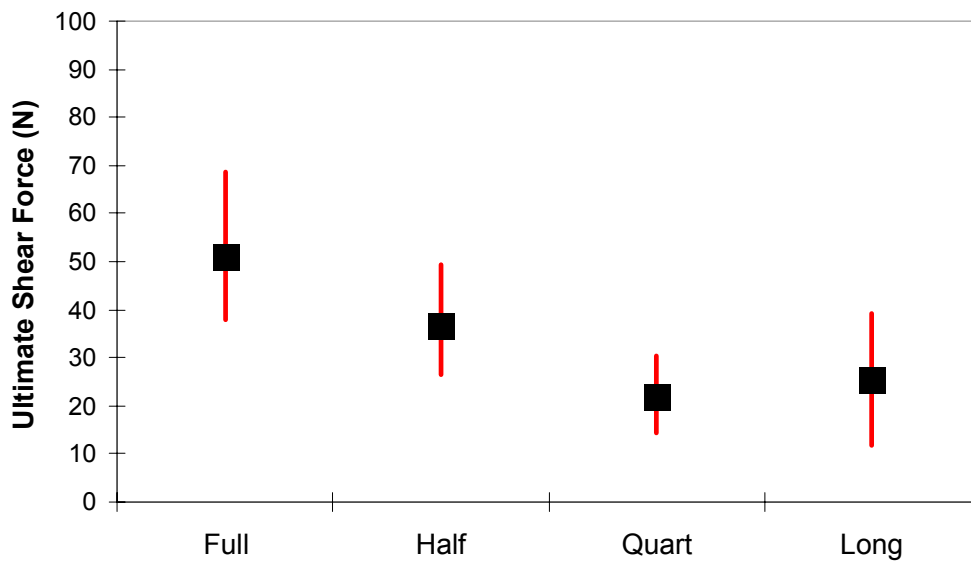


Figure 13 : R1206 shear test results for four stencil aperture designs (75µm stencil thickness for material A)

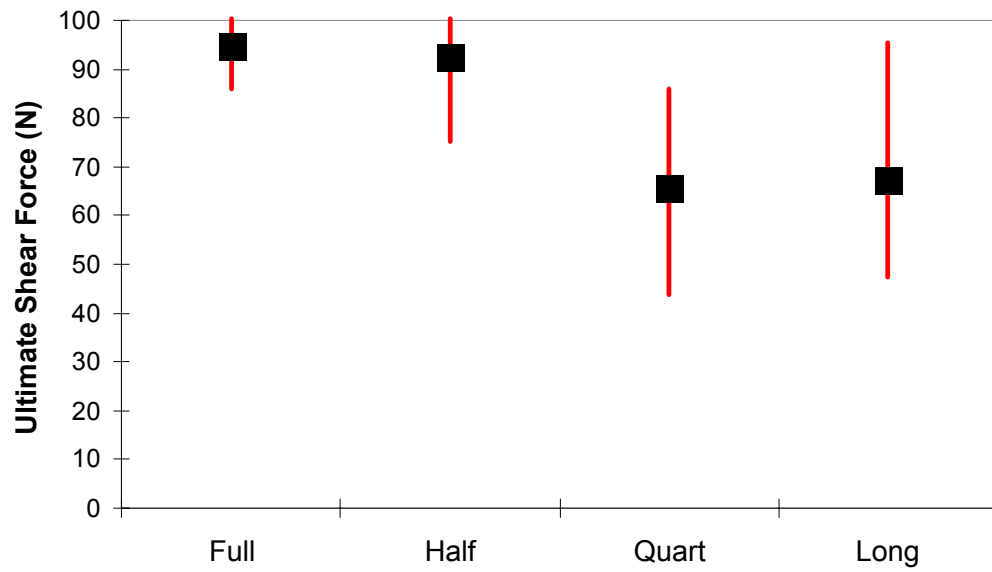


Figure 14 : R1206 shear test results for four stencil aperture designs (125µm stencil thickness for material B)

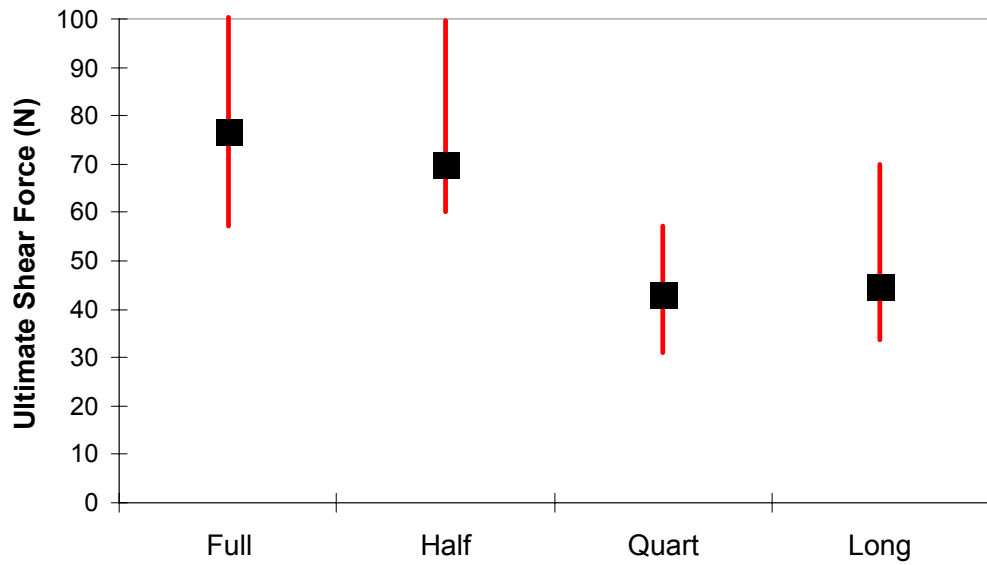


Figure 15 : R1206 Shear test results for four stencil aperture designs (75 µm stencil thickness for material B)

3.2 ELECTRICAL CONTINUITY MEASUREMENTS

For all measurements, an electrical resistance (for a daisy-chain circuit) in excess of 100 Ω was considered a failure.

3.2.1 R1206/Material A

Figure 16 and 17 show the electrical performance of joints of material A (for the two stencil thicknesses and R1206 components). There is little difference between the results for the two stencil thicknesses. The half stencil design was as reliable as the alternative stencil designs.

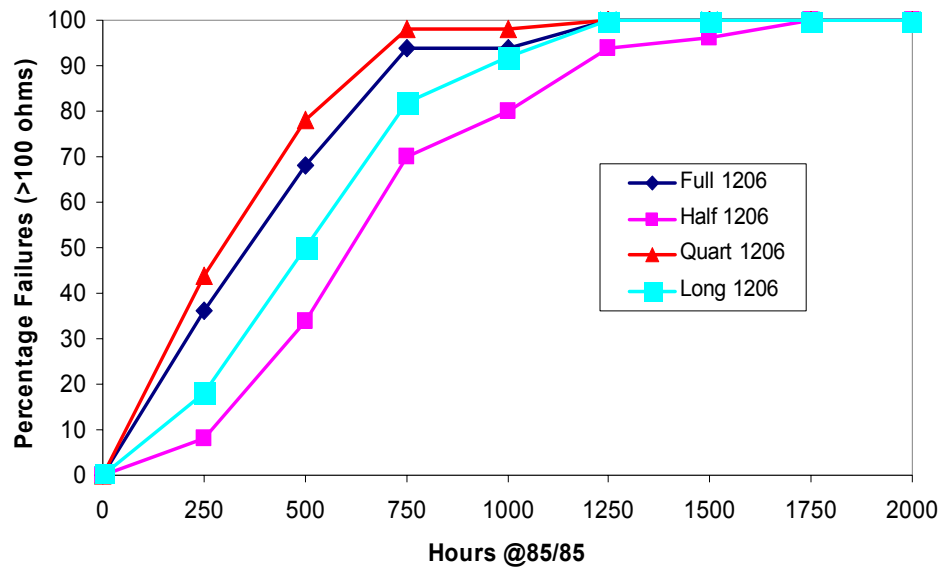


Figure 16 : R1206 electrical performance of material A (125µm stencil thickness)

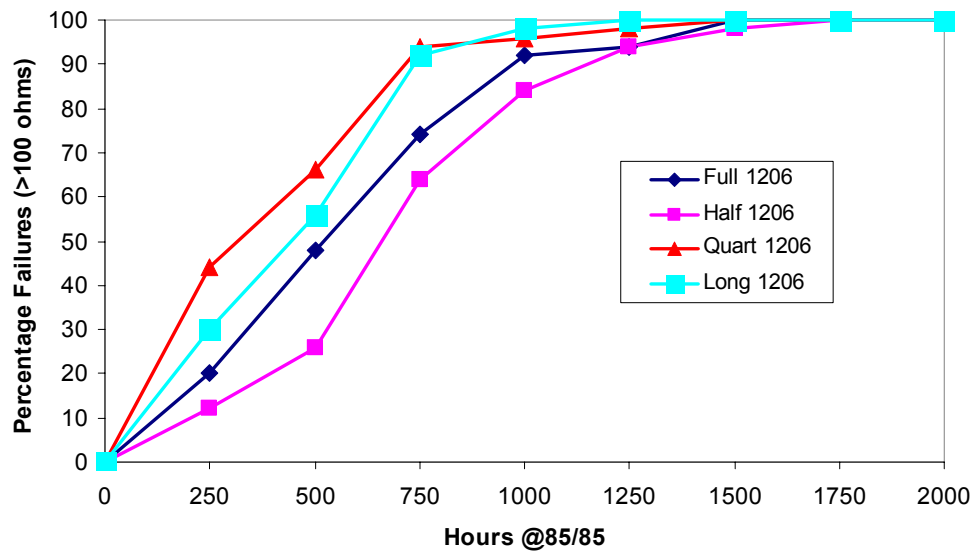


Figure 17 : R1206 electrical performance of material A (75µm stencil thickness)

3.2.2 R1206 / Material B

Figure 18 and **Figure 19** show the electrical performance of the joints for material B (for the two stencil thicknesses for R1206 components). There are few differences between the results for the stencils for material B although the overall performance of this material was better than that of material A. The joints made with the half stencil design were as reliable as those of its alternatives. However, the quarter stencil design for the thinner stencil did exhibit more failures than the other designs.

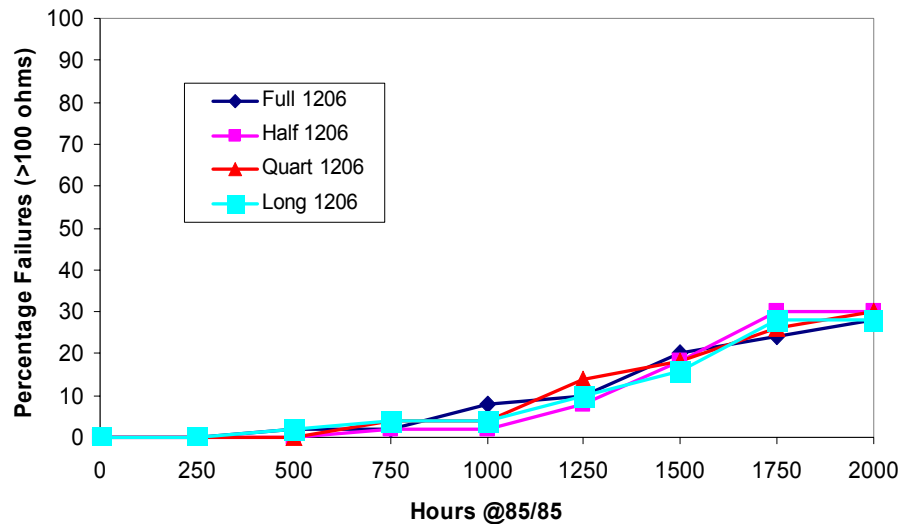


Figure 18 : R1206 electrical performance of material B (125 µm stencil thickness)

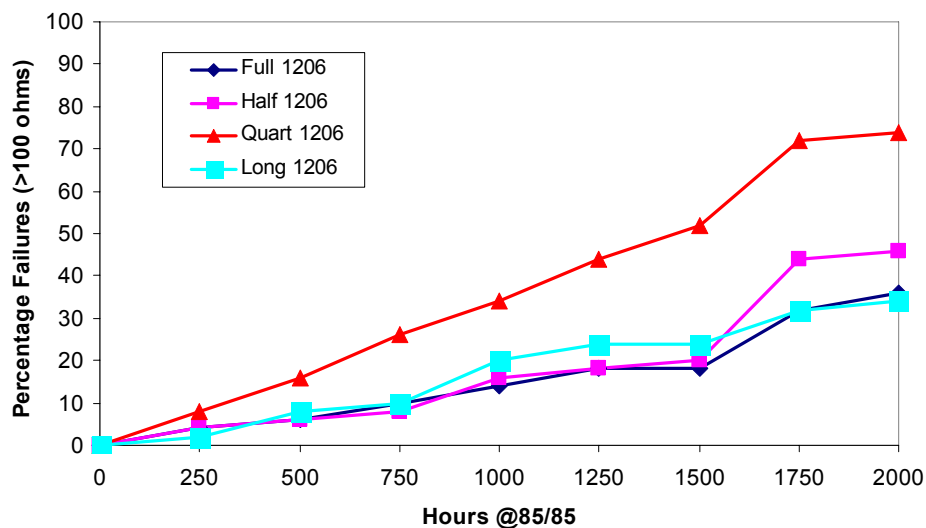


Figure 19 : R1206 electrical performance of material B (75 µm stencil thickness)

3.2.3 SOIC / Material A

Figures 20 and 21 show the electrical performance of the joints of material A (for the two stencil thicknesses and SOIC components). There is little difference between the results for the two stencil thicknesses. The joints made with the half stencil design were as reliable as those of its alternatives.

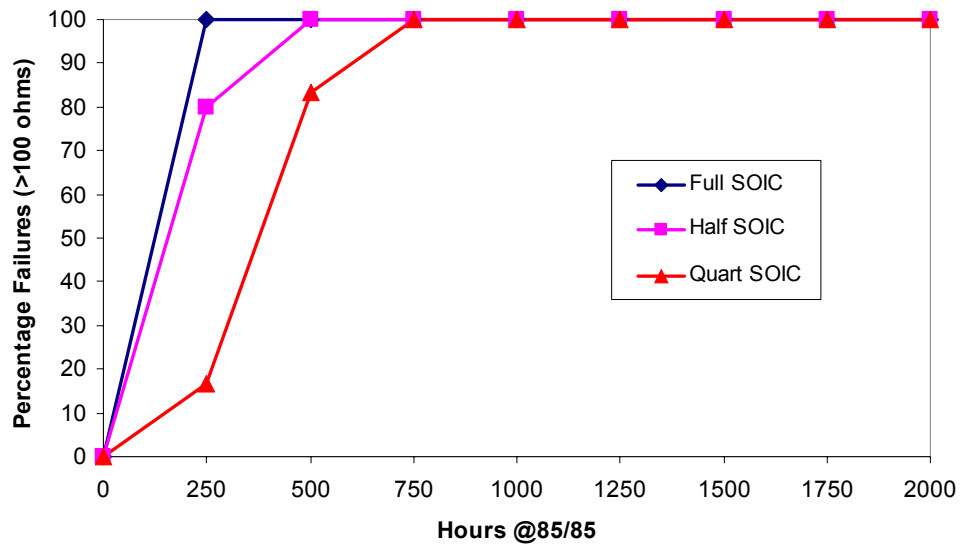


Figure 20 : SOIC electrical performance of material A (125 μ m stencil thickness)

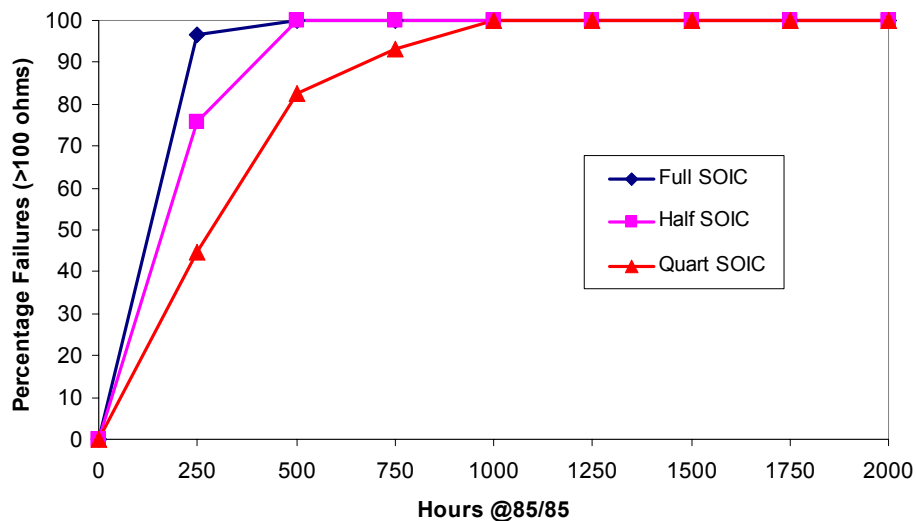


Figure 21 : SOIC electrical performance results of material A (75 μ m stencil thickness)

3.2.4 SOIC / Material B

Figures 22 and 23 show the electrical performance of the joints of material B (for the two stencil thicknesses and SOIC components). There are few differences between the results for the stencils for material B although the performance of this material was again better than that of material A. The joints made with the half stencil design were as reliable as those of its alternatives.

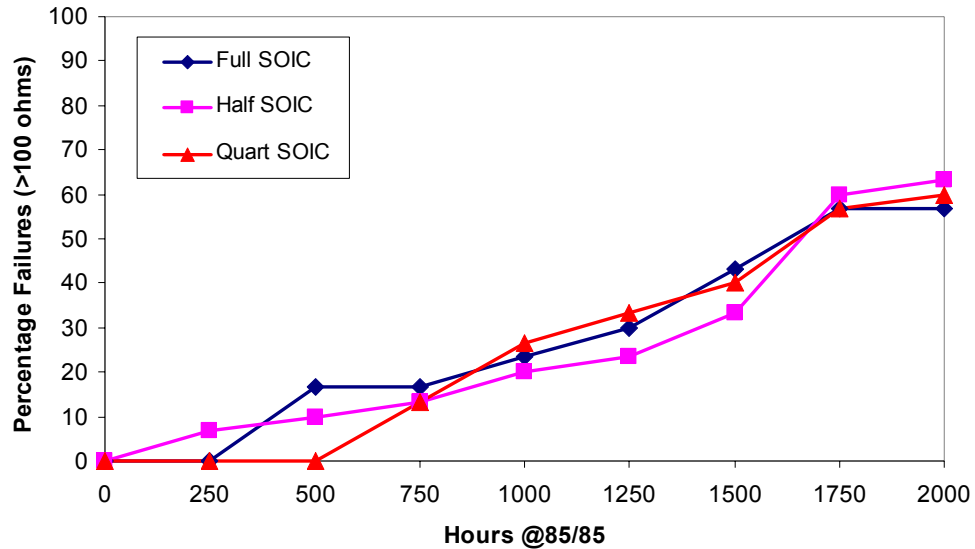


Figure 22 : SOIC electrical performance of material B (125 µm stencil thickness)

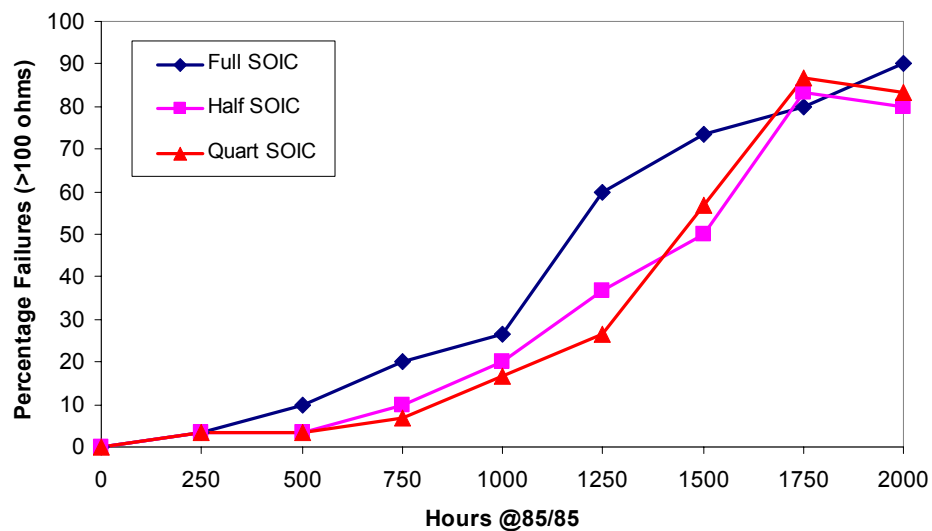


Figure 23 : SOIC electrical performance of material B (75 µm stencil thickness)

3.2.5 Overglueing R1206 Components

Figure 24 and 25 present the results for R1206 joints manufactured using material B, a 5 μm stencil, and with and without over-glueing respectively. The results show that using the over-glueing a significant improvement in reliability over 2000 hours of damp heat testing, can be achieved.

Figure 24 is reproduced from Figure 19 and is shown again to ease comparison.

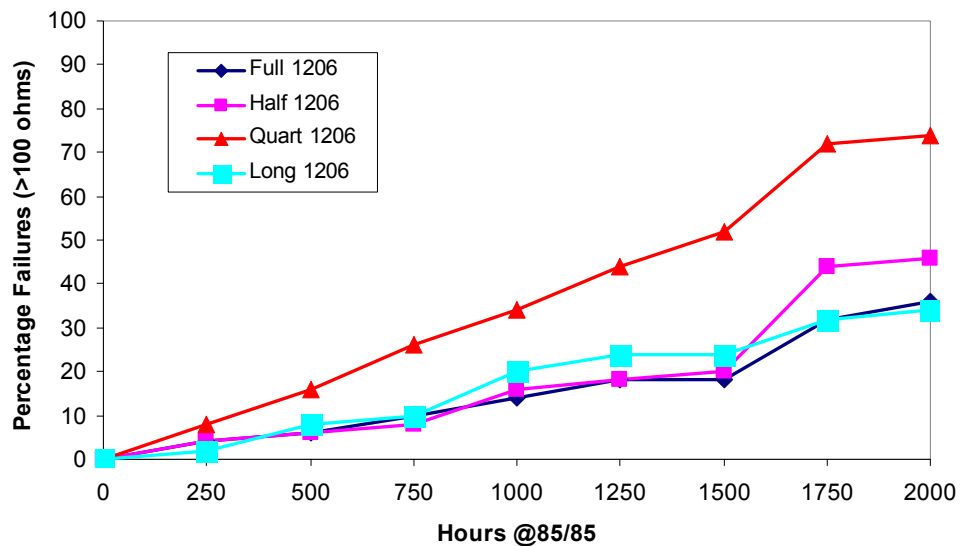


Figure 24 : R1206 electrical performance of material B (75 μm Stencil Thickness without additional adhesive)

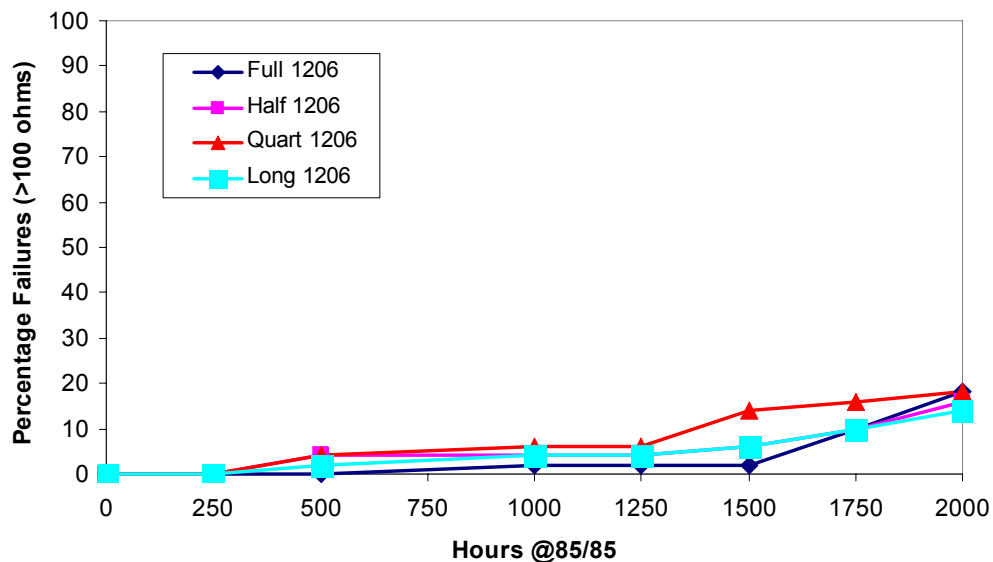


Figure 25 : R1206 electrical performance of material B (75 μm stencil thickness with additional adhesive)

3.2.6 Overglueing SOIC Components

The results for SOIC joints manufactured using material B, a 75 μm stencil, and with and without over-glueing, are presented in Figures 26 and 27 respectively. The results show that with the overglueing there is no significant improvement in reliability over 2000 hours of damp heat testing. Figure 26 is reproduced from Figure 23 to ease comparison.

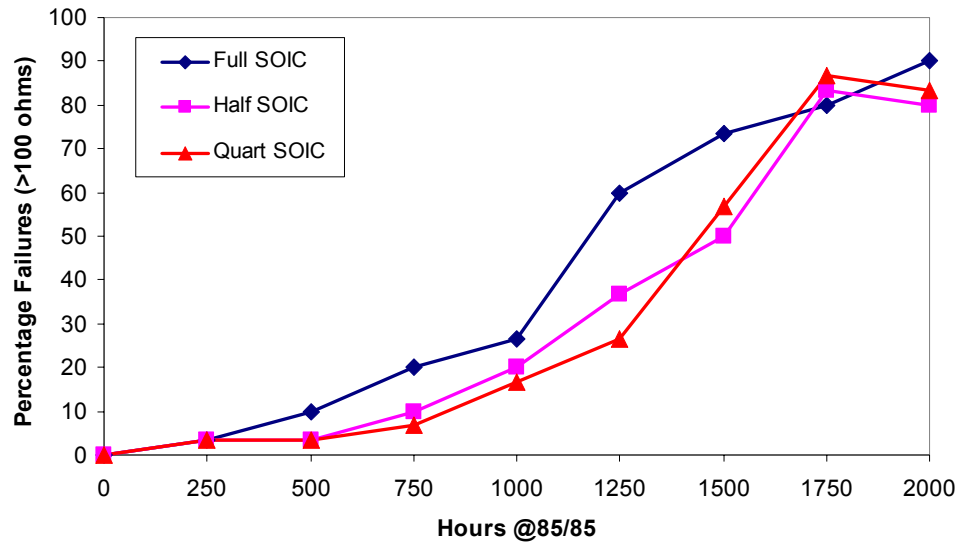


Figure 26 : SOIC electrical performance of material B (75 μm stencil thickness without additional adhesive)

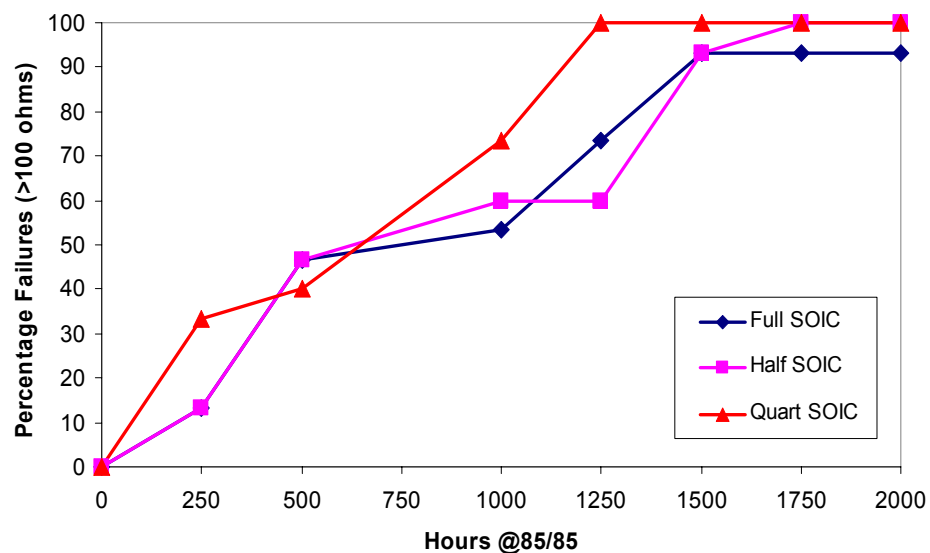


Figure 27 : SOIC electrical performance of material B (75 μm stencil thickness with additional adhesive)

3.2.7 Conformal Coating / R1206 Components

Figure 28-30 present the results for R1206 joints manufactured using material B, a 125 μm stencil, with and without coating. Three coating conditions were used: no conformal coating, a water-based coating and a solvent-based coating respectively. The results indicated that a slight improvement in reliability over 2000 hours of damp heat testing was achieved using conformal coating.

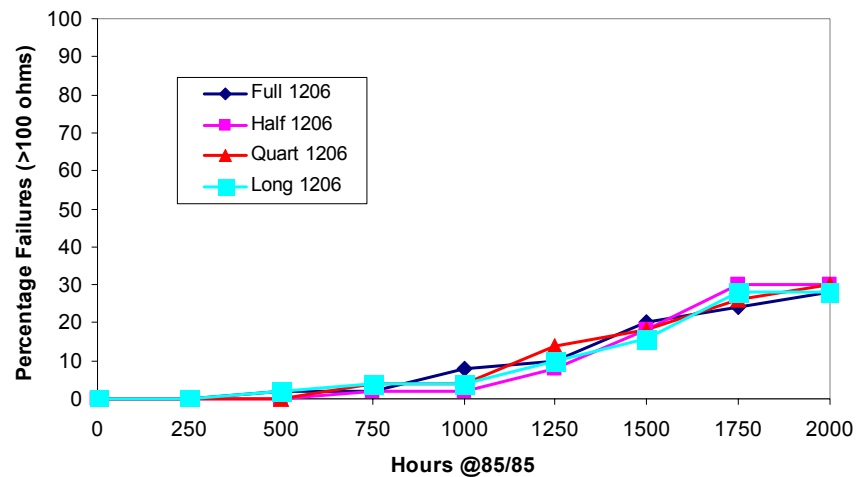


Figure 28: R1206 electrical performance of material B (125 μm stencil thickness without conformal coating)

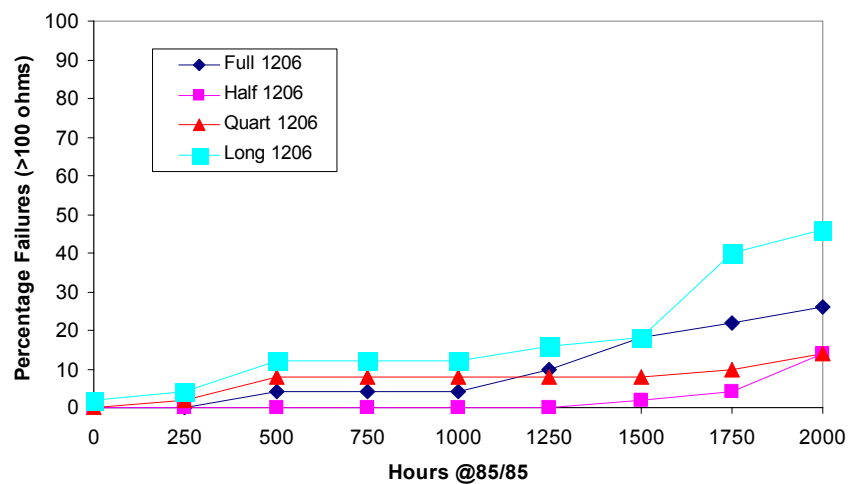


Figure 29 : R1206 electrical performance of material B (125 μm stencil thickness with water-based conformal coating)

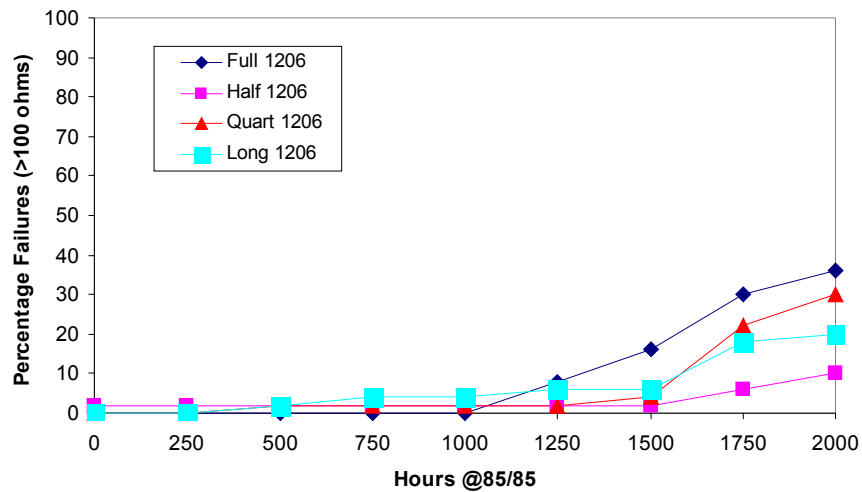


Figure 30 : R1206 electrical performance of material B (125 μm stencil thickness with solvent-based conformal coating)

3.2.8 Conformal Coating / SOIC Components

Figure 31-33 present the results for SOIC joints manufactured using material B, a 125 μm stencil, with and without coating. Three coating conditions were used: no conformal coating, a water-based acrylic coating, and a solvent-based acrylic coating respectively. The results indicated that there was no improvement in reliability over 2000 hours of damp heat testing using conformal coating.

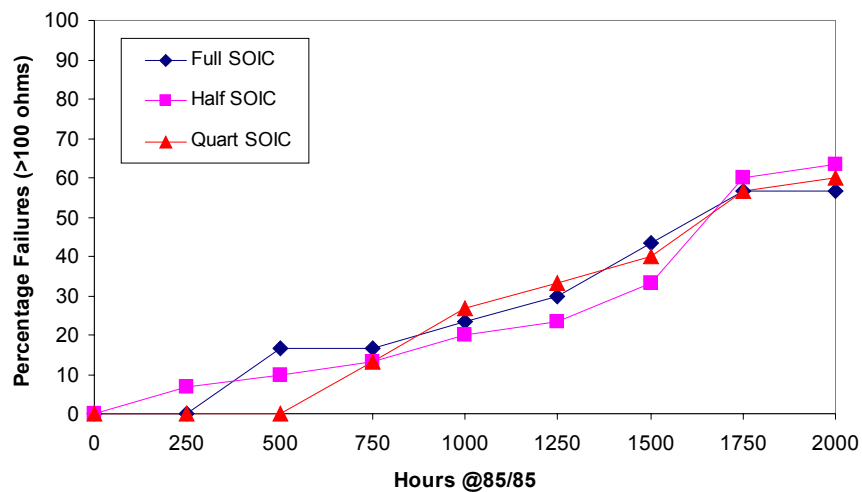


Figure 31: SOIC electrical performance of material B (125 μm stencil thickness without conformal coating)

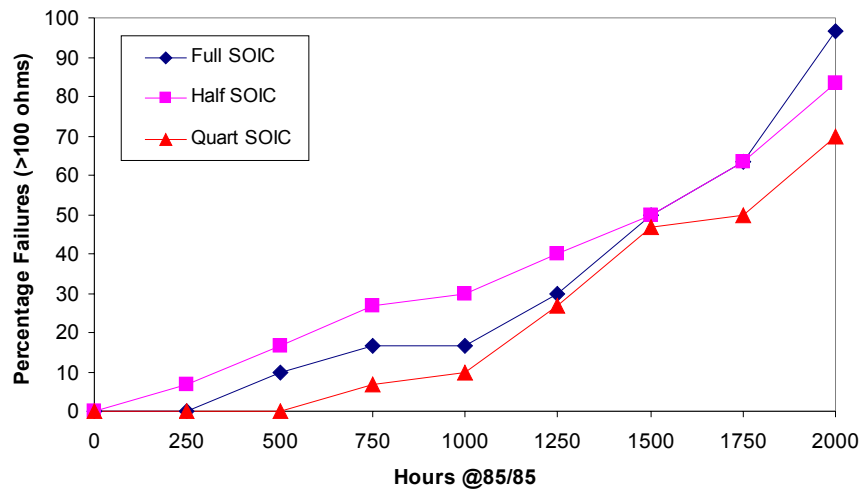


Figure 32 : SOIC electrical performance of material B (125µm stencil thickness with water-based conformal coating)

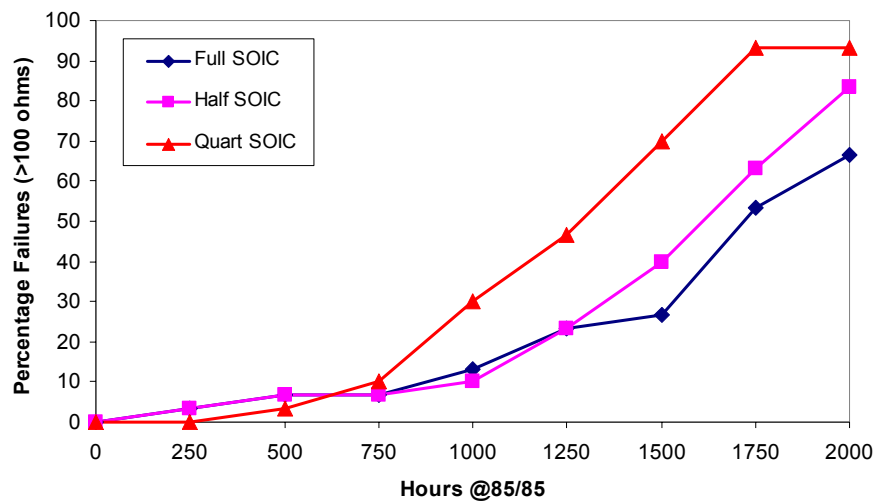


Figure 33 : SOIC electrical performance of material B (125µm stencil thickness with solvent-based conformal coating)

4 DISCUSSION

4.1 STENCIL THICKNESS

Dimensional measurements on samples manufactured with stencils having thicknesses of both 75 μm and 125 μm , indicated that the stand-off of the component from the PCB land was dependent on the pressure of the placement system, not on the thickness of the material deposited through the stencils (see Figure 6 and Figure 7). However, problems were experienced for a limited number of R0603 components using the thicker stencil (125 μm). Conductive adhesive had pushed under the components, and caused shorts between the normally isolated component lands. This occurred for joints made with the full and half aperture designs for material A. Figure 34 illustrates worst case examples of these shorts for material A, as well as a limited short occurring with the use of the full aperture design and the 75 μm stencil. Figure 35 shows similar shorts using material B and the 125 μm stencil, but there were none with the same material and the 75 μm stencil. (NB. The red cross on the images, indicates unacceptable deposits). No shorting was noted with the R1206 components for either material (Figure 36). Neither were shorts observed with SOIC components for either material A or B, but the full aperture design for the 125 μm thick stencil was close to producing shorting between adjacent leads (Figures 37 and 38). Overall deposition of excessive ICA material (resulting in under component shorting under the smaller components from a combination of thicker stencil and full aperture design) cannot be recommended.

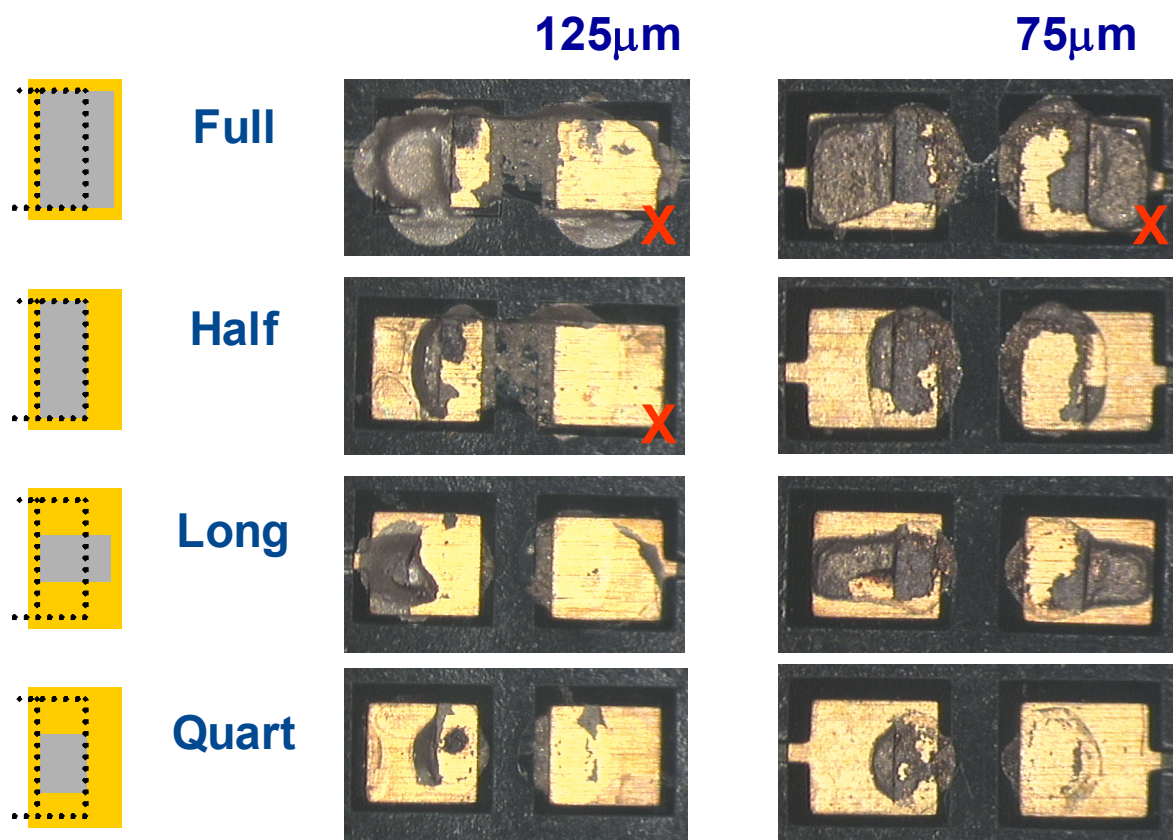


Figure 34 : Worst case examples of bridging beneath R0603 components for material A

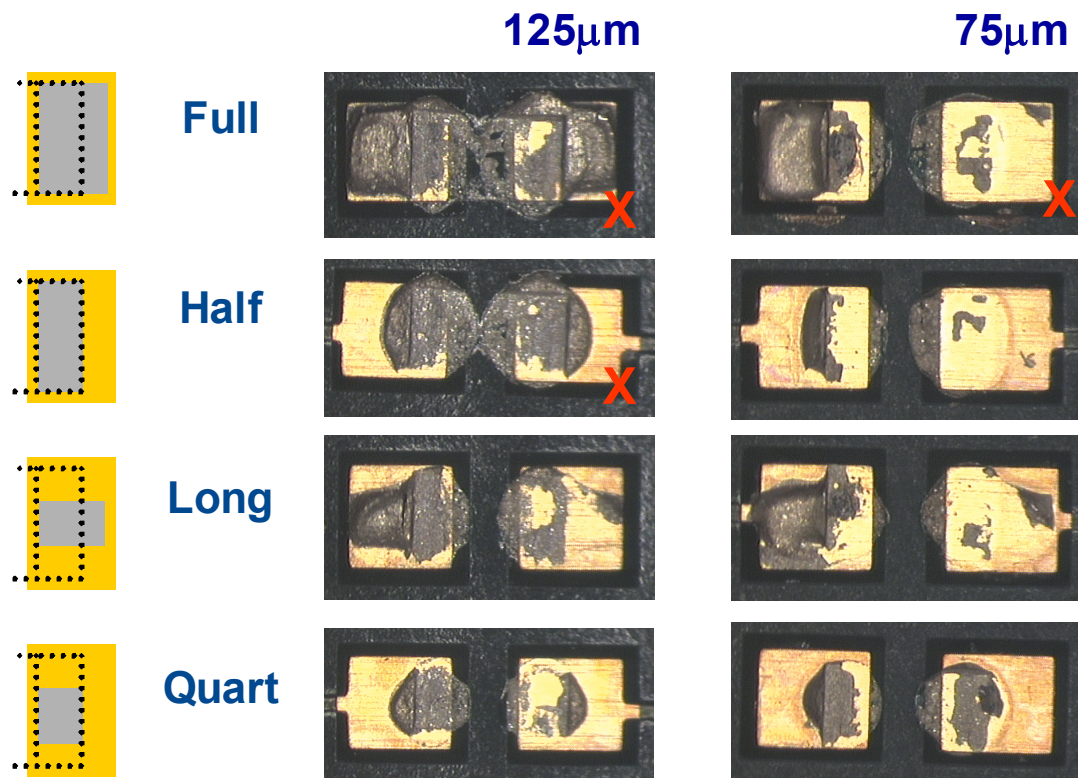


Figure 35 : Worst case examples of bridging beneath R0603 components for material B

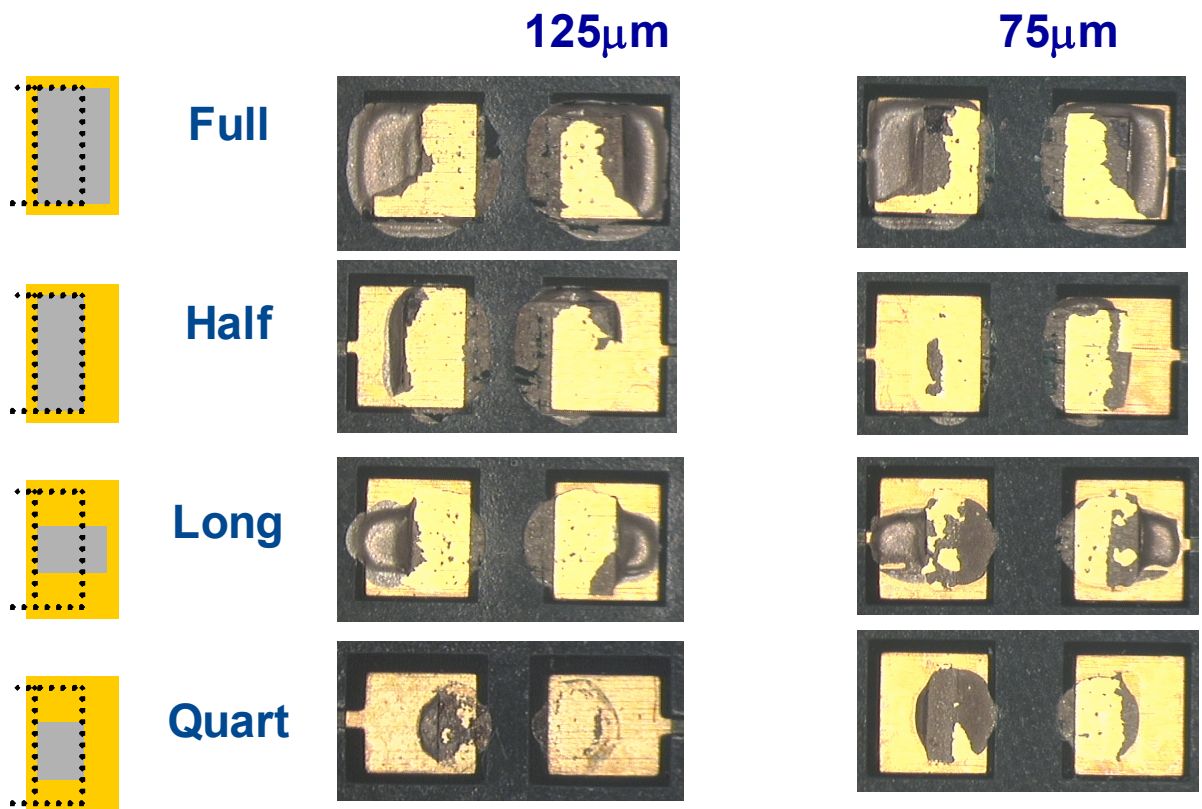


Figure 36 : Worst case examples of bridging beneath R1206 components for material A

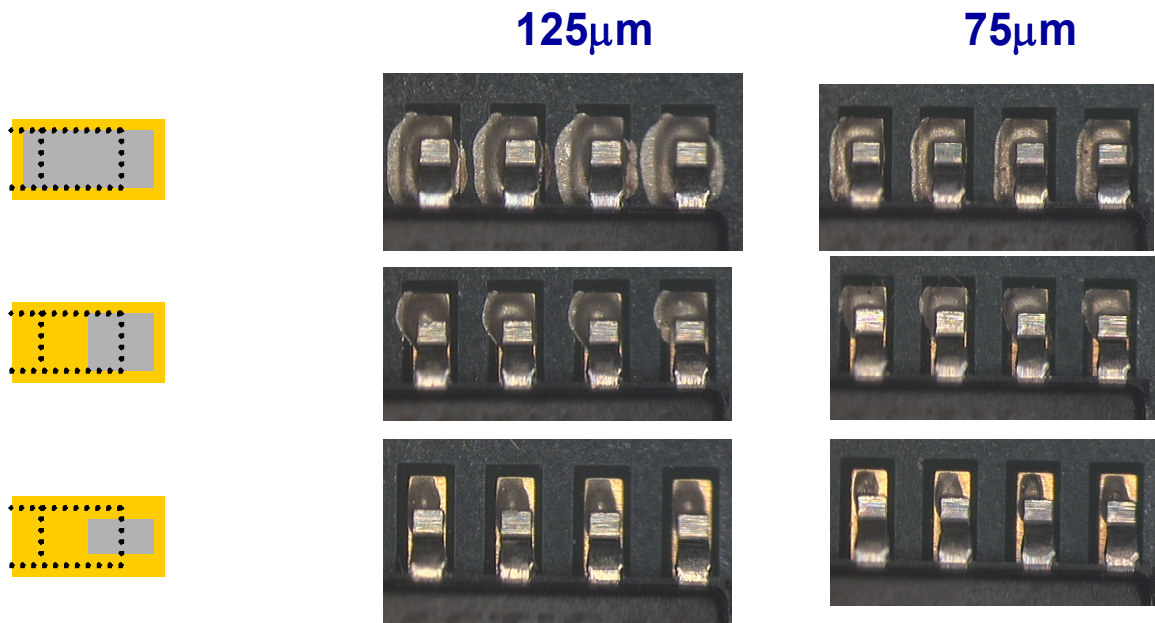


Figure 37 : Worst case examples of bridging around SOIC components for material A

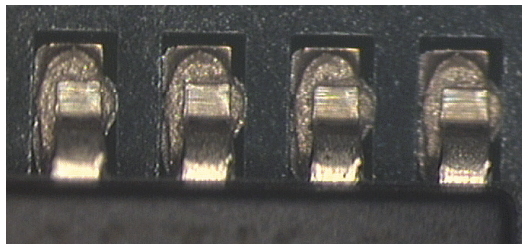


Figure 38 : Worst case examples of bridging around SOIC components for full print aperture and material B

Problems were experienced with the design of stencil apertures for SOIC components. For the half aperture design, the aperture was positioned on the outer half of the SOIC land. For the components used, the toe of the device was lower than the leading heel and finished slightly outboard of the centre of the land (see Figure 39). This resulted in very little of the SOIC lead overlapping the adhesive on the land and therefore poorer adhesive bonding than would be desired. The land design used was the IPC standard, designed to fit all SOIC components. Users of a half aperture design should note that the position of the half aperture design needs to be such that the toe of the lead should be inline with the outer portion of the aperture to ensure maximum bond area. The higher position of the heel of the lead above the toe may also cause problems with minimal bond areas if the heel position is greater than the thickness of adhesive deposited.

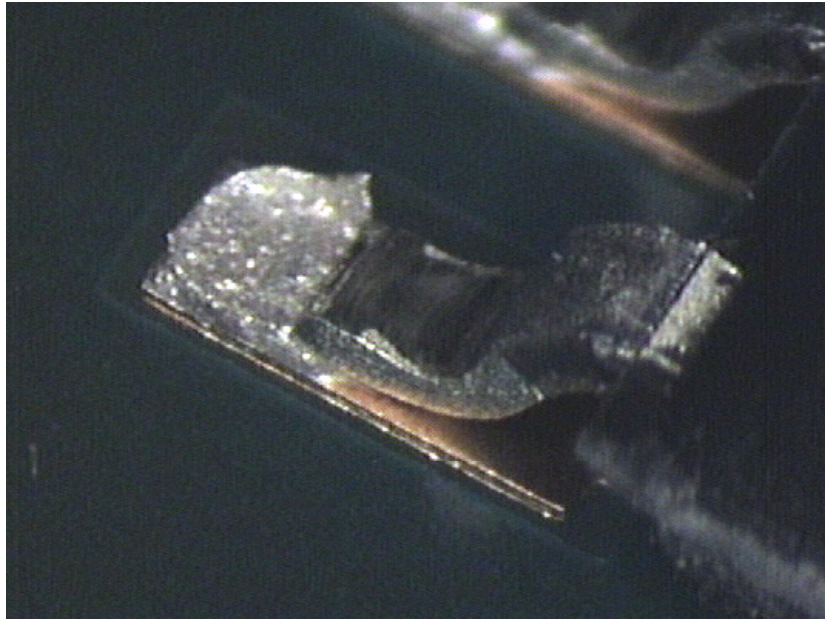


Figure 39 : SOIC joint showing position of lead in relation to half stencil aperture design deposit

In terms of damp heat reliability testing, little difference was noted between the joints made with the 75 μm or 125 μm thick stencils. Whilst the thicker stencil samples (125 μm) gave higher shear strengths, the thinner stencils (75 μm) used less ICA material, which resulted in a lower cost process, and gave better stencil release for smaller apertures.

4.2 STENCIL APERTURE DESIGN

For resistor components, the long and quarter aperture designs gave joints of lower shear strengths than those of the full or half aperture designs (see Figures 14 to 17), and clearly this is because the bond area of these aperture designs is smaller than for the half and full aperture designs. The full aperture designs gave joints of slightly greater shear strengths than those of the half aperture designs, because the extra adhesive was pushed slightly up the end of the resistor components, giving a greater bond area (see Figure 6 and 7).

Joints from the quarter resistor design exhibited lower reliability for the thinner 75 μm stencil and therefore cannot be recommended, but otherwise few differences were evident in reliability between the different R1206, or R0603, aperture designs. There was also little difference in reliability between the joints with the SOIC aperture designs.

4.3 OVER-GLUEING AND CONFORMAL COATING

The results for those assemblies using over-glueing and conformal coating indicated that, although there was some benefit to resistor joint reliability from using these additional materials, there was no advantage for the SOIC components (see Figures 26 to 35).

Benefits in resistor joint reliability alone would probably not justify the additional costs of either materials or the processing of over-glueing or conformal coating. However, over-glueing does improve mechanical shock resistance and therefore should be considered as a means of producing a higher reliability isotropic conductive adhesive assembly.

5 CONCLUSIONS

5.1 STENCIL THICKNESS CONCLUSIONS

- Reliability trials using assemblies built with two different thicknesses of stencil and two different ICAs, showed few differences between the use of 75 μm and 125 μm stencils in terms of reliability.
- The placement pressure rather than the stencil thickness determines the stand-off of components.
- Using the thicker stencil (125 μm) did cause some bridging beneath R0603 components for larger area stencil aperture designs.
- Using the thicker stencil also resulted in joints with higher shear strengths in the as-manufactured condition, but otherwise gave no advantage.
- Thinner stencils (75 μm) are more attractive as they use less ICA material, producing a lower cost manufacturing process.
- Thinner stencils also provide better stencil release for smaller apertures, since the stencil wall area is correspondingly smaller than its counterparts for a thicker stencil.
- Therefore the 75 μm stencil has been chosen as the preferred option for the next phase of this project, a technology demonstrator utilising a production circuit.

5.2 STENCIL APERTURE CONCLUSIONS

- Assemblies using four different resistor and three SOIC stencil aperture designs have been subjected to damp-heat reliability testing. Those designs for resistors that resulted in smaller bond areas (long and quarter aperture designs), gave joints with lower shear strengths, which may be significant.
- The aperture covering the complete component pad (full design) resulted in some bridging beneath R0603 components, particularly when using the thicker stencil. The aperture design printing paste on the inside half of the pad (half design) also resulted in some bridging under R0603 components, but only when using the thicker stencil.
- For the four resistor aperture designs, there were few differences in the reliability of the corresponding joints.
- The aperture design using the least amount of material (quarter design) did result in joints with poorer reliability when using the thinner stencil.
- There were few differences in reliability performance between joints resulting from the different SOIC aperture designs.

- Potential issues were encountered regarding the positioning of smaller SOIC apertures in relation to lead differences between component suppliers. Because the position of the toe of the lead varies considerably between component suppliers, positioning of smaller gull-wing stencil apertures to ensure adequate bond area will be difficult, particularly for end-users who multi-source the same component. Hence, a full design may be necessary.

5.3 OVERGLUEING AND CONFORMAL COATING CONCLUSIONS

- The reliability trials of assemblies incorporating over-glueing and conformal coatings, indicated that whilst there were some benefits to resistor reliability performance during damp heat testing, there were no advantages for SOICs. Although the benefits in damp heat reliability performance alone may not justify the additional material and application costs, over-glueing does have a benefit in significantly improving mechanical shock resistance.

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