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**Measuring the Effect on
Isotropic Electrically
Conductive Adhesive
Reliability of Substrate and
Component Finishes**

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Measuring the Effect on Isotropic Electrically Conductive Adhesive Reliability of Substrate and Component Finishes

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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 a suitable test regime was identified to generate relevant reliability data. In this work, those tests have been employed to investigate whether the finishes on the components and/or PCBs have any effect on the reliability of the ICA joints after exposure to damp heat conditions.

The effect of different finishes has been found to be very adhesive material dependent. Two adhesives were studied, one of which produced joints the reliabilities of which were relatively unaffected by changes in component or PCB surface finish. However, with the second material and components having the PdNi metal finish, the joints displayed a more stable resistance than those made using components having a high tin content plated finish. Performances could be further improved by cleaning the components prior to assembly, although this may not be feasible on a production environment.

The surface finish on the PCB was found to have a smaller effect than did the component finish. Again the results were dependent on the adhesive material, with the joints using the better performing material exhibiting little difference irrespective of the PCB surface finish. In the case of the second material, PCBs having the ENIG (electroless nickel/immersion gold) finish did produce joints which performed as well as those having the immersion tin or silver finishes. Cleaning ENIG subsequent joints for some component finish combinations.

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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 will force 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 they replace. This is expected to cause a number of issues 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 (low temperature) alternative to solder for the assembly of these types of components.

The restrictions on the use of lead in solders have also caused concerns 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. If sufficient field reliability were to be demonstrated, then these materials could find a more widespread market. But to achieve this, the industry needs to understand better the field failure mechanisms of these materials and to develop corresponding test methods to assess both field reliability and process quality.

In consequence, in phase 1 of this project (Reference 1) potential test regimes for determining the reliability of joints made using isotropic conducting adhesives (ICA) were reviewed, and a representative accelerated ageing condition identified. The study involved examining joints on test boards produced from a matrix experiment using two ICA materials, a range of components, eight ageing regimes, and four assessment techniques (electrical conductivity, shear testing, drop testing and SIR). The results indicated that:

- The performances of the two ICA materials were broadly similar – the resistances of the bulk materials were stable over all the testing regimes
- When used as component interconnect, the materials performed well, particularly when subjected to thermal cycling, exceeding the expectations of typical end-users
- The parameters of an appropriate stress screening regime were: unbiased joints, 85 °C, 85%RH for 1000 hours
- Other potential screening regimes studied all exhibited significant drawbacks.

- For future work on ICAs, the 85 °C/85%RH damp heat test should be used: it provides a means to differentiate between assembly parameters, particularly for leaded SM components.

The 85 °C/85%RH condition also addresses probably the weakest aspect of ICAs, that is loss of conduction between conducting particles by a chemical reaction forming a non-conducting layer. This damp heat environment is useful in driving this degradation process.

The work reported here is for the second phase of this project, studying the effect of PCB and component finishes on the reliability of ICA joints.

2 METHODOLOGY

2.1 TEST VEHICLE DESIGN AND DETAILS

A test vehicle, incorporating SOIC gull-wing lead formats was designed and manufactured. This format was chosen because it was available in a range of termination finishes, and the following were included in the study; tin (Sn), tin/bismuth (SnBi), and palladium-nickel (PdNi). Each component finish type was from a single source.

A populated assembly is shown in Figure 1. The assembly utilises daisy-chain components to enable electrical continuity to be measured through assembled components using the edge connector on the left. The PCB was manufactured from double-sided FR4 laminate 1.6 mm thick. The PCB surface finishes used were immersion gold on electroless nickel (ENIG), immersion silver, and immersion tin.

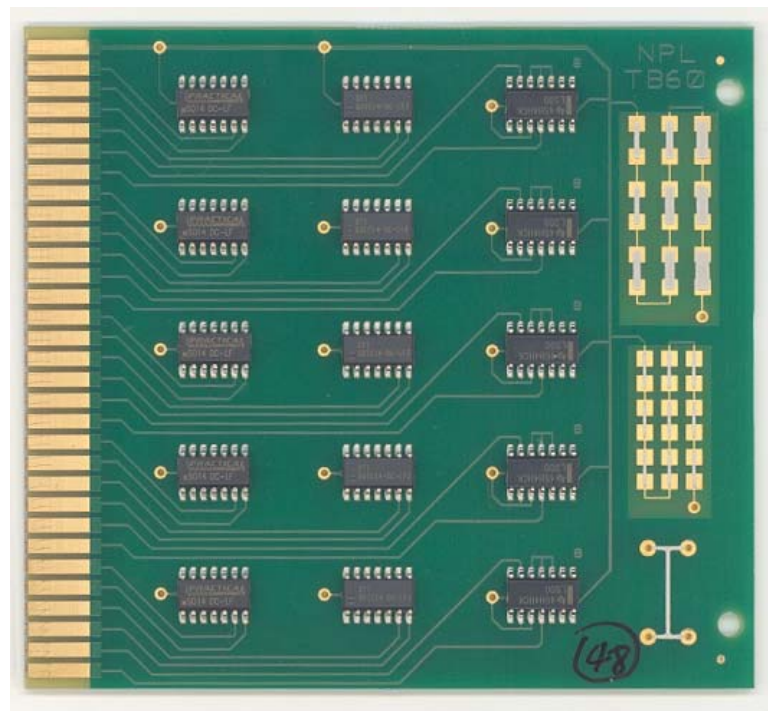


Figure 1 : Example of populated test assembly

Some components were assembled in the as-received condition. However, further sets of components and PCBs were assembled after being immersed for 15 minutes in an agitated 75% isopropyl alcohol/25% de-ionised water mixture at 40 °C to remove any surface contaminants.

The PCB design incorporated a series of interconnect patterns designed to be used to monitor the performance of the ICA alone. These interconnect patterns are shown in Figure 2 and Figure 3 with the printed ICA in position. The details for the pads for the interconnect pattern, are detailed in Table 1 and Figure 4.

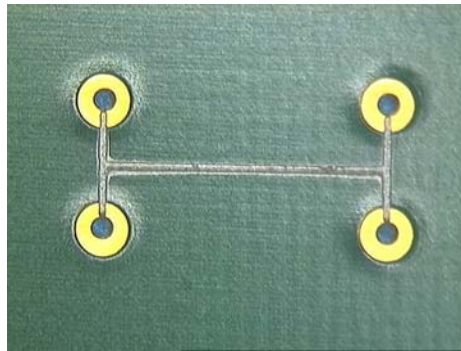


Figure 2: I-link interconnect pattern

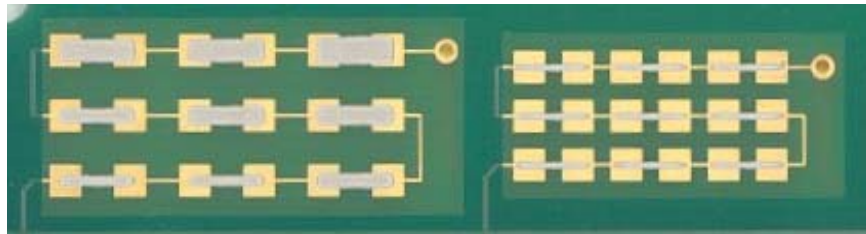
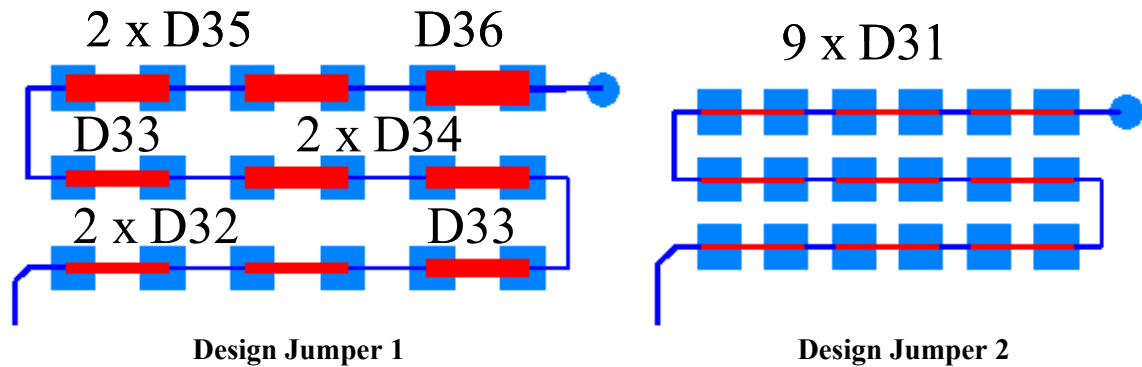


Figure 3: Jumper interconnect pattern

Table 1: Jumper sizes

D code	width [μm]	width [in]	Gap [μm]	Estimated height [μm]	estimated area [μm ²]	measured width [μm]	measured area [μm ²]
31	254	0.0100	1000	100	25400	427	32118
32	508	0.0200	2000	120	60960	715	71535
33	826	0.0325	2000	120	99060	1010	98566
34	1143	0.0450	2000	115	131445	1205	122615
35	1461	0.0575	2000	105	153352.5	1580	143190
36	1778	0.0700	2000	100	177800	1800	166591

**Figure 4: Jumper sizes**

2.2 ISOTROPIC CONDUCTIVE ADHESIVE DETAILS

Experimental work was undertaken on two representative commercially available isotropic conductive adhesives. These adhesives were both single component, silver-loaded epoxy adhesives 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 values for the two materials are given in Table 2.

Table 2 : Comparison of manufacturers' quoted materials data

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

2.3 TEST VEHICLE ASSEMBLY

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

2.4 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 identified in phase 1 of this project to be the most effective at increasing joint resistances.

2.5 ELECTRICAL CONTINUITY MONITORING

Three assemblies of each material were subjected to stress screening as detailed above for the full 2000 hours. 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 ELECTRICAL CONTINUITY MEASUREMENTS – AS-RECEIVED COMPONENTS AND PCBS

For all measurements, an electrical resistance for a daisy-chain circuit of over 200 ohms was considered a failure. The initial resistances the tin- and SnBi-finished components was ~4.5 ohms, as these were internally short-circuited, and included contributions from cabling and connections. However, the PdNi finished components were only available as NAND gates with a typical internal resistance of 100 ohms. It was noted that generally from one reading to the next, a time of 250 hours at 85 °C/85%RH, the resistance increased from its initial value to above 200 ohms.

3.1.1 ENIG Substrates Results

The cumulative electrical failures for both materials A and B with as-received components and as-received ENIG substrates, are presented in Figures 5 and 6. With both materials, tin- terminated components exhibited the lower reliability (i.e. greater number of failures) than the SnBi- or PdNi-terminated components. With material A, PdNi-terminated components performed better than either of the other component finish alternatives. Generally, there were fewer failures associated with material B than with material A, and there was little difference between the number of failures for each component finish using material B.

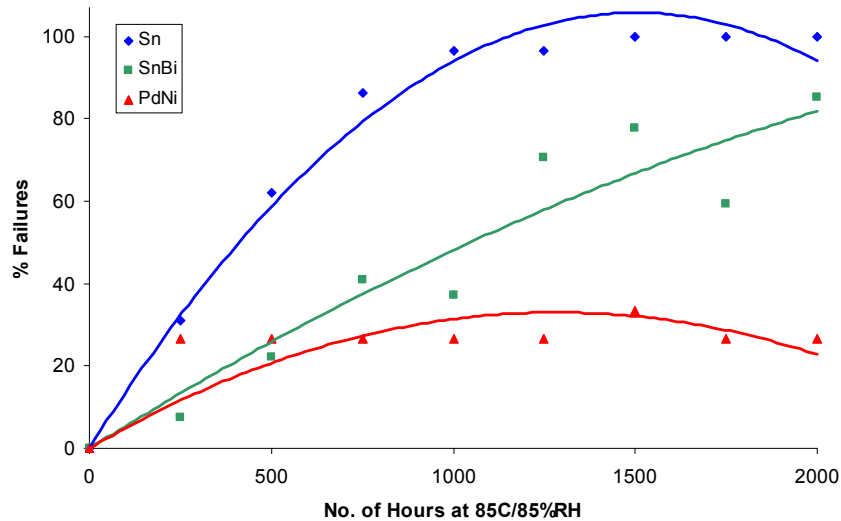


Figure 5: Cumulative electrical failures – Material A, as-received ENIG substrate, as-received components

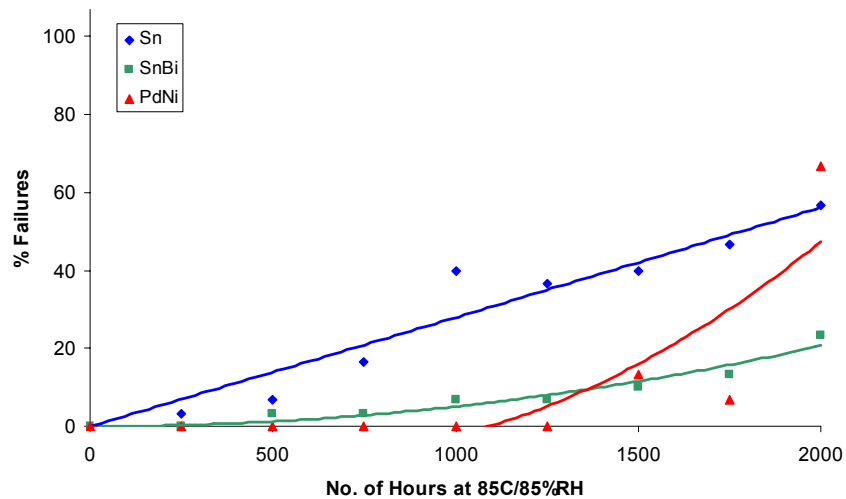


Figure 6: Cumulative electrical failures – Material B, as-received ENIG substrate, as-received components

3.1.2 Immersion Tin Substrate Results

The cumulative electrical failures for both materials A and B with as-received components and as-received immersion tin substrates, are presented in Figures 7 and 8. For both materials, the performances of all three component finishes were similar to those for the ENIG substrates with tin-finished components exhibiting the worse performance of the three finishes. Material B produced fewer failures than material A, with less differentiation between the component finishes.

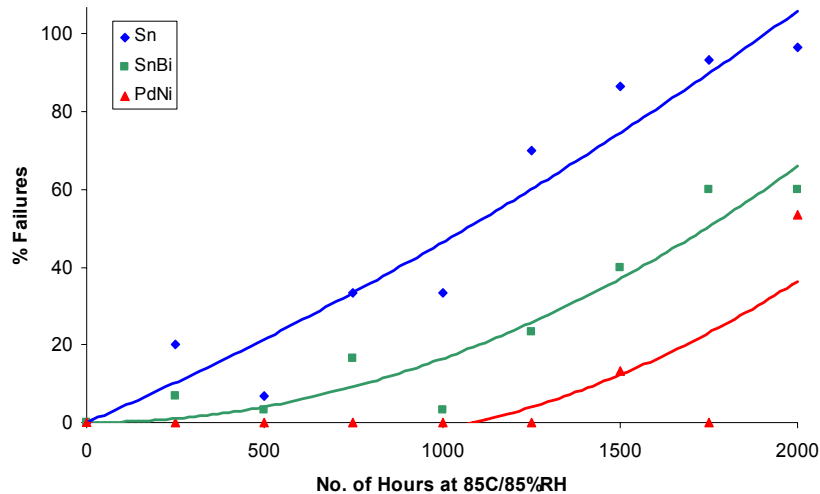


Figure 7: Cumulative electrical failures – Material A, as-received tin substrate, as-received components

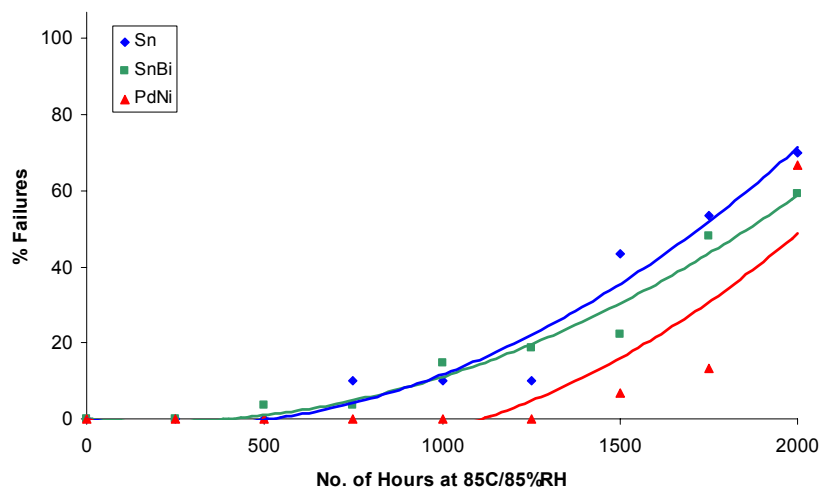


Figure 8: Cumulative electrical failures – Material B, as received tin substrate, as-received components

3.1.3 Immersion Silver Substrate Results

The cumulative electrical failures for both materials A and B with as-received components and as-received immersion silver substrates, are presented in Figures 9 and 10. As above, for both materials the performances of all three component finishes were similar to those for the ENIG and tin substrates, with tin-terminated components exhibiting the worst performance of the three finishes. Again material B produced fewer failures than material A.

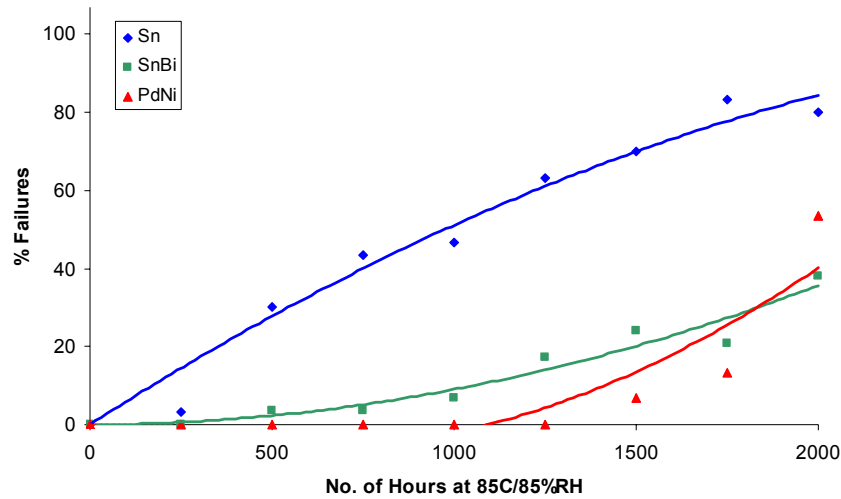


Figure 9: Cumulative electrical failures – Material A, as received silver substrate, as-received components

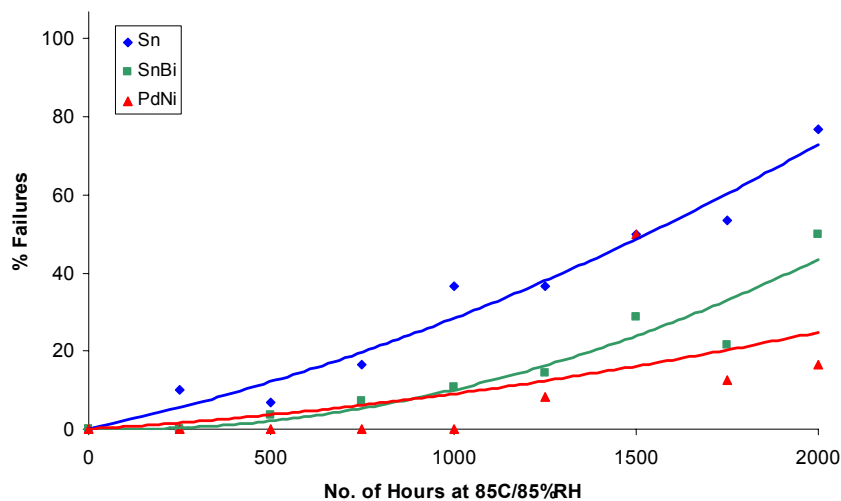


Figure 10: Cumulative electrical failures – Material B, as-received silver substrate, as-received components

3.2 ELECTRICAL CONTINUITY MEASUREMENTS – AS-RECEIVED AND CLEANED COMPONENTS AND PCBS

3.2.1 ENIG Substrates with Tin-terminated Components

The cumulative electrical failures for both materials A and B with as-received and cleaned combinations of ENIG substrates and tin-terminated components, are presented in Figures 11 and 12. The results for both materials indicate that in general cleaning either the component or the substrate has little effect on reliability (i.e. number of failures). However, cleaning the substrate prior to assembly using material A may have some small benefit. Again material B produced fewer failures than material A.

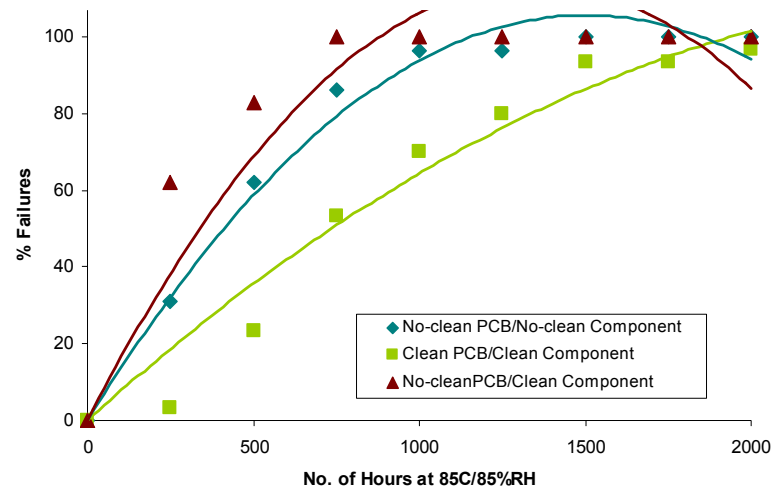


Figure 6: Cumulative electrical failures – Material A, as-received and cleaned ENIG substrates, as-received and cleaned tin-terminated components

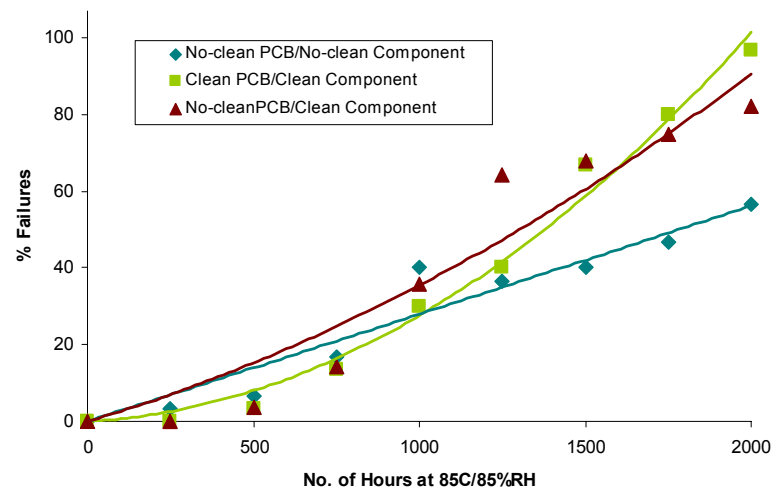


Figure 7: Cumulative electrical failures – Material B, as-received and cleaned ENIG substrates, as-received and cleaned tin-terminated components

3.2.2 ENIG Substrates with PdNi-Terminated Components

The cumulative electrical failures for both materials A and B with as-received and cleaned combinations of ENIG substrates and PdNi-terminated components, are presented in Figures 13 and 14. The results show that for both materials, cleaning the ENIG substrate prior to assembly leads to a marked improvement in the reliability, whilst cleaning the component does not produce such an improvement.. It is also clear that a cleaned system with no tin from substrate or component produces no, or very few, failures for either ICA material.

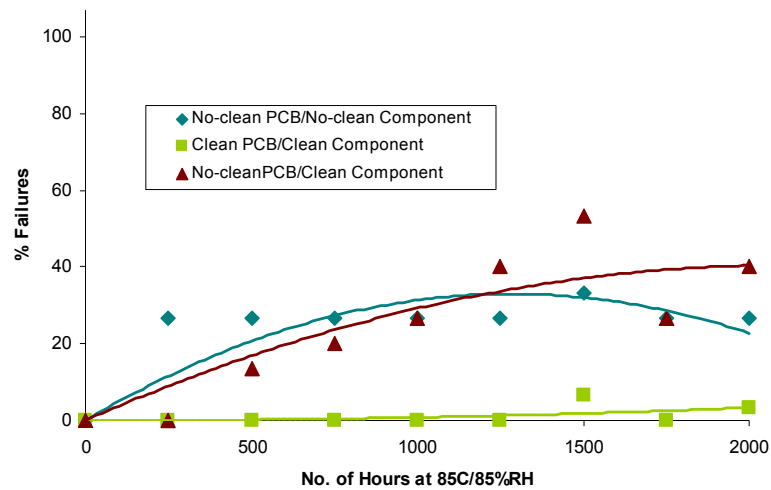


Figure 8: Cumulative electrical failures – Material A, as received and cleaned ENIG substrates, as-received and cleaned PdNi-terminated components

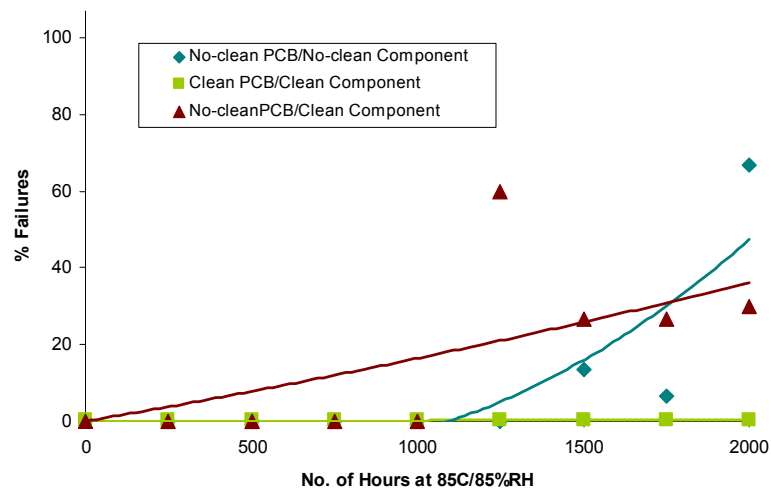


Figure 9: Cumulative electrical failures – Material B, as-received and cleaned ENIG substrates, as-received and cleaned PdNi-terminated components

3.2.3 ENIG Substrates with SnBi-Terminated Components

The cumulative electrical failures for both materials A and B with as-received and cleaned combinations of ENIG substrates and SnBi-terminated components, are presented in Figures 15 and 16. The results show that cleaning the ENIG substrate had little effect on reliability, whilst surprisingly, cleaning the component did appear to reduce the reliability (i.e. increase the number of failures).

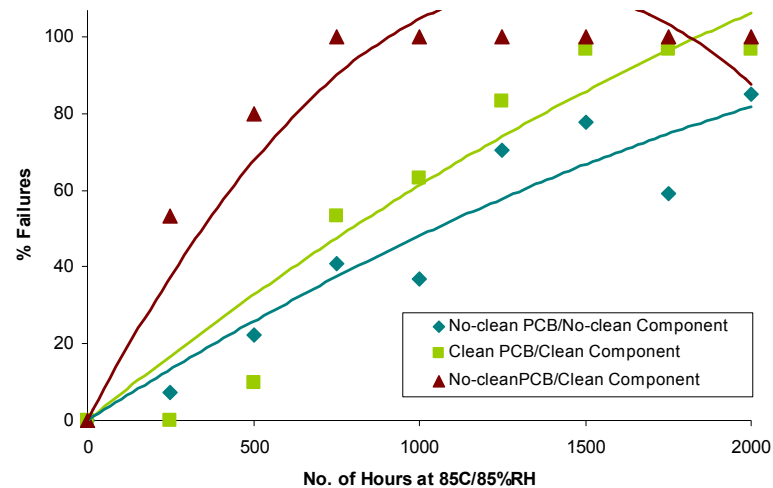


Figure 10: Cumulative electrical failures – Material A, as-received and cleaned ENIG substrates, as-received and cleaned SnBi-terminated components

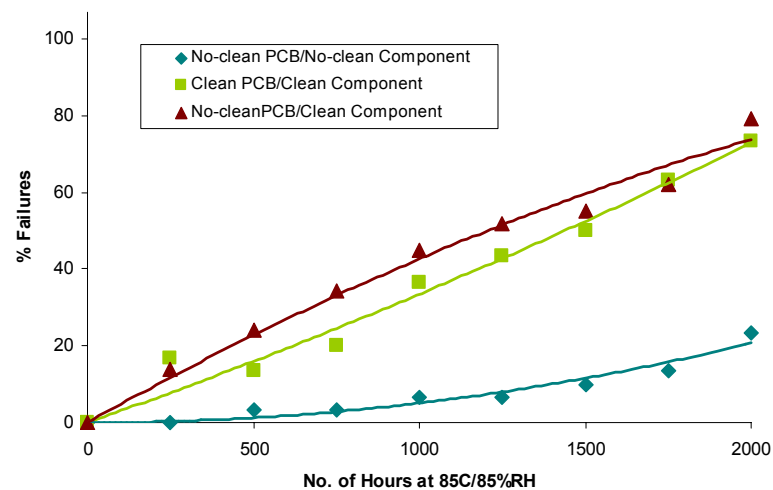


Figure 11: Cumulative electrical failures – Material B, as-received and cleaned ENIG substrates, as-received and cleaned SnBi-terminated components

3.2.4 Immersion Tin Substrates with Sn, SnBi and PdNi-terminated Components

The cumulative electrical failures for both materials A and B with as-received and cleaned combinations of tin substrates and tin-, PdNi- and SnBi-terminated components are presented respectively in Figures 17-19. The results highlight that not cleaning the substrate or the components did not significantly alter the reliability performance. With both materials A and B, cleaning PdNi-terminated components and immersion tin-finished PCBs produced failure-free assemblies after 2000 hours of damp heat testing. Cleaning SnBi-terminated components reduced their reliability.

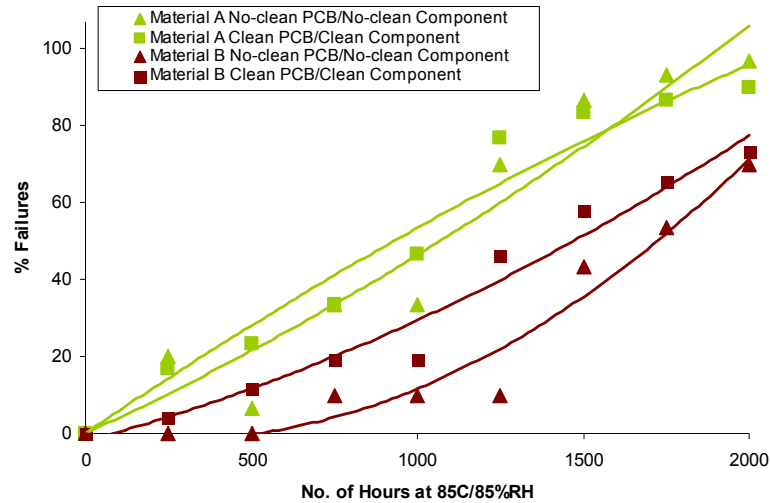


Figure 12: Cumulative electrical failures – Materials A and B, as-received and cleaned tin substrates, as-received and cleaned tin-terminated Components

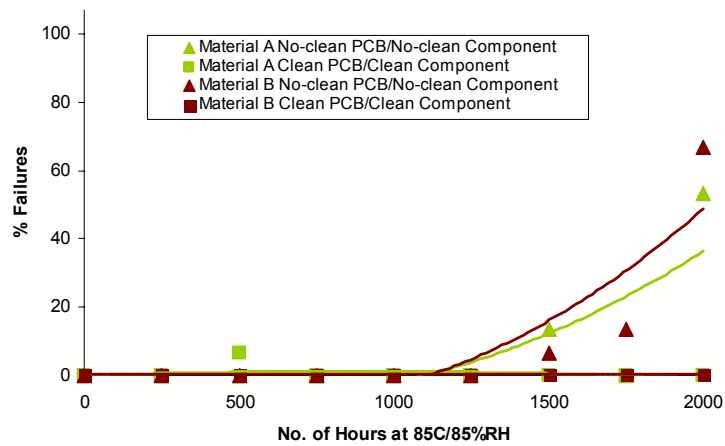


Figure 13: Cumulative electrical failures – Materials A and B, as-received and cleaned tin substrates, as-received and cleaned PdNi-terminated components

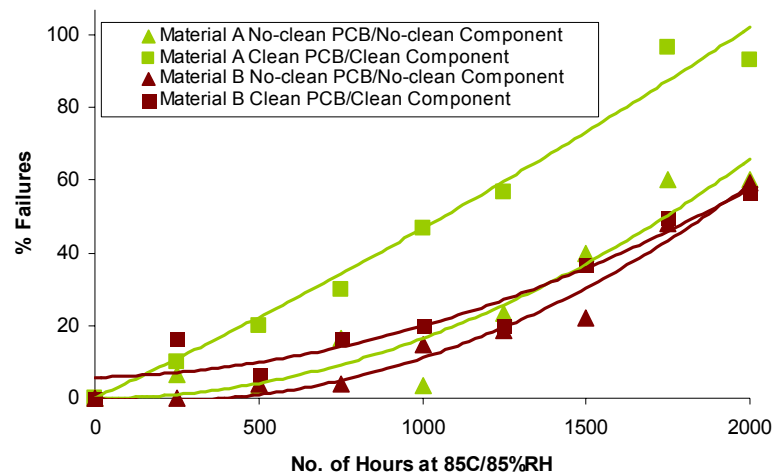


Figure 14: Cumulative electrical failures – Materials A and B, as-received and cleaned tin substrates, as-received and cleaned SnBi-terminated components

3.2.5 Immersion Silver Substrates with Sn, SnBi and PdNi-terminated Components

The cumulative electrical failures for both materials A and B with as-received and cleaned combinations of silver substrates and Sn-, PdNi- and SnBi-terminated components are presented respectively in Figures 20-22. With the exception of the results for SnBi-terminated components, cleaning either the substrate or the components did not appear to significantly alter reliability performance. However, with SnBi-terminated components, cleaning the components reduced reliability performance. Again, with cleaned PdNi-terminated components and Material B, no failures were observed.

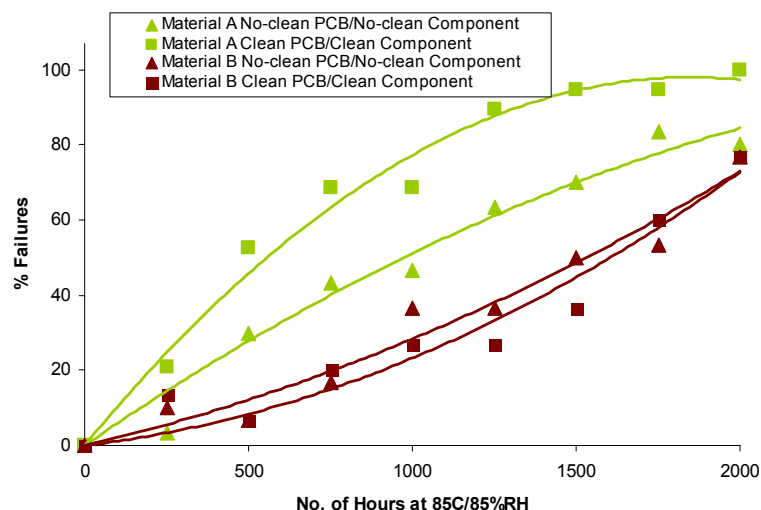


Figure 15: Cumulative electrical failures – Materials A and B, as-received and cleaned silver substrates, as-received and cleaned tin-terminated Components

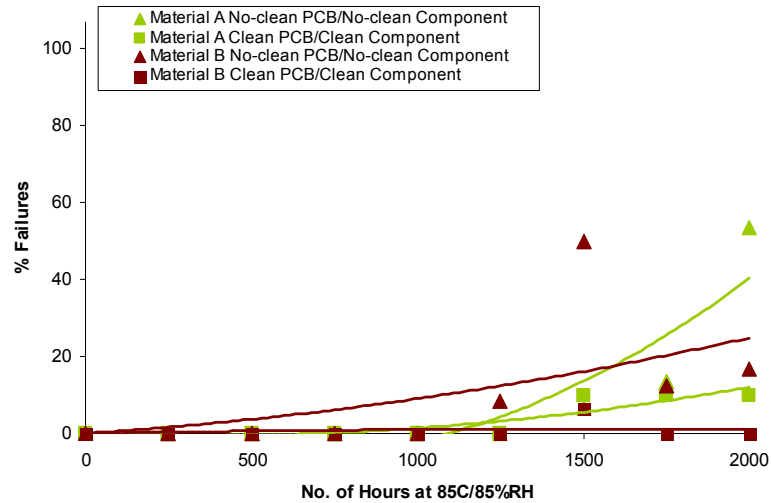


Figure 16: Cumulative electrical failures – Materials A and B, as-received and cleaned silver substrates, as-received and cleaned PdNi-terminated components

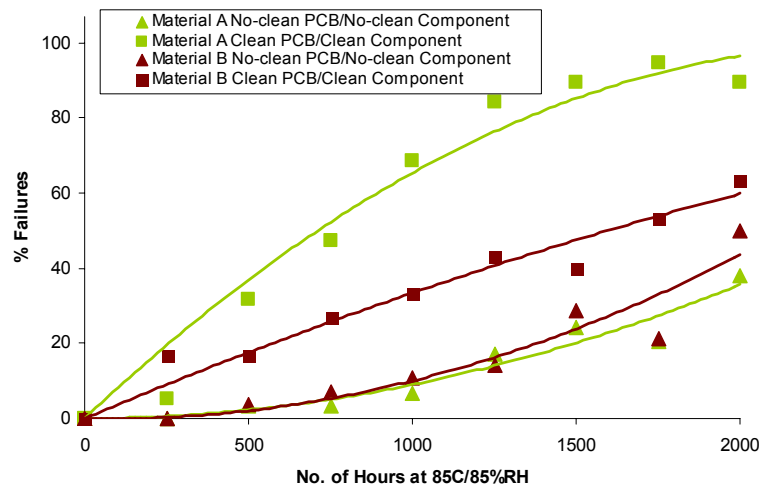


Figure 17: Cumulative electrical failures – Materials A and B, as-received and cleaned silver substrates, as-received and cleaned SnBi-terminated components

3.3 ELECTRICAL CONTINUITY MEASUREMENTS, CONTINUITY LINKS – AS-RECEIVED AND CLEANED PCBS

3.3.1 I-link Results

Because the I-links were only intended as a check of material performance independent of component finish, only limited data were available from testing these patterns. Of all links tested, few showed significant resistance increases before 1000 hours after damp heat testing.

Resistances did increase after 1000 hours but there was little difference between the performances of the various PCBs. However, the only combinations to record no resistance increases above 10 ohms were cleaned silver PCBs with both materials

3.3.2 Material A Jumper Results

Figure 18 and Figure 19 show the average resistance measurements for the continuity links of printed jumpers for material A. In the results for all the jumpers, where multiple data sets had approximately zero ohms, sequential sets of results have been offset from zero ohms for clarity of presentation. For jumper design 1, where the jumpers were of different width, no clear indication was obtained of any benefits of cleaning the substrate. However, with the second jumper design, cleaning the substrate did produce a small reduction in resistance increases.

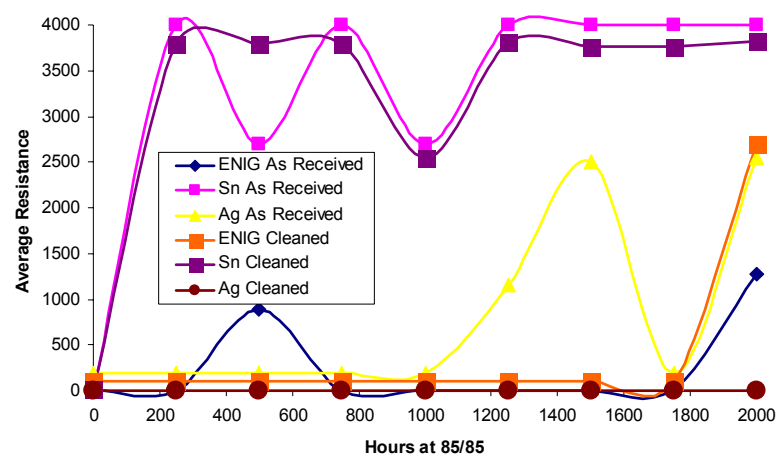


Figure 18: Average resistance measurements for continuity links of jumper 1 design of material A on ENIG, tin and silver substrates, both as-received and cleaned.

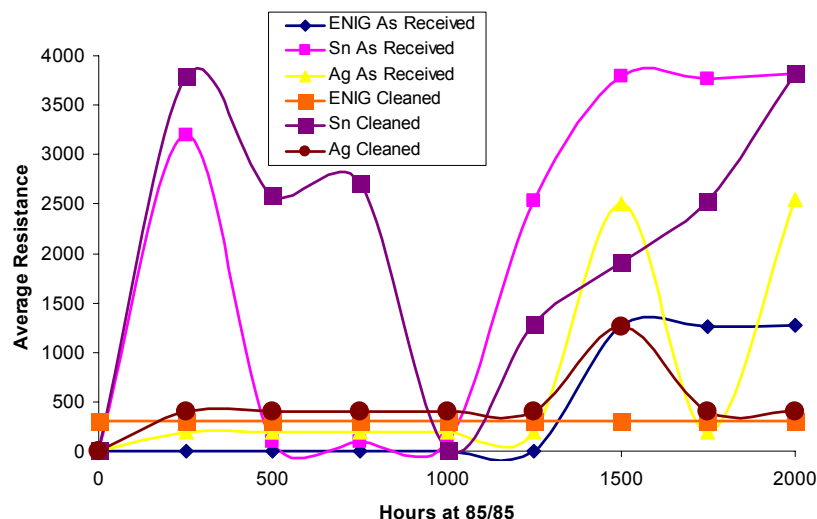


Figure 19: Average resistance measurements for continuity links of jumper 2 design of material A on ENIG, tin and silver substrates, both as-received and cleaned.

3.3.3 Material B Jumper Results

Figure 20 and 26 show the average resistance measurements for the continuity links of printed jumpers for material B. For both jumper designs, there are no clear indications of any benefits from cleaning the substrates.

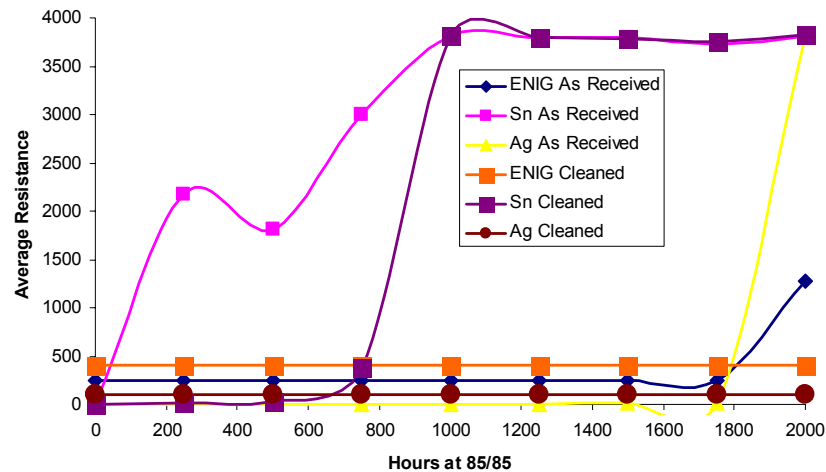


Figure 20: Average resistance measurements for continuity links of jumper 1 design of material B on ENIG, tin and silver substrates, both as-received and cleaned.

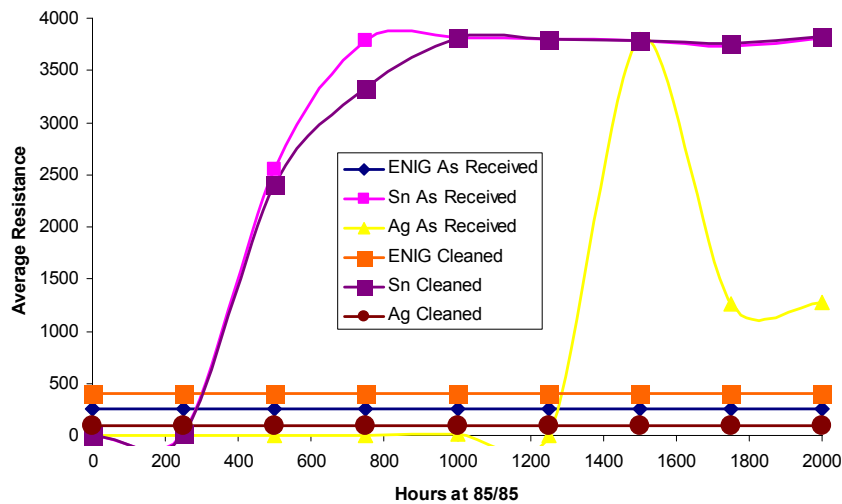


Figure 21: Average resistance measurements for continuity links of jumper 2 design of material B on ENIG, tin and silver substrates, both as-received and cleaned.

4 DISCUSSION

4.1 COMPONENT FINISHES

The work reported here was designed to determine if the surface finishes of components or PCBs had any effect on the reliability of isotropic conductive adhesive joints. Clearly from these results, any effect is dependent on the conductive adhesive utilised, with material B performing better and being more tolerant of different finishes than material A.

When assembled in the as-received, uncleaned, condition, the joints made to tin-terminated components with material A were generally quicker to degrade than were joints made with other component finishes. This was particularly evident in Figure 5, Figure 7 and Figure 9. There was significantly less effect with material B.

The differences observed when using PdNi- and SnBi-terminated components were less contrasting. But joints formed using PdNi-terminated components performed better than their SnBi-terminated counterparts on uncleaned substrates. Again this was particularly evident with material A. Certain combinations with PdNi-finished components produced zero failures, even after 2000 hours exposure at 85°C/85%RH.

4.2 PCB FINISHES

With PCB surface finishes there was again a materials compatibility issue. For material B, there was little difference between the results from joints on components with any of the three surface finishes. But with material A differences were noted as demonstrated in Figure 22-29. It is evident that joints made using the ENIG PCB finish did not perform as well as those using the immersion tin or silver finishes, whatever the finish on the components. There was little difference in the results of joints made using the immersion tin or silver-finished PCBs, whatever the finish on the components.

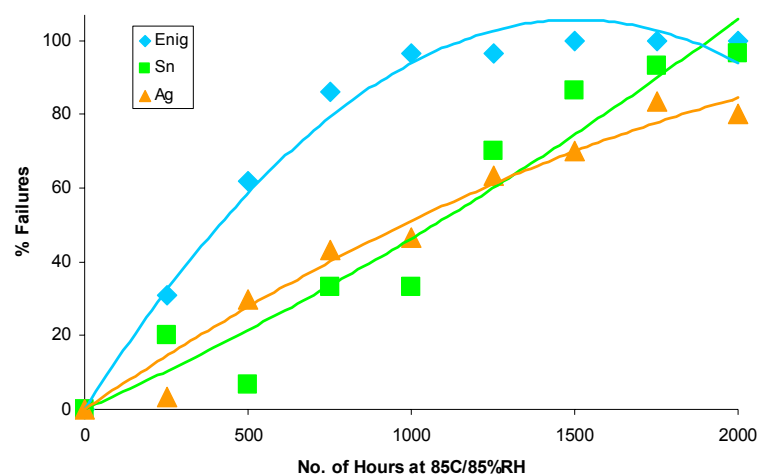


Figure 22: Relative performance of as-received PCB surface finishes with material A and tin-terminated as-received components

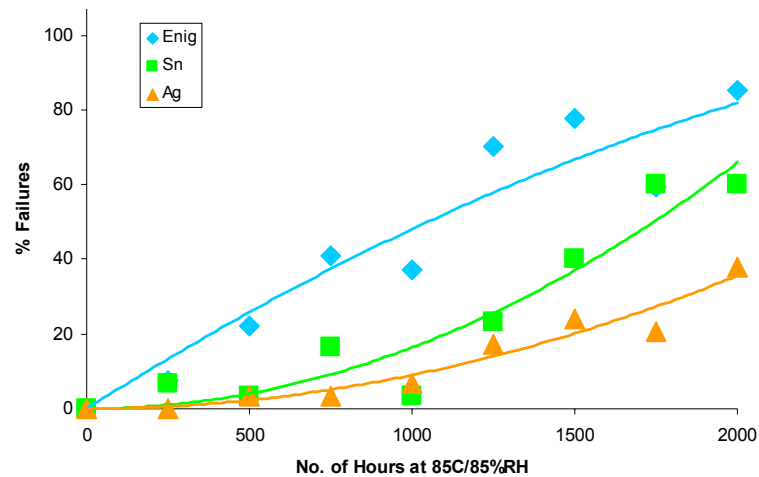


Figure 23: Relative performance of as-received PCB surface finishes with material A and SnBi-terminated as-received components

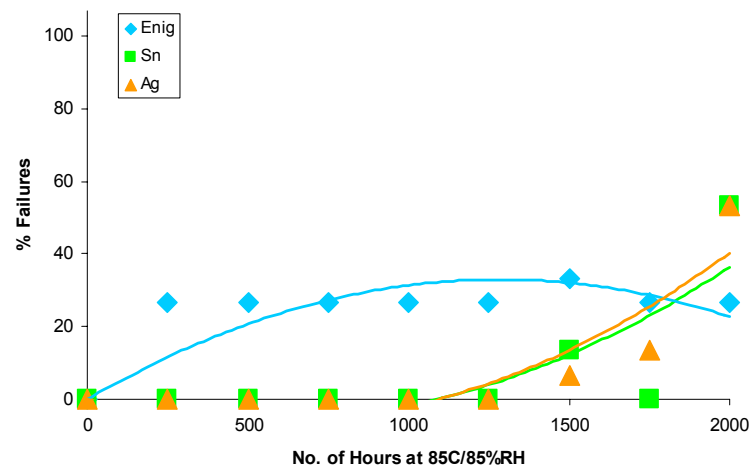


Figure 24: Relative performance of as-received PCB surface finishes with material A and PdNi-terminated as-received components

4.3 CLEANING COMPONENTS AND PCBS

When components or PCBs were cleaned prior to assembly, the situation was more complicated.

The results indicate that cleaning ENIG substrates can improve joint performance, this being particularly true for the results from the continuity links with material A (see Figure 18 and Figure 19). There was little apparent benefit in cleaning either of the other two PCB surface finishes.

Cleaning components prior to assembly had a very mixed effect on joint reliability. Cleaning PdNi-terminated components did generally improve reliability, with

combinations such as cleaned PdNi-terminated components and cleaned PCBs (ENIG, Ag and Sn), experiencing no failures after 2000 hours at 85°C/85%RH.

The cleaning of tin- and SnBi-terminated components did nothing to improve the reliability and many combinations involving cleaned components of these types produce joints with a much reduced performance. This may be due to the cleaning method used. The warm mixture of IPA and de-ionised water may have caused a non-electrically conducting oxide to form on the Sn- or SnBi-plated finishes. This might have led to increased resistances during ageing or reduced adhesion of the conductive adhesive during assembly, which may also have had the effect of degrading performance.

However, as indicated above, a number of combinations, particularly involving PdNi-terminated components survived 2000 hours of testing at 85°C/85%RH without any significant increase in joint resistance.

4.4 SUMMARY OF TERMINATION FINISH

Surface finish has been shown to be an important factor in determining the conductivity of ICA joints during exposure to the 85°C/85% RH environment. Systems containing tin are more prone to lose conductivity, and conversely noble metal systems are more immune to degradation. This is a major concern as the industry is showing many signs that the component termination of choice will be pure tin. However, choice of ICA material is critical, with the two materials in this study producing very different results. ICA materials are continually being developed, and the inclusion of oxidation inhibitors will play a significant role in tackling the tin compatibility issue. It is interesting to note that the addition of Bi has a beneficial effect, and it is possible that other additions may also have some beneficial effect.

Environmental factors are going to be more relevant to aging of termination finishes for ICAs than for solders. That cleaning can have an effect on conductivity, improving it or degrading it, is noteworthy. Cleaning can of course remove adventitious contamination and hence improve the bond quality, as seen with some of the ENIG results here. But also in some cases the conductivity subsequently deteriorated in the ageing test, and hence the cleaning may also drive the oxidation process further and actually interfere with the attainment of a good ICA joint.

5 CONCLUSIONS

The salient conclusions from this work are:

- Some benefit can be gained by the assembler in using ICAs, if a choice of component finish is possible. Certainly, the noble metal component finish of PdNi produced joints which performed better than joints using components with other plated finishes. Cleaning of these components may also improve their performance but this may not be feasible in a production environment, as components will have to be unloaded from any tape or tubing, cleaned and reloaded to fit placement systems.
- Component plated finishes with high tin contents do not benefit from cleaning using an IPA/water mix. This may be due to the water in the mix causing an

oxide to form on the component finish, which would be detrimental to any subsequent damp heat performance.

- Cleaning substrates may be more feasible in a production scenario, where it may be possible to install in-line cleaners prior to adhesive printing, or to request a suitable cleaning regime to be undertaken by the PCB manufacturer with subsequent packaging to preserve the cleanliness. However, in this work the effect of cleaning the substrate has been shown to be negligible, and it is likely that the cost of cleaning, unless a part of a normal PCB manufacturing operation, may outweigh any benefits obtained.
- In these trials, the ENIG surface finished PCBs did not perform as well as those finished with immersion silver or immersion tin. As each finish was single sourced, this difference may be substrate batch-related.

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7 REFERENCES

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