

# REPORT

## Impact on Assembly Yields when Substituting Palladium Finished for Tin/Lead Finished Components

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by

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## **ABSTRACT**

There is concern within certain parts of the industry on using palladium finished components. Palladium finished components have lower solderability which potentially will have an adverse effect on process yield. This study compares process defect levels between similar SOIC14 components with palladium and tin/lead finishes, using several assembly processes. Some of these assembly processes achieved a zero defect level with tin/lead finished components, and also achieved a zero defect level with palladium finished components. However, the process operating window is much narrower and many manufacturers will not be able to make the transition quickly and simply to a zero defect process with palladium finished components. Indeed 33% of the manufacturers in this study did not achieve this transition. This work has identified some of the reasons for the narrower process window and highlights some of the pitfalls of introducing palladium finished components.

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Approved on behalf of Managing Director, NPL, by Dr C Lea,  
Head, Centre for Materials Measurement and Technology

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## 1 INTRODUCTION

There has been a debate in recent years on the level of success of substituting palladium finished components into processes that are using components with conventional tin/lead finish. The attraction for using a palladium finish for the component manufacturer is that a manufacturing step is avoided, with a consequent cost saving. With conventional assembly techniques the lead frame of the component is not plated until after assembly is completed. However, with palladium, the lead frame is plated prior to any component assembly process and hence the requirement to plate the termination with a solderable coating is removed. The product also becomes lead-free, which has environmental benefits.

There have been a number of end users who have reported difficulties in maintaining process yields when attempting to use palladium finished components. Processes can be optimised to accommodate the different soldering properties of palladium, but this is not an option with which process engineers are comfortable. For any specific process that is optimised for today's complex printed circuit assemblies (PCAs), the added requirement of re-optimisation of the reflow soldering profiles to accommodate poor solderability on new component finishes is not welcomed.

The observed difference in process properties of palladium finished components can be directly attributed to the metallurgy of the finish. Palladium is a non-fusible coating, that is to say it does not melt during soldering, as with a conventional tin/lead finish. The melting point of palladium is 1552°C. This has significant implications in terms of solderability. With the tin/lead finish, the solder on the termination melts and combines with the applied solder and facilitates fast wetting over the entire plated area of the termination. However, with the palladium finish, the applied solder must dissolve the palladium in a reaction that makes steady progress along the termination. A schematic cross-section through the surfaces of the two finishes is shown in Figure 1. Although the palladium finish in Figure 1 shows a simple nickel layer on the substrate, this can be more complicated with intermediate coatings of nickel and palladium depending on the manufacturer.

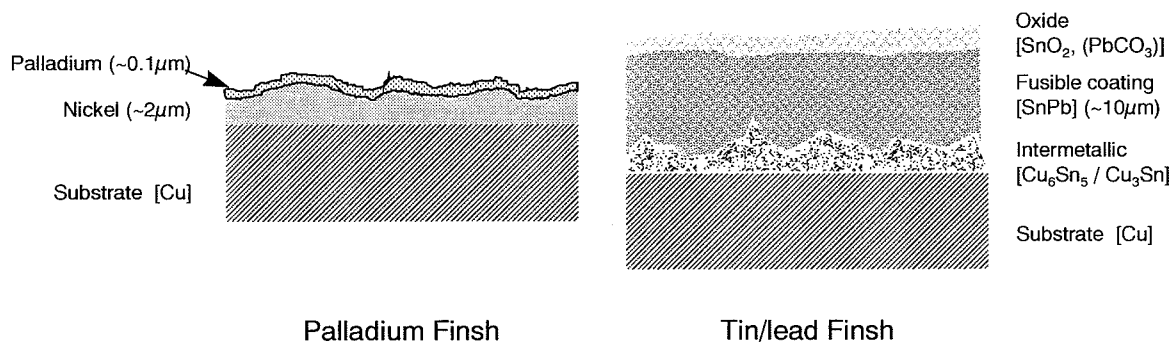


Figure 1 Schematic of the layer structure on component terminations

It is important to realise that with the tin/lead finish this fusible coating can melt ahead of the wetting front and so disrupt and assist the flux in the break up and dispersal of the oxide, to provide a perfectly wettable surface. This is key to the excellent solderability of tin/lead finishes. The solder in the joint therefore combines with the solder already present on the component to make a joint with the intermetallic and substrate. As mentioned above the wetting across the palladium surface is limited by the dissolution of palladium into the solder. The solder joint in this case is essentially between the solder and the underlying nickel layer,

since the palladium will have been dissolved in the solder. The palladium is a noble metal applied to protect the nickel, and must be displaced for a joint to be made. It is instructive to consider the relative dissolution rates of palladium, copper, silver, gold and tin in tin60-lead40, and these are shown in Figure 2.

It is clear from Figure 2 that the dissolution rate of palladium is over 4 orders of magnitude less than tin and that within the soldering time of a few seconds only  $0.3\mu\text{m}$  can be dissolved. Hence to make a good joint with the nickel layer under the palladium, the coating can only be a maximum thickness of  $0.3\mu\text{m}$ , if the applied solder is to dissolve the palladium and form the intermetallic joint with the nickel. On palladium finished components the palladium is typically  $0.1\mu\text{m}$  thick, which is adequate in terms of dissolution, but can be problematic in terms of porosity and protection of the underlying nickel from oxidation.

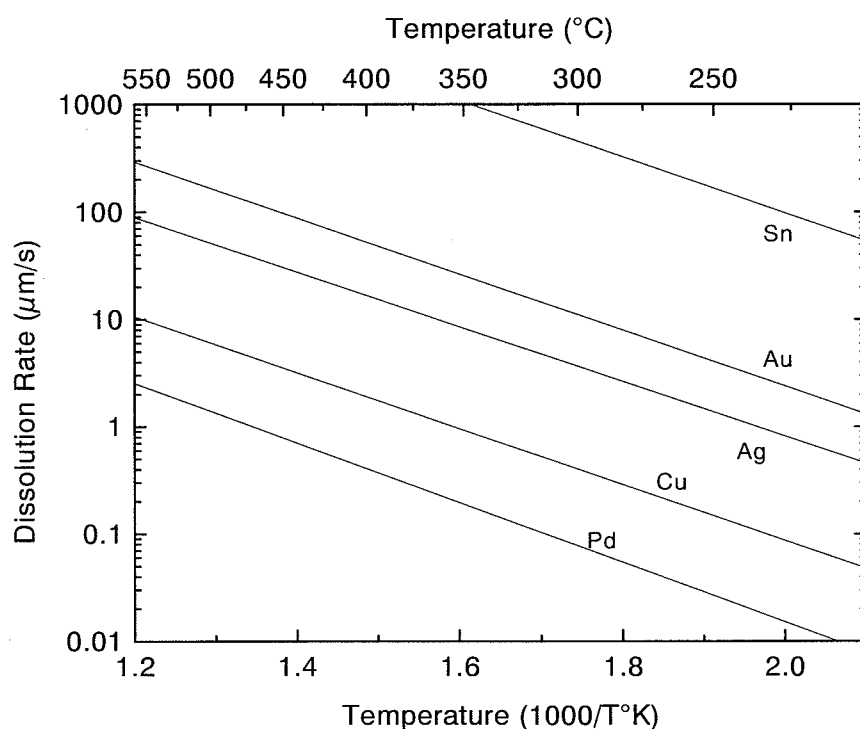


Figure 2: Dissolution rates of various metals in solder as a function of temperature<sup>(1)</sup>

In this work we set out to establish how well palladium finished components perform when inserted into existing processes that have been optimised for standard tin/lead finished components. For this project NPL collaborated with Matra BAe, Measurement Technology Limited, Motorola, Quantel, and Wandel & Goltermann. These companies all used their standard process. NPL purchased sufficient components from a single manufacturer's batches and PCBs from a single supplier so that all partners used identical components and boards. The component style chosen for the components was an SOIC14 package. It was the aim from the outset to split the as-received palladium components into three sets. One set would remain in the as-received condition and the other two sets would be aged to produce two lower degrees of solderability. Approximately 4000 components were required for each batch. Purchasing a single batch of 12000 components from a single batch or lot proved to be impossible, with distributors generally having difficulty in tracking manufacturers' lot numbers. It did however prove possible to purchase single lots of 4000

components. A similar sized batch of tin/lead finished components was also purchased and used as a bench mark. After ageing two sets of the palladium components, all four sets were sent to the project partners for assembly. Following this step all the boards were returned to NPL for visual inspection and assessment of the solder joints. NPL also carried out solderability and surface spectroscopy studies, and some joint strength studies.

## 2 EXPERIMENT

A simple single sided FR4 80 x 80 mm board with a hot air solder levelled finish and without resist was used. Each board took 25 SOIC14 components arranged in a 5 x 5 array. NPL obtained four sets of 4000 components. Two of the sets, each comprising 4000 palladium finished SOIC14s, were selected for ageing at 155°C in an air circulating oven. In summary there was:

- Set 1: Conventional tin/lead (SnPb) lead finish
- Set 2: Lot 1, palladium finish, as received
- Set 3: Lot 2, palladium finish with ageing treatment 1
- Set 4: Lot 3, palladium finish with ageing treatment 2

Each partner was sent 110 boards and 650 components from each of the four sets and was required to assembly 25 boards for each component set.

### 2.1 Solderability Measurements

The solderability of the components was carried out using a Multicore MUST II machine. The test conditions were in accordance with the IEC standard 68-2-69, and the instrument was used in the solder globule mode, using a 60/40 SnPb solder. A 25 mg pellet was used and the solder temperature was 235°C. The immersion speed was 1mm/s, the immersion depth 0.1mm. No pre-heat was used. The flux used was pure rosin with 0.5% halide, in accordance with IEC 68-2-20 and was purchased from Multicore Solders as Actiec 5. The force data were acquired over a 5 second period. The leads were dipped at an angle of 45°.

### 2.2 Surface Analysis

Surface analysis of the component terminations was carried out with a Varian CMA using a 3 keV electron beam at 45°, and rastered over a 70 x 100µm area. The surface was sputtered with 2 keV Ar<sup>+</sup> at an angle of 45°. A sputter yield of 3 was used to calculate sputter depth. In calculating compositions Auger peak intensities were corrected using sensitivity factors from ref 2. In plotting the depth profiles the peak intensities were normalised to 100%.

### 2.3 Strength Test

The strength tests were carried with a Farco F125, loading in a shear test at 3mm/min. The load was applied to the side of the lead, with the body removed.

### 2.4 Company Process Details

Brief details of the assembly processes of the six different manufacturers, including NPL, are given below:

Manufacturer A :

- Stencil printing of SN62 RMA paste using a 150 micron chemically etched stainless steel stencil.
- The components were autoplaced.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 215°C,
  - b) maximum molten solder time = 65 secs
- Semi-aqueous cleaning was used

Manufacturer B :

- Stencil printing of SN62 RMA paste using a 150 micron laser cut stainless steel stencil.
- The components were autoplaced.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 213°C,
  - b) maximum molten solder time = 54 secs
- No cleaning was applied.

Manufacturer C :

- Stencil printing of SN60 modified rosin paste using a 150 micron laser cut stainless steel stencil.
- The components were autoplaced.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 216°C,
  - b) maximum molten solder time = 75 secs
- No cleaning was applied.

Manufacturer D :

- Stencil printing of SN62 medium residue level resin based paste using a 200 micron electroformed stencil.
- The components were autoplaced.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 220°C,
  - b) maximum molten solder time = 46 secs
- No cleaning was applied.

Manufacturer E :

- Stencil printing of SN63 RMA paste using a 150 micron laser cut stainless steel stencil.
- The components were autoplaced.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 220°C,
  - b) maximum molten solder time = 48 secs
- No cleaning.

Manufacturer F :

- Stencil printing of SN63 aqueous based paste using a 150 micron laser cut stainless steel stencil.
- The components were manually placed.
- Reflow soldered in air atmosphere,
  - a) maximum temp = 232°C,
  - b) maximum molten solder time = 45 secs
- No cleaning was applied.

## 2.5 Visual Inspection

The visual inspection of the resulting solder joints was undertaken by a single operator using a binocular zoom microscope at 15X magnification. Illumination was provided by a fibre optic fed ring illuminator. The four corner joints of each device were inspected and scored individually based on the scoring system shown in Figure 3. In total some 60,000 solder joints were inspected and scored.

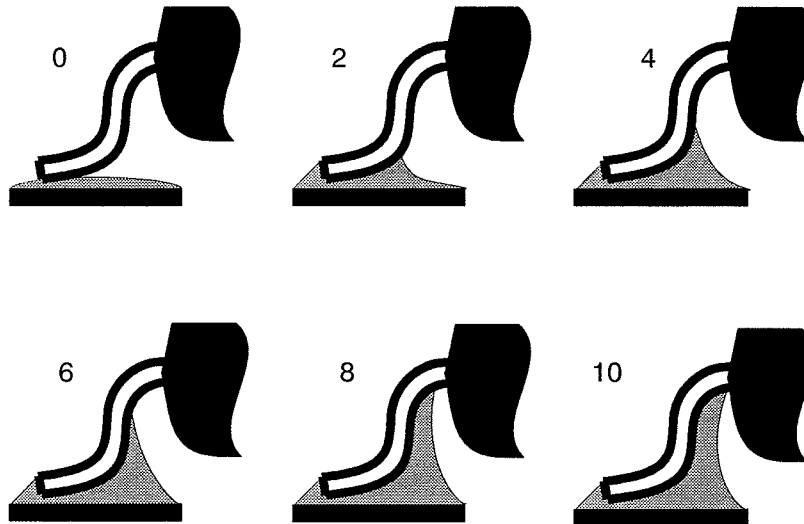


Figure 3: Schematic representation of solder joint scores used in the visual inspection.

## 3 RESULTS

### 3.1 Solderability

As part of the procurement exercise a number of palladium finished components were purchased from various distributors. As might be expected these components had a range of date codes. The impact of the date of manufacture on solderability was tested, and the data are plotted in Figure 4.

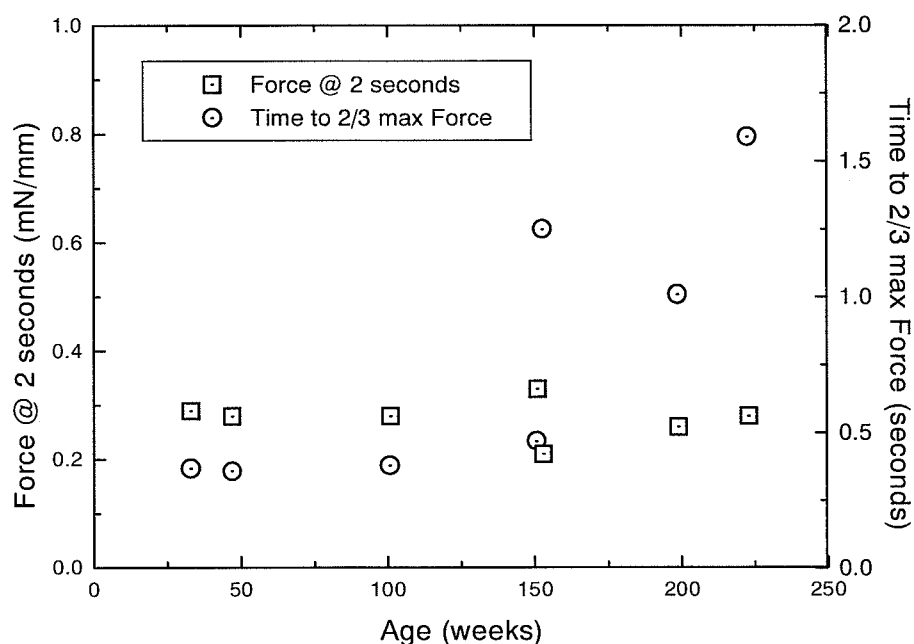


Figure 4: Solderability data, the force at 2 seconds and the time to 2/3 of the maximum wetting force, are plotted as a function of component date code.

It is clear from Figure 4 that the force at 2 seconds is not significantly influenced by storage time. However the time to 2/3 of the maximum force does increase after 3 years, increasing up to 2 seconds, which is the pass/fail limit in the ANSI-J-Std 002. Figure 4 also shows how it is possible to purchase rogue sets of components, and that for a given date code there can be a range of solderabilities. This indicates that either variations exist in leadframe manufacture or that storage conditions can significantly affect solderability. There are two sets with similar ages of 3 years. However, they have very different solderability characteristics, with one batch having a significantly longer wetting time of approximately 1.2 seconds. This illustrates the difficulties of relying on date code information.

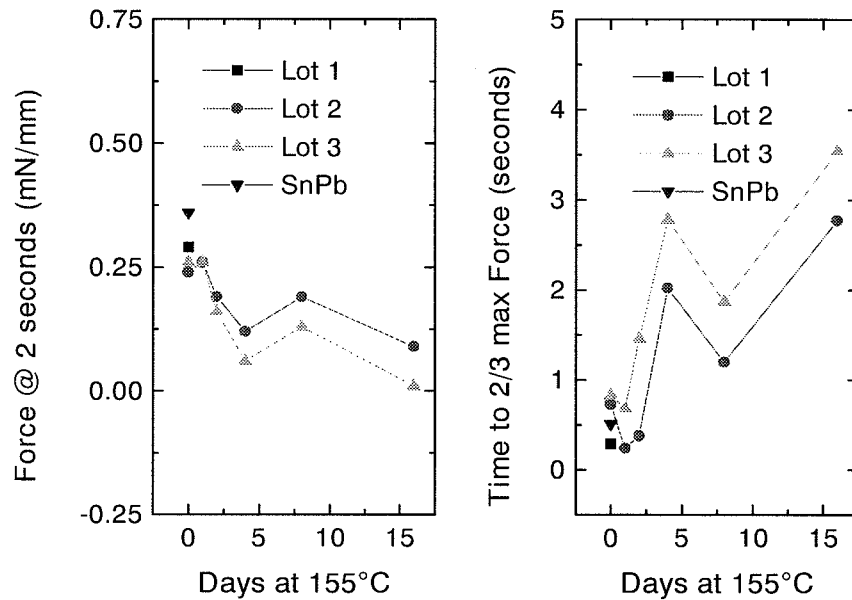


Figure 5: Solderability data from the four sets of components. Lots 2 and 3 are aged at 155°C for various times.

As described above 4 sets of components were procured. The as received solderability and the degradation in solderability with heat treatment at 155°C are shown in Figure 5. The two lots with poorer as-received solderability, Lots 2 and 3, were selected for exploratory accelerated ageing treatment in air at 155°C. From Figure 5 it is clear that Lot 3 has the poorer solderability. Hence, Lot 3 was selected for a long heat treatment of 16 days, and Lot 2 for 2 days, both at 155°C. This approach was intended to produce a range of solderability for the palladium finished lots. The following describes the final four sets:

- Set 1: Conventional tin/lead (SnPb) lead finish
- Set 2: Lot 1, palladium finish in the as-received condition
- Set 3: Lot 2, palladium finish with 2 days ageing at 155°C
- Set 4: Lot 3, palladium finish with 16 days ageing at 155°C

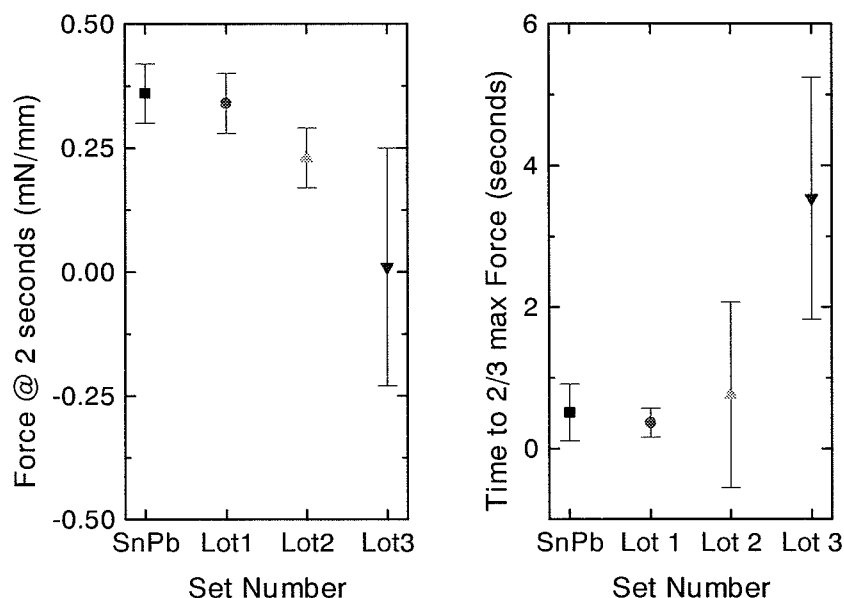


Figure 6: Solderability data from the four sets of components. Lots 2 and 3 are aged at 155°C for various times.

The success of this can be judged in the results of Figure 6, which are solderability data from the actual sets following the ageing treatments where applicable. For both the force at 2 seconds and the time to 2/3 of the maximum force there is little difference between the tin/lead and the as-received palladium finished components of Lot 1. Between the palladium finished sets of Lot 1 to Lot 3 there is a continuous trend in reducing solderability.

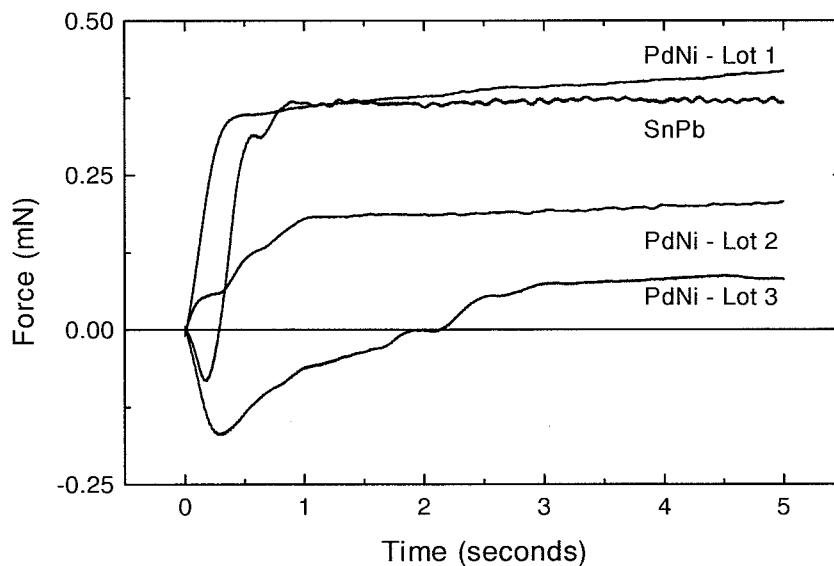


Figure 7: Examples of averaged wetting curves from the four sets of components. The data for Lots 2 and 3 are for the components in the aged condition.

Typical wetting curves for the four sets are shown in Figure 7. These curves graphically illustrate how inferior the solderability of Lots 2 and 3 is to the as-received condition. Perhaps of more interest, is the continuing improvement in wetting force of Lot 1, reflecting the slow progress of the wetting front up the component lead. This slow progress can be attributed to the low dissolution rate of palladium. It should be noted that the solderability data for the tin/lead finish will be influenced by the tin/lead coating above the wetting front draining off the lead into the solder fillet that forms during the wetting test. Hence, the wetting force will be diminished in comparison to the palladium finished leads.

The wetting reaction on the palladium finish is controlled by the dissolution reaction, which in turn is very temperature dependent. Here we explore the effect of conducting the wetting test at 220°C, 15°C below the previous tests. According to Figure 2 this difference results in a 32% reduction in the dissolution rate. For these tests we only used the central leads, since for the outer leads the thermal demand prevented repeatable wetting at this temperature. It must be realised that the temperature in the wetting test is not comparable to that in a reflow cycle. In the reflow cycle there is a significant pre-heat and then up to a minute above the liquidus. The wetting test by comparison lasts only 5 seconds, and there is no pre-heat. The results of these tests are shown in Figure 8.

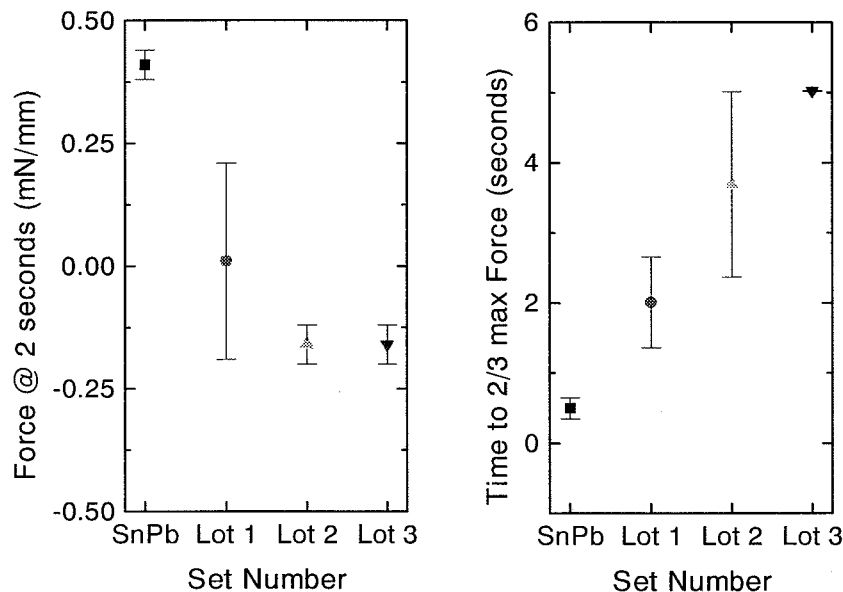


Figure 8: Solderability data from the four sets of components. Lots 2 and 3 are aged at 155°C for various times. The wetting balance test temperature was 220°C.

These results show that lowering the testing temperature does not significantly change the solderability of the tin/lead finished components. However, the solderability of the palladium finished components diminishes significantly. There is now a significant difference between the tin/lead and Lot 1, a difference which was not apparent when testing at 235°C. The force at 2 seconds for Lots 2 and 3 are both at the minimum, and there is now a trend of increasing wetting time through the different sets. The overall solderability of the palladium finished components appears to be worse.

***The wetting results reveal that the testing temperature is critical for palladium finishes, and that the intention of producing a range of solderability has been successfully achieved.***

### 3.2 Surface Analysis

The surface of the palladium components was investigated to establish whether there were compositional and morphology differences. Auger spectroscopy scans of the three palladium lots are shown in Figure 9.

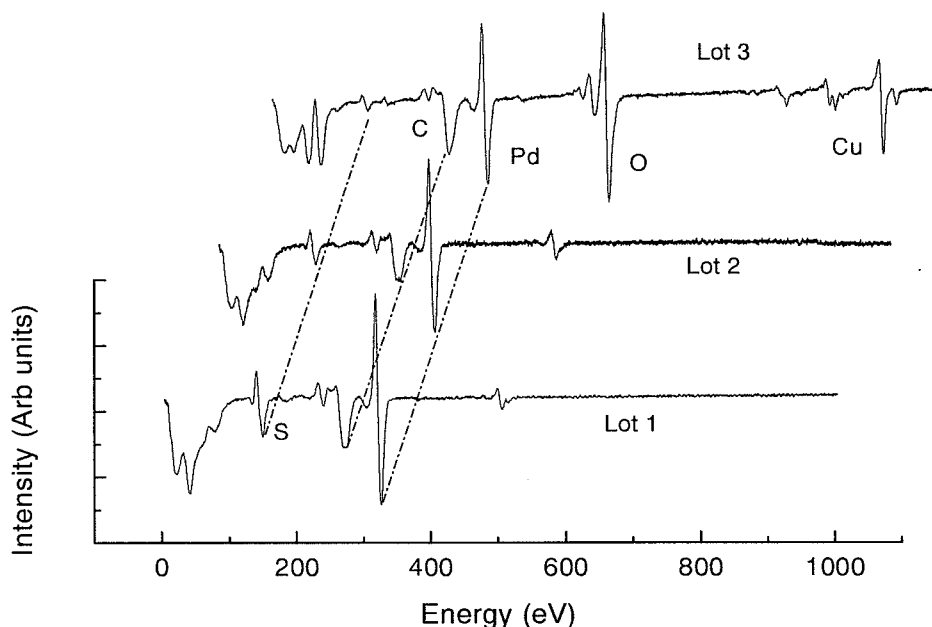


Figure 9: Auger wide scan spectra of the three palladium lots, without sputter profiling. Lots 2 and 3 are in the aged condition. The three spectra are plotted with the same scales, but Lots 2 and 3 are displaced to aid viewing

These spectra show that Lot 1 and 2 are very similar, having similar intensity peaks for palladium, carbon, sulphur and oxygen. Lot 3 is different in that it is more heavily oxidised and there is copper on the surface. These spectra are from the surface prior to any sputtering. It is clear that Lot 1 is only weakly oxidised, and that even after ageing at 155°C for 2 days for Lot 2 the surface has not changed significantly. The stronger oxygen peak in Lot 3 is therefore most likely associated with the copper. The near surface region can be conveniently analysed using argon ion sputtering, and Auger spectra were taken as the surface was sputtered to establish the composition as a function of depth. These results are shown in Figure 10 to 12.

The results for Lot 1 in Figure 10 show that oxygen and sulphur are only present on the surface, and are probably adventitious, and only weakly bound to the surface. Carbon extends below the surface to 8nm, and is probably associated with some residue from the plating.

Figure 11 shows the results for Lot 2 in both the as-received and aged condition. The results for Lot 2 in the as-received condition differ from Lot 1 in that there is significantly less carbon at the surface. Ageing Lot 2 components for 2 days has only a marginal effect on the surface, in doubling the carbon presence from 1 to 2nm.

Lot 3 results in Figure 12 show that the copper noted above in Figure 9 is only at the surface of the aged components. No copper was seen on the surface of the as-received components. There is a similar layer of 2nm of carbon which is not influenced by the 16 day ageing temperature.

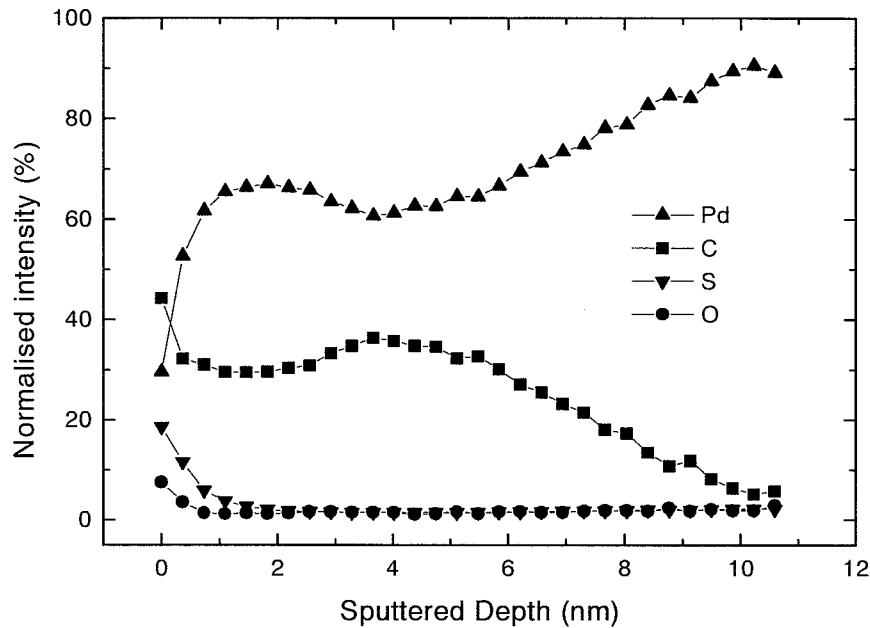


Figure 10 Auger sputter depth profile of Lot 1.

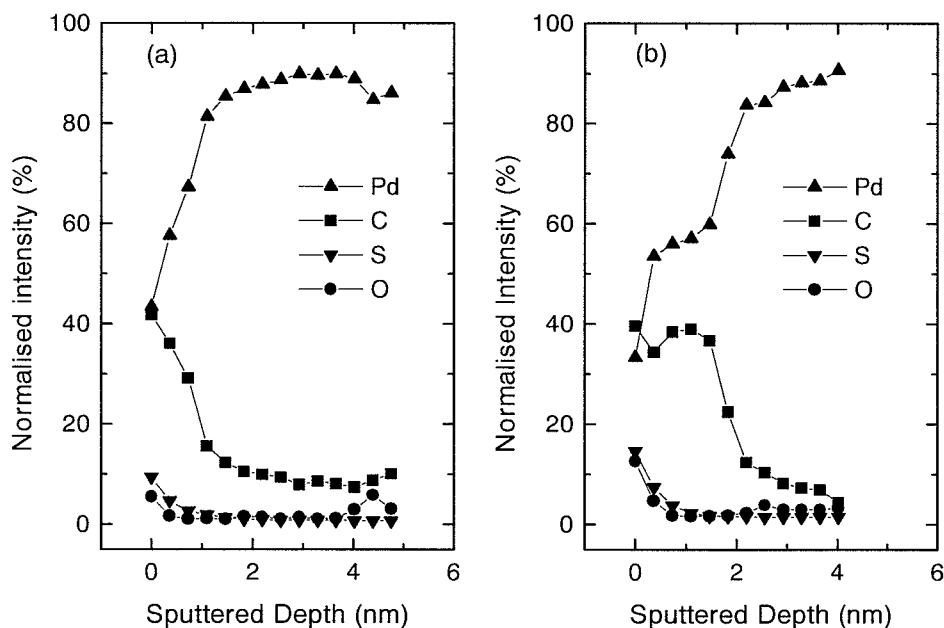


Figure 11 Auger sputter depth profiles of Lot 2. Figure (a) is for the as-received condition, and Figure (b) is for the aged condition of 2 days at 155°C.

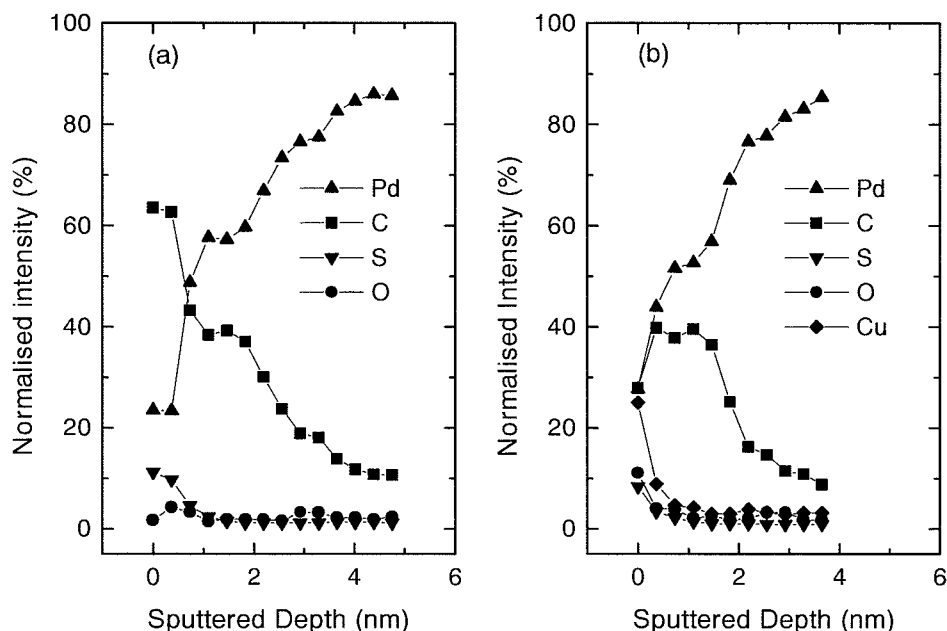


Figure 12 Auger sputter depth profiles of Lot 3. Figure (a) is for the as-received condition, and Figure (b) is for the aged condition of 16 days at 155°C.

The sputter depth profile analysis does not reveal significant changes in surface composition. Hence, there is no evidence to attribute change in solderability to variations in surface composition. Artificial ageing at 155°C is expected to cause oxidation of the underlying nickel layer, and it is this that will cause a loss of solderability during natural ageing. The Auger profiling data do not reveal excessive oxidation, or the presence of nickel at the surface following solid state diffusion, so the condition of the underlying nickel can only be a matter of speculation.

It is very interesting that Lot 3, with the poorest solderability has copper at the surface. For copper to be at the surface it must have migrated from the underlying substrate. This implies that there is a much higher level of copper in the palladium and underlying nickel layer. If significant amounts of copper intermetallics form, especially along paths of fast diffusion such as grain boundaries, then the flow of solder over the surface can be arrested or even prevented. This will be exacerbated by oxygen diffusion into the palladium coating.

Although copper and oxygen diffusion will occur on the atomic scale it is of interest to look at the coating on a more macro scale. Scanning electron microscope (SEM) images for the three lots are shown in Figures 13 to 15. The images are taken from the bottom side of the lead, and around the heel area, the critical part for wetting.

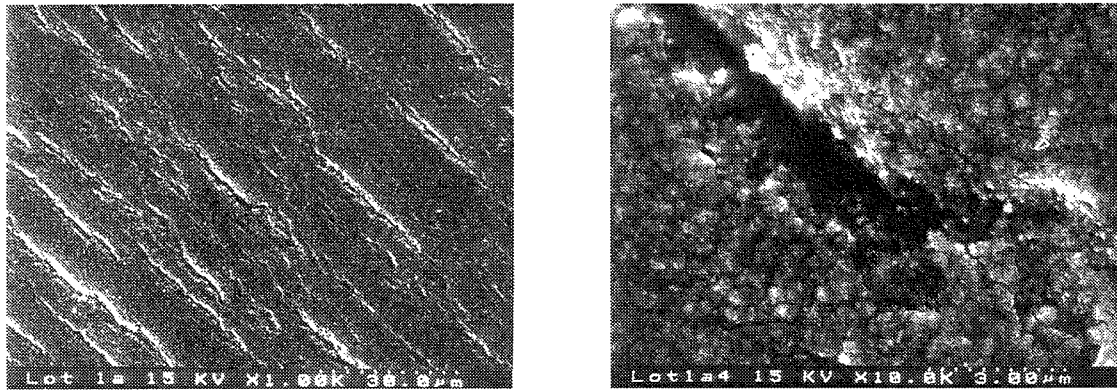


Figure 13 SEM micrographs of the surface of Lot 1 components, at 1000 and 10,000 times magnification

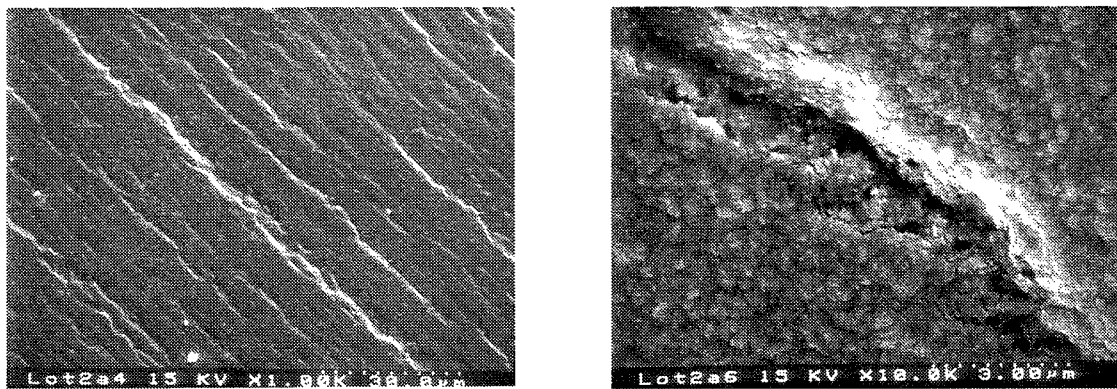


Figure 14 SEM micrographs of the surface of Lot 2 components, at 1000 and 10,000 times magnification

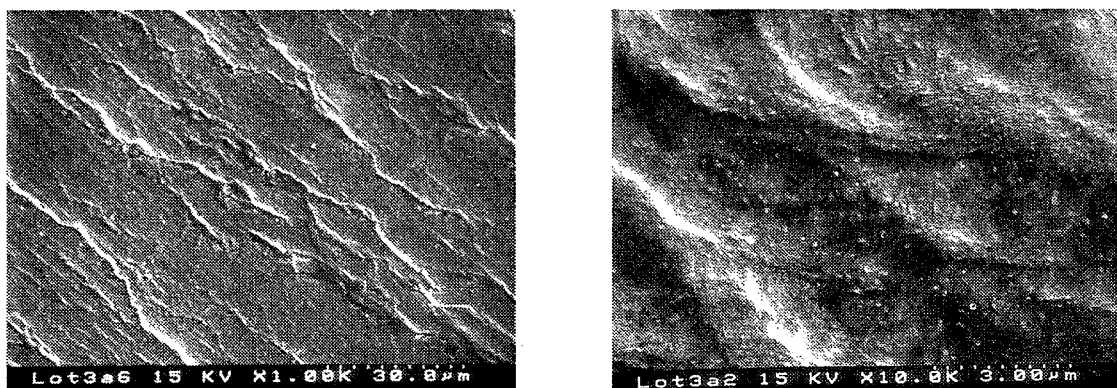


Figure 15 SEM micrographs of the surface of Lot 3 components, at 1,000 and 10,000 times magnification

The micrographs at 1,000 times for the three Lots are very similar in showing a flat surface with cracking running along one axis. These are probably a feature of the nickel and palladium plating. However, in Figure 13 and 14 at 10,000 times, looking into one of these features, the coating can be seen to be cracked, with a deep crevice. The high magnification micrographs also reveal differences in the morphology between Lots 1 and 2, and that of Lot 3. Lots 1 and 2 have small nodules, approximately  $0.3\mu\text{m}$  in size, whereas

Lot 3 is much smoother, and there are numerous small precipitates. Whether these difference are significant is not known.

***These results show that artificial ageing of the components produces only marginal changes in the surface composition. Differences in surface morphology were observed but this does not seem to affect the solderability, see the as-received data in Figure 5. The Auger data for Lot 3 show traces of copper, and this may be the clue as to how the coating actually ages ie copper diffusion into the coating, forming intermetallics which interfere with the soldering process.***

### 3.3 Process Yield and Visual Inspection

As described above the assembly yield was assessed using visual inspection criteria. A total of 60,000 joints were assessed for all the companies and boards. The results of this analysis for the individual companies are shown in the following Figures 16 to 21. The results are plotted as a percentage of the total number of joints inspected. For each set this number is 2,500.

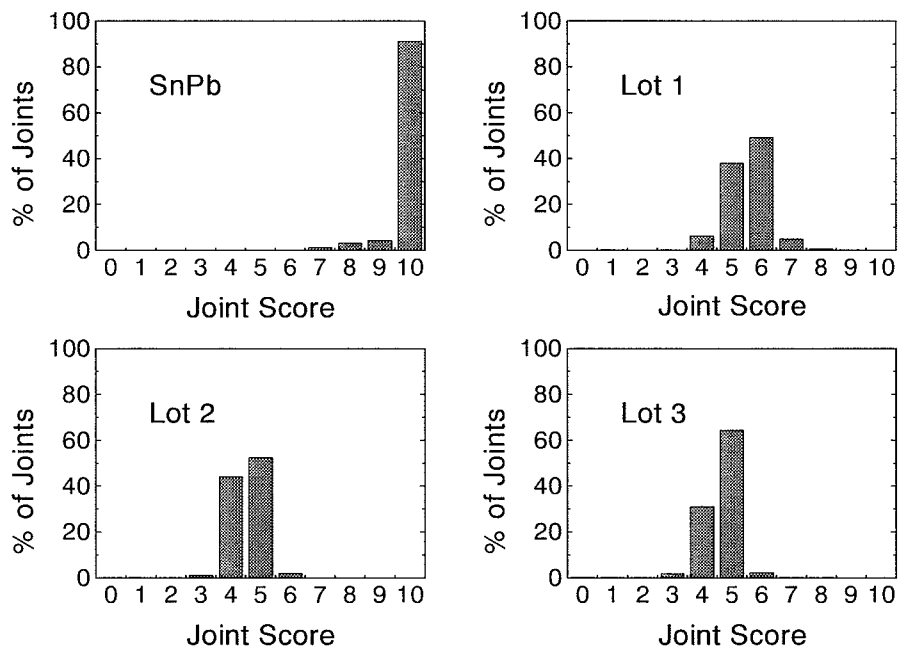


Figure 16: Company A visual inspection scores for the various sets

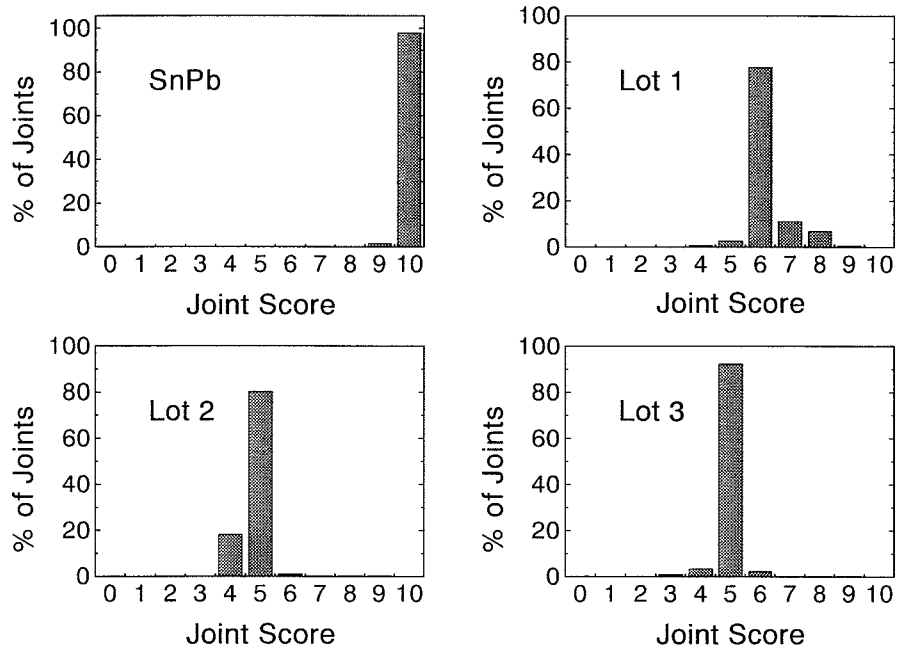


Figure 17: Company B visual inspection scores for the various sets

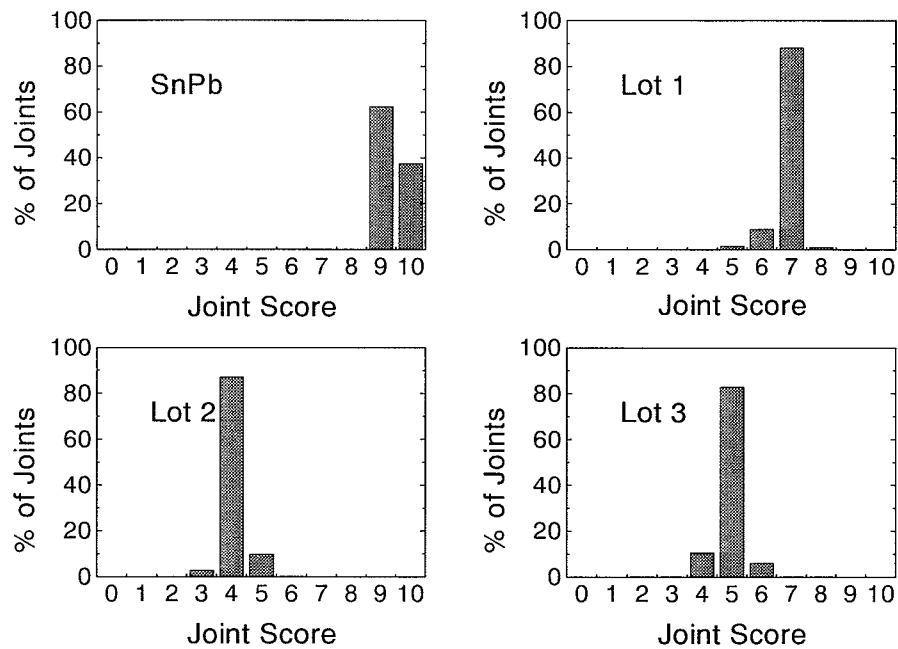


Figure 18: Company C visual inspection scores for the various sets

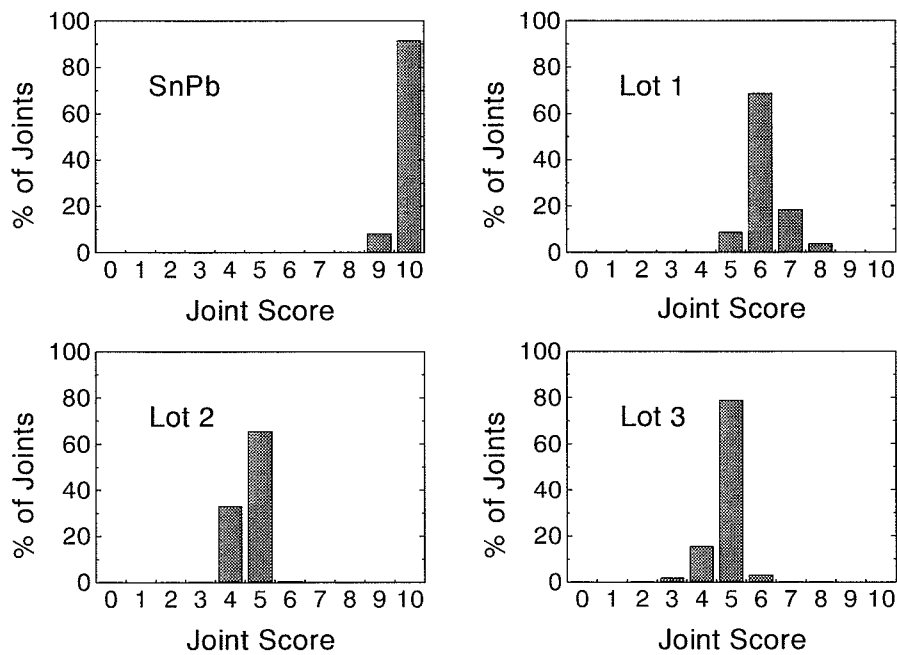


Figure 19: Company D visual inspection scores for the various sets

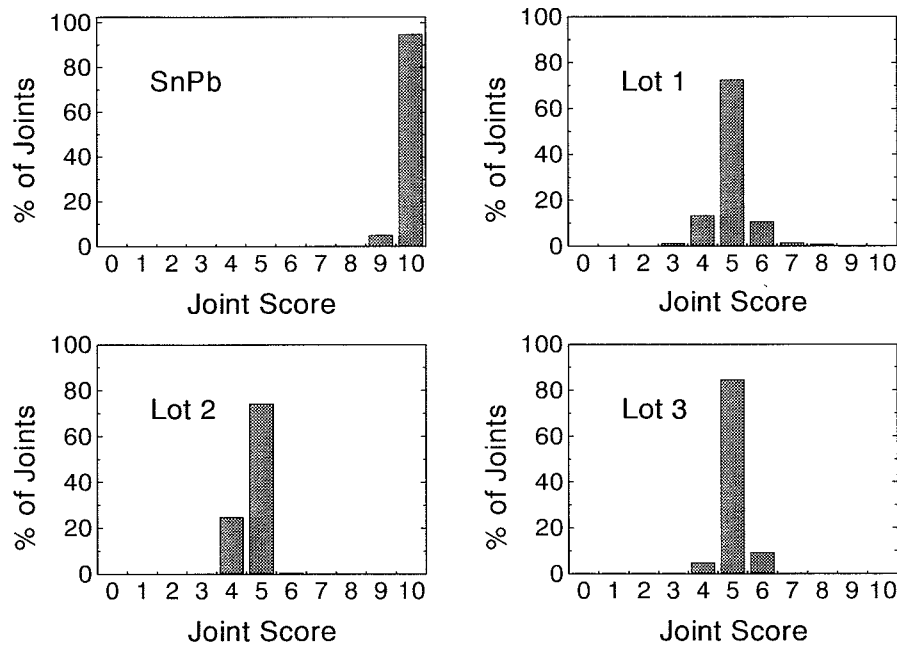


Figure 20: Company E visual inspection scores for the various sets

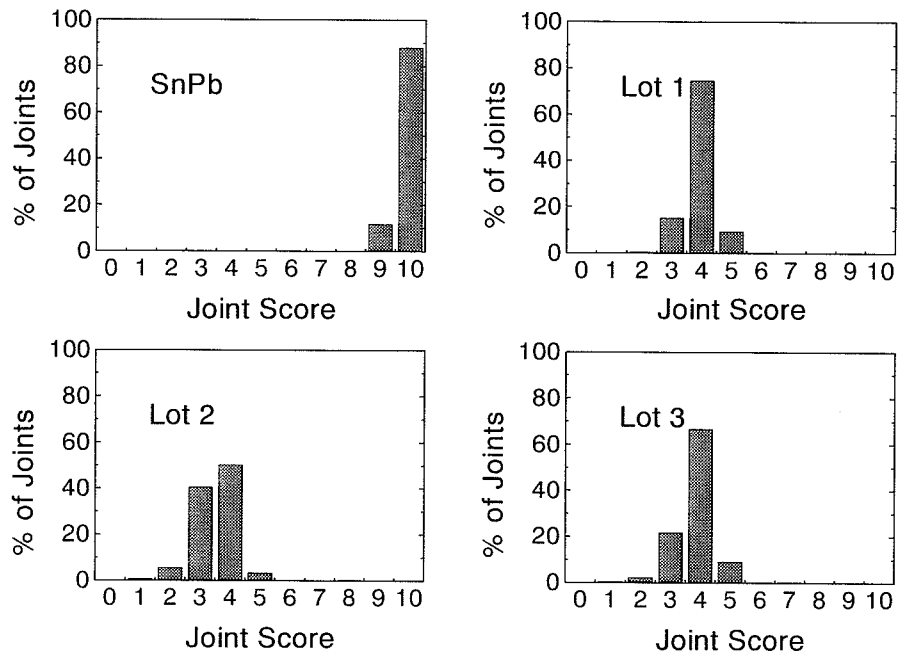


Figure 21: Company F visual inspection scores for the various sets

For all the companies for the as-received components, it can be clearly seen that the average visual inspection score for Lot 1 components is significantly lower than for equivalent tin/lead components. The average score for the as-received Lot 1 components does vary depending on the manufacturing process. Ageing of the palladium finished components appears to have only a marginal effect, with the average visual inspection scores for Lots 2 and 3 very similar and only slightly less than Lot 1. Company C was slightly unusual in having poorer scores for the tin/lead components, but the highest for Lot 1. Company F had significantly lower yields for the palladium components.

The average score for each set of components is given for each company in Figure 22.

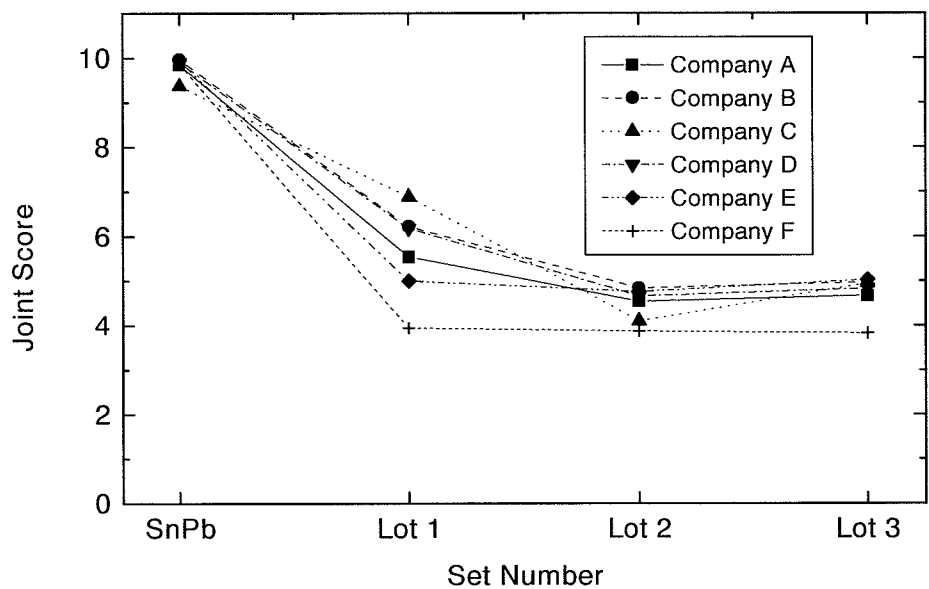


Figure 22 The average score for all set of components, for each company

Figure 22 clearly shows how consistently good the tin/lead components are, and that the palladium components always have poorer joint scores. Lots 2 and 3 have very similar joint scores, with the scores from all the companies almost identical apart from Company F. With Lot 1 there is a fairly wide range of joint scores. Typical micro-sections of the joints are shown in Figure 23 and 24.

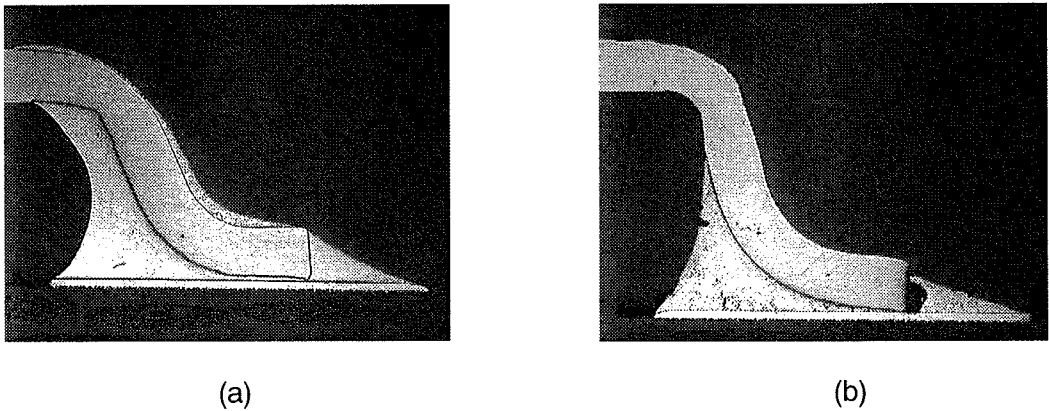


Figure 23 Cross-section of the tin/lead finished components (Fig a), and of the palladium finished Lot 1 components (Fig b)

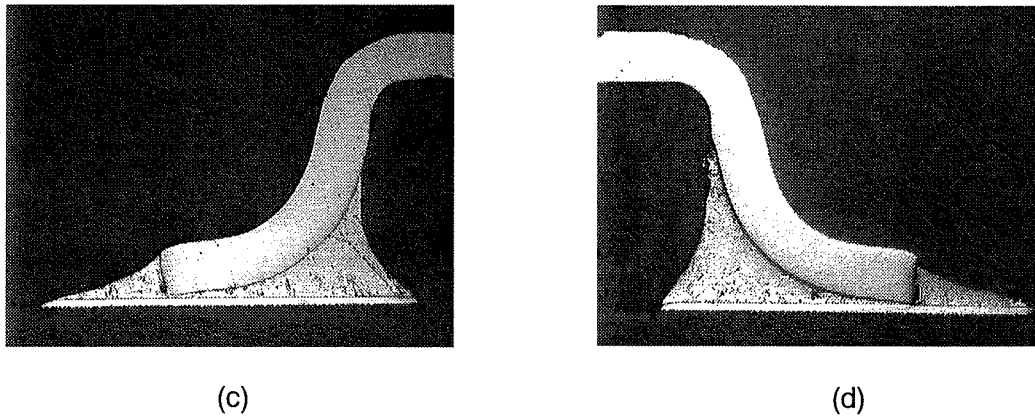


Figure 24 Cross-section of the palladium finished Lot 2 components (Fig c), and of the palladium finished Lot 3 components (Fig d)

These micro-sections clearly show the difference between the tin/lead and the palladium finished components. It is clear from these micrographs that the fillet rise on the heel is less than that on the tin/lead components. It is also apparent from these Figures that solder on the top side is significantly different between the tin/lead and palladium finished components. This may reflect the different solderability of the two finishes. But it may also be a function of the tin/lead finished components being coated with solder, and hence distinguishing the origin of the solder on the lead top side may be problematic.

In the above analysis the joint score for each company was considered, and in Figure 22 we plotted the average of these scores. However, of equal interest is the number of joints that are considered to be failures. Using Figure 3 we take a typical industry approach and define a joint with a score of 3 and above as an acceptable joint, and a joint with a score of 2 and less as an unacceptable joint. Using this definition we can see the average scores in Figure 22 are all acceptable. We now count the number of joints with a score of 2 or less, and plot the results in ppm of the number of joints inspected, i.e. this is normalised from the 2500 joints inspected for each category, so that 2500 defects will correspond to  $10^6$  ppm. The visual inspection scores are plotted as process yield, or defect levels, for the four sets of components and for each company in Figure 25. In this Figure there is an axis break to accommodate the high defect levels of Company F.

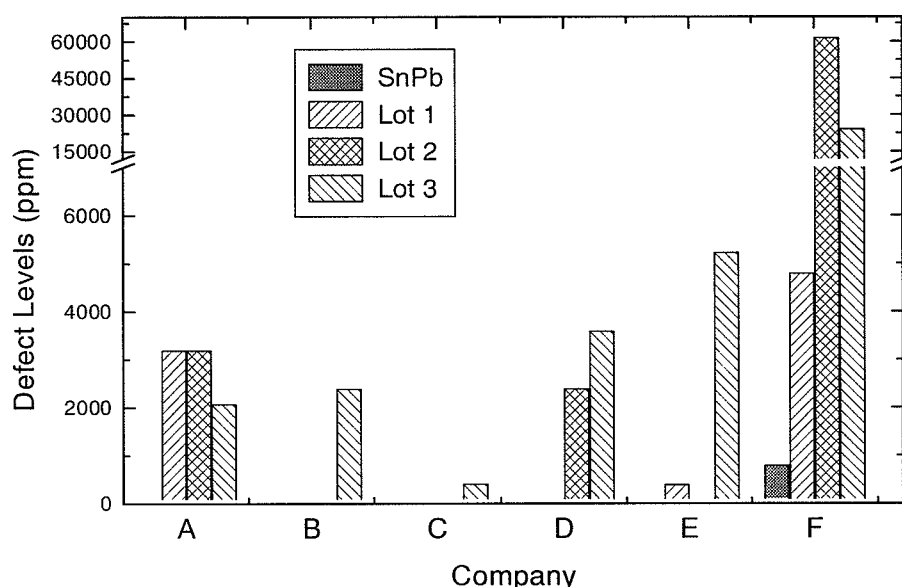


Figure 25 Defect levels for the four sets of components for each of the six companies

Figure 25 reveals a different picture to that in Figure 22, and clearly demonstrates there is a big difference in the ability to solder consistently these components between the companies. Company C is particularly successful, only attaining 400ppm defect levels on Lot 3. Company F by comparison is significantly less successful in achieving low defect yields. Companies B, C and D all achieved a zero defect process with the Lot 1 components, and Companies B, C and E all achieved a zero defect process with the Lot 2 components. Companies B and C achieved a zero defect process for both Lot 1 and Lot 2 components. All the companies, except F, show a zero defect process for the tin/lead components.

Company F was the only company to use manual placement of components, as opposed to autoplacement. The defects observed for Company F on the tin/lead components could be attributed to component misplacement, and therefore, are not due to solderability factors. This placement issue for Company F with the tin/lead components will also be a factor with the defect levels with the palladium finished components, and is a significant factor in why the results for the palladium components are worse than for the other companies. Figure 25 shows that in most instances Lot 3 results in the highest defect levels. The results from the six companies can be combined to show the average effect of using the various sets of components.

In Figure 26 the overall defect levels for all the companies are plotted. Note the defect levels are normalised against 15,000 inspected joints. The results are heavily skewed by Company F. Removing these results from the analysis, the data are re-plotted in Figure 27. This approach is sensible, since we are investigating the affect of solderability on process yield, and the results from Company F are heavily influenced by another factor, i.e. that of placement accuracy.

The results in Figure 27 are very important, and give a fairly representative view of the effect on process yields for industry on moving from tin/lead to palladium finished components. With a zero defect process and tin/lead components, moving to palladium finished components, the defect levels jump to 700ppm. It can also be seen that the artificial ageing of the palladium finished components did have a significant effect. The defect rates for Lot 2

components are approximately twice that for the as-received Lot 1 components. Lot 3 components aged for 16 days exhibit more than twice the defects than for Lot 2.

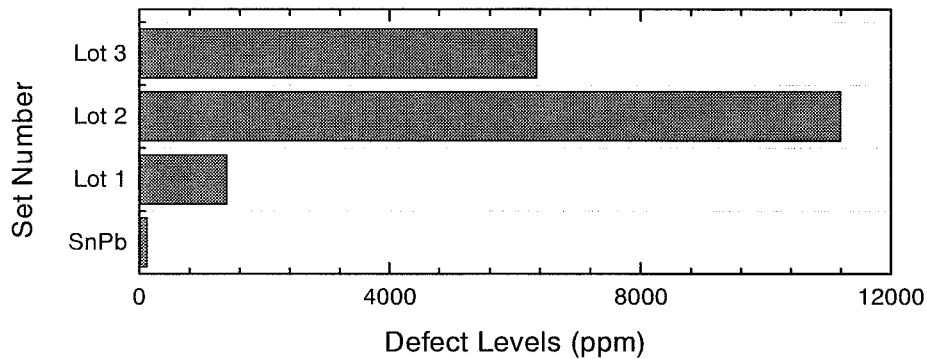


Figure 26 Defect levels for the different sets of components, using data from all the companies

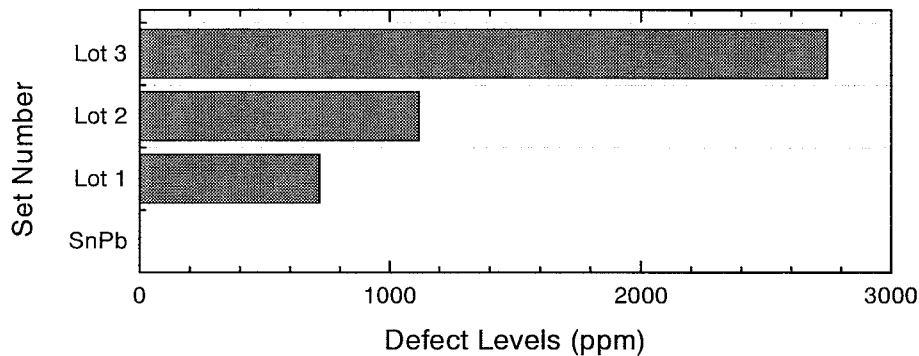


Figure 27 Defect levels for the different sets of components, using data from all the companies, except Company F

***The use of visual inspection analysis to produce process yields has been very effective in characterising the influence of substituting palladium finished components for conventional tin/lead finished components. Typical solder joints formed with palladium are satisfactory but heel fillets are smaller than those with tin/lead components. The defect levels achieved by the companies varied considerably. Some companies were able to accommodate the palladium components without loss of process yield. Significantly, however, for others running with a zero or low defect process with tin/lead components, the introduction of palladium components does have a serious and deleterious impact.***

### 3.4 Joint Strength

As described above the test was carried out in a shear mode. It was not possible to perform the test in a pull mode. The body of the component was removed prior to testing. The shearing tool made contact just above board level and along the vertical side of the lead. The displacement of the tool is plotted against the resistive force of this action in Figure 28. Each curve is an average of seven measurements.

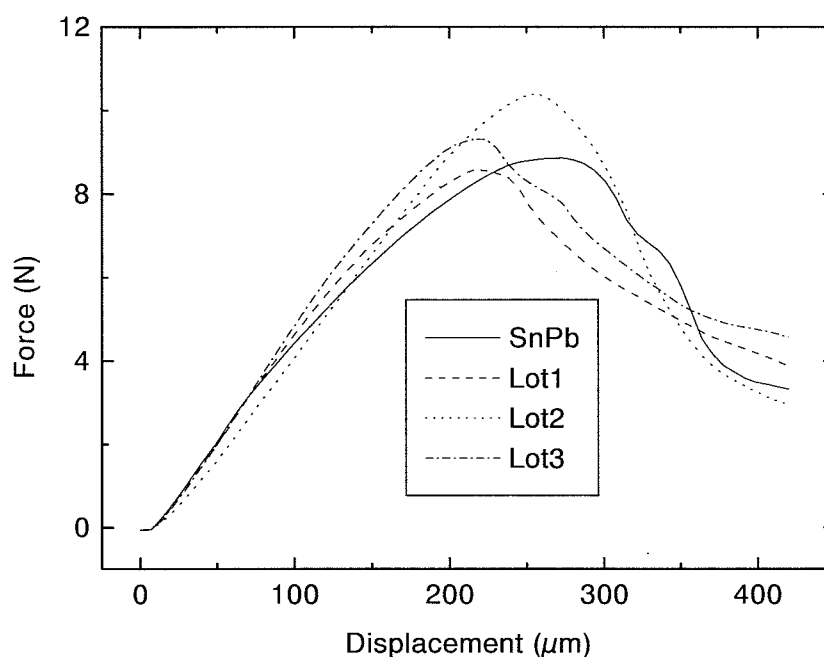


Figure 28: The average shear force to remove a component lead

The strength results show there is very little discrimination between the various sets of components, specifically there is no significant difference between the tin/lead finish and the palladium finished components. These results indicate that this measurement method is not sensitive to variations in joint characteristics.

#### 4 DISCUSSION

The visual inspection and the process yield proved to be the most telling in terms of distinguishing performance of component lead finish. The visual inspection scores showed there is a marked difference between the solder fillets formed on tin/lead and palladium finishes, the average scores varying from 10 to 6 respectively. With an acceptable joint having a score of 3 and above, the palladium joints are clearly still at an acceptable level and will give good reliability. A score of 2 or less is considered a failure in IPC-A-610B<sup>(3)</sup>, Class 3. While a joint of 2 or less might not result in a field failure, there is no certainty. A score of three or more, is evidence that wetting of the lead has occurred, and there should not be an issue with fatigue life.

The lower fillet score may be the result of two factors ie less solder on the palladium finished components, and the poorer wetting. The poorer wetting of palladium compared to other metals is shown in Figure 1, and this is given added weight when comparing the solderability data in Figures 6 and 8. The solderability data show that for a fall in 15°C in wetting balance test temperature, the wetting time of Lot 1 components increases from 0.5s to 2s, a significant change. This reduced wetting propensity is significant with reflow soldering, since it will result in the wetting front progressing more slowly up the heel of the lead. The size of the heel fillet will also be a function of the volume of solder. With the palladium finished leads the solder originates only from the supplied solder paste. However, with tin/lead finished leads there is already a solder coating on the lead and this solder will contribute to the solder in the joint. If we assume that of an 8μm coating, 5μm is free to

move and contribute to the joint, then there is 20% more solder available for the tin/lead than there is for the palladium components.

Measuring average joint scores, while clearly revealing a marked difference between the tin/lead and palladium finished components, is not as important as counting the number of defect joints. The defect level results, plotted in Figure 25 for the individual companies, yields the most insight into using palladium finished components. It was discussed above that for three of the companies, B, C and D, that using the palladium finished components of Lot 1 had no impact whatsoever on their defect levels. Considering their processes we can see that they are all very similar, and more specifically there are no significant differences in terms of solder paste and reflow conditions. So what are the differences that result in the observed variation in defect level? It is the opinion of the authors that as SOIC14 components do not self centre during the reflow process it is placement accuracy that is the key to interpreting the defect levels, assuming that process parameters and solderability are constant.

It was noted above that Company F was the only one to use manual placement of components, and that this was the influential factor on process yield. Having established placement accuracy as the deterring factor for Company F the assemblies from the other companies were scrutinised more carefully. It is clear from the results of Company A in Figure 25 that component placement could be an issue. Close inspection showed that component misplacement had occurred, even though the components had been autoplaced, confirming the suspicion that placement accuracy is important. There is some corroborative evidence in Figure 16 where the distribution of joint scores are wider for Company A than for Companies B, C, D and E where the scores tend to be more single valued. This wider distribution of scores is consistent with Company A having more defects. It was argued above that the poor placement accuracy by Company F dominated its defect levels, and hence its results were removed from the average of all companies. Since we have now argued that Company A results have an element of placement error influencing defect levels, the overall defect levels are re-calculated just for Companies B, C, D and E. These results are plotted in Figure 29.

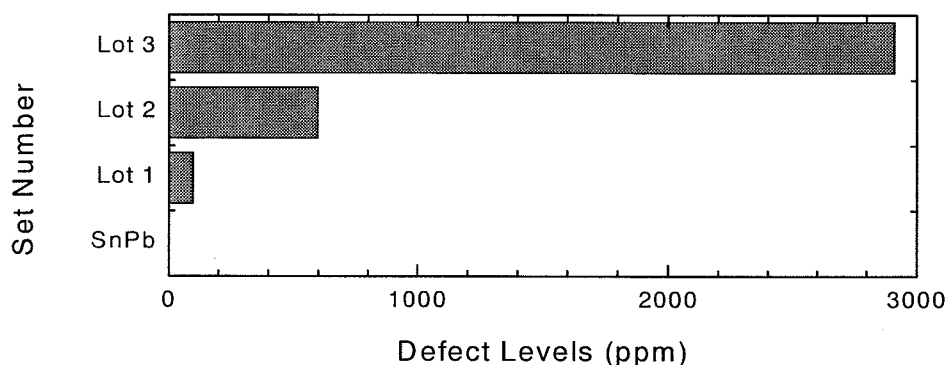


Figure 29 Defect levels for the different sets of components, using data from Companies B, C, D and E

The results in Figure 29 show that there is only a marginal change in going from tin/lead to palladium finished leads. This selective presentation of the results shows the impact of moving to palladium components in the most favourable light. Hence it is only with everything else optimised in the process that no ill effect will be observed in shifting to palladium components. By comparison the exceptionally good solderability of tin/lead

components can cover up deficiencies elsewhere in the process. In this analysis we have removed the influence of placement, however for many companies achieving perfect placement accuracy will be problematic. The problem is likely to be most severe with small volume companies, that lack the high performance and accuracy of the best placement machines.

It is interesting to note that Company A achieved zero defects with the tin/lead finish components with the same placement accuracy. The defects observed were re-checked to determine the cause of the defects. Overall between the three palladium lots the defects were either due to placement errors or issues to do with planarity, with a 50:50 split. No defects were observed with the tin/lead finished components, and hence there were no issues with planarity or placement. This can be attributed to the superior solderability of the tin/lead components.

For Company A's Lot 1 components, all the defects were attributed to poor placement. We can define a placement error with reference to Figure 30. As can be seen the misplacement we refer to here is of leads being placed off the back of the pad, and is not due to a lateral error and leads moving towards adjacent pads.

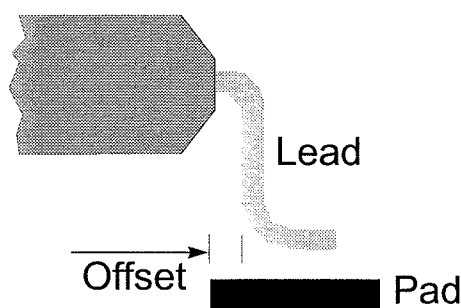


Figure 30 Schematic of component offset

The offset is measured between the inside of the lead heel and the inside edge of the pad. If the lead heel is over the pad, as shown in Figure 30, then the offset is considered to be positive. If the heel is outside the pad, then the offset is negative, and the component can be considered to be misplaced. The offsets for defect joints from Company A's Lot 1 were measured, along with offset measurements from the only two joints with a visual inspection score of 3, and a selection of joints with a visual inspection score of 4. These results are plotted in Figure 31.

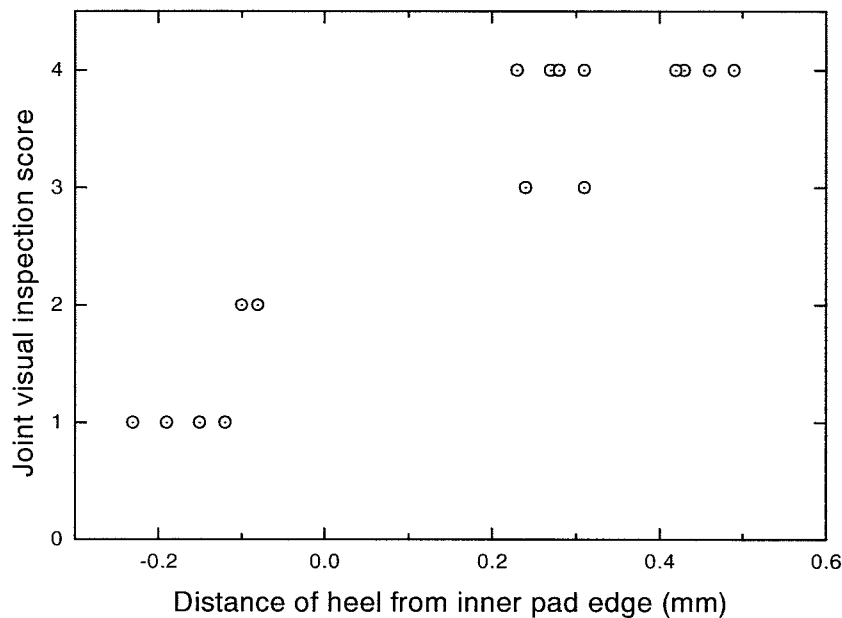


Figure 31 The correlation between the offset of the heel and the visual inspection score.

Figure 31 clearly indicates that as the offset becomes negative (and the heel overhangs the pad), the visual inspection score falls to a 2 or less, showing that there is a clear correlation between placement accuracy and process yield for these palladium finished leads.

It was commented above that with the tin/lead components, with the same placement error as for the palladium components, defects did not occur. This difference in defect rates can be attributed to the low dissolution rates of palladium in solder. For such misplaced components, wetting from the board pad and up the heel of the lead, which is overhanging the pad, becomes more restricted. In this scenario the solder front is constrained to pass around and up the lead. For the palladium finished components this requires the solder wetting front to have a low contact angle, or excellent solderability. With the tin/lead finish leads during reflow the solder coating on the lead will melt and combine with the solder on the pad, and so enhance the formation of the solder fillet. This mechanism is absent for the palladium finished leads and hence misalignment is more critical. It is the reflow of the tin/lead coating that is the critical difference between the two coatings. The reflow of the coating facilitates soldering, creating a wider process window.

It is pertinent to note that for this test board the assembly and reflow process are very straightforward to set up. In reality circuit boards are generally far more complex and temperature variations across a board will be higher than were experienced here. We have seen above that the solderability of palladium is critically dependent on temperature and hence if there are lower reflow joint temperatures due to local but high thermal demand, solder joint defects will be higher. For smaller assembly lines with narrower process windows the introduction of palladium components may have a more detrimental effect than shown here.

**Solderability testing proved effective at distinguishing between different components and ageing conditions. By lowering the test temperature from 235 to 220°C the discrimination between the different sets of components was enhanced, particularly between the tin/lead and the as-received palladium finished components.** The

measure of the time to 2/3 of the maximum force, as shown in Figure 8, proved to be particularly useful in this respect. This trend in solderability reflects the trend in defect levels seen in Figure 27. It is therefore useful to plot this solderability measure against defect levels. We use the Figure 27 data, since they exclude Company F results which are dominated by a nonsolderability factor. The correlation between solderability and defect levels are plotted in Figure 32.

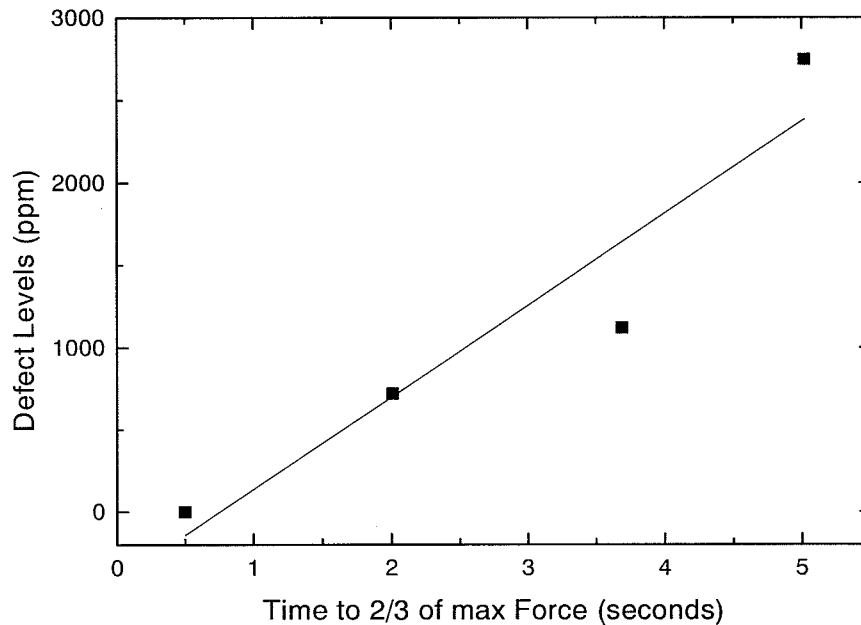


Figure 32: The correlation between solderability and defect levels. All the Companies except F are included. The wetting data were obtained at 220°C.

**Figure 32, is very important, as it shows that there is a clear correlation between solderability and defect levels. Hence, this correlation can be used to predict defect levels for these SOIC components, and is a powerful tool in determining the suitability of components for production, prior to their use.**

The above analysis can be repeated with the data in Figure 29 and using different solderability data. By plotting the defect levels in Figure 29 with the data in Figure 6, the force at 2 seconds for the measurements taken at 235°C, we obtain the plot in Figure 33. We again see that there is a good correlation between solderability and defect levels. **This illustrates that it is possible to select wetting balance parameters that will correlate with defect levels.** It is also apparent from Figure 33 that there is very good discrimination from the wetting balance data.

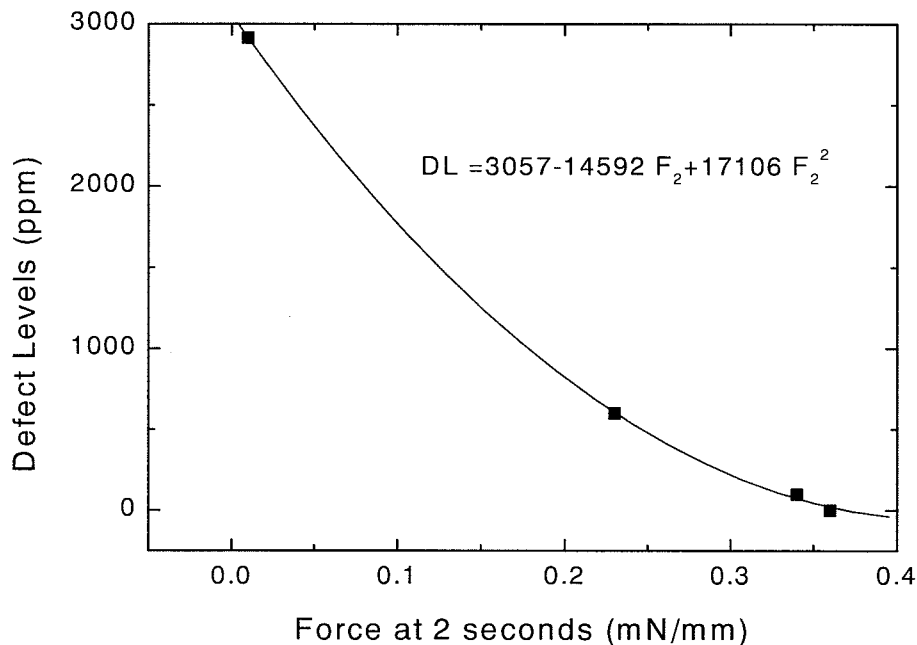


Figure 33: The correlation between solderability and defect levels. All the Companies except A and F are included. The wetting data were obtained at 235°C.

The surface analysis results and force measurement were discussed above in the experimental section. The results do not impact on the other analyses and are not discussed further here.

## 5 CONCLUSIONS

- Variations in component solderability are readily detected using a wetting balance. At lower test temperatures (220°C), tin/lead finished components generally give better solderability results than palladium components. There is less discernible difference between the component types when tested at 235°C.
- Artificial ageing of the palladium components produced only marginal changes in surface composition although soldering results show that changes in the coatings had occurred. Hence deterioration of solderability must be a result of changes in the palladium layer, or at the palladium-nickel interface. It is probable that it is the oxidation of the underlying nickel that is responsible for a loss of solderability. This may be further exacerbated by the presence of copper in the palladium layer.
- The shape and amount of fillet rise of solder joints on palladium finished components are significantly different from tin/lead components. The fillet rise at the heel is less for palladium finished components.
- The process yield when using palladium finished components has been shown to be highly dependent upon the soldering process. Moving from tin/lead to palladium finished components may result in increased defect levels. Comparing five manufacturers using

autoplacement of components, average defect levels rose from zero with tin/lead to 700ppm with palladium finished components. However, it should be noted that three of the six manufacturers collaborating in this work, soldered as-received palladium finished components without any increase in solder defect levels compared to tin/lead components. No discernible difference could be noted between the soldering processes of these three manufacturers and that of the other three companies. There is evidence to suggest that the yield of soldering palladium finished components is less tolerant of component misplacement than similar tin/lead finished components. This indicates that inferior solderability will reveal shortcomings elsewhere in the process.

- This study used a very simple board with only a few components. Temperature non-uniformity across the board during the reflow was consequently minimal. However with complex boards much larger variations in temperature will be encountered. Low reflow joint temperatures will adversely impact on the solderability of palladium components, to a much greater extent than tin/lead finished components. Hence, the introduction of palladium components for certain processes has a far more severe impact on process yield than shown here.
- A relationship between solderability and defect levels has clearly been established. A value of less than 1 sec for the time to 2/3 of maximum force, with a wetting test temperature of 220°C, is required by some manufacturers to obtain a zero defect process. However, some manufacturers do not need such solderable components and can obtain a zero defect process with components that have a time to 2/3 maximum force of greater than 3 seconds. A correlation with wetting data at 235°C was also demonstrated when all placement effects were removed from the defect data.
- Strength measurements proved unreliable, and unable to discriminate between a score of 10 for tin/lead solder fillets, and a score 6 for palladium solder fillets.

## ACKNOWLEDGEMENTS

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