

Processability of Lead- Free Component Termination Materials

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ABSTRACT

The performance of four types of lead-free finishes has been evaluated and compared to a Palladium Gold (PdAu) alternative. The four types, tin (Sn), tin-silver (SnAg), tin-copper (SnCu) and tin-bismuth (SnBi) were assessed for plating ductility, solderability, moisture ingress, process yield and tin whisker propensity. The PdAu finish was also assessed for wirebondability.

All the finishes gave acceptable performance for solderability, process yield, moisture ingress and plating ductility. The PdAu also exhibited acceptable wire bond pull strengths. None of the finishes showed whiskering under hot damp conditioning. There were two exceptions, one was a Sn finish plated using a redundant Sn chemistry, and the other was a SnCu finish. Even in these two examples, no whiskers were located on components but only on lead frame salvage, where the components had been cropped in the final operation during their manufacture.

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Approved on behalf of the Managing Director, NPL
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CONTENTS

1	INTRODUCTION	1
2	FINISHES INVESTIGATED	3
2.1	PURE SN FINISHES	3
2.2	TIN BISMUTH FINISHES	3
2.3	TIN COPPER FINISHES	3
2.4	TIN SILVER FINISHES	3
2.5	GOLD/PALLADIUM FINISH.....	3
3	PLATING DUCTILITY INSPECTION USING SCANNING ELECTRON MICROSCOPY	4
3.1	PLATING DUCTILITY INSPECTION PROCEDURE	4
3.2	RESULTS	4
3.3	PLATING DUCTILITY INSPECTION DISCUSSION	8
4	WIRE BOND PULL STRENGTHS	8
5	SOLDERABILITY MEASUREMENT	10
5.1	SOLDERABILITY MEASUREMENT PROCEDURE.....	10
5.2	DISCUSSION OF SOLDERABILITY RESULTS	20
6	MOISTURE INGRESSION MEASUREMENTS	21
6.1	MOISTURE INGRESSION MEASUREMENT PROCEDURE.....	21
6.2	MOISTURE INGRESSION MEASUREMENT RESULTS.....	21
6.3	DISCUSSION OF MOISTURE INGRESSION RESULTS	21
7	PROCESS YIELD MEASUREMENT	22
7.1	PROCESS YIELD MEASUREMENT PROCEDURE :	22
7.2	PROCESS YIELD RESULTS :.....	23
7.3	DISCUSSION OF PROCESS YIELD RESULTS :.....	29
8	TIN WHISKER PROPENSITY MEASUREMENT	35
8.1	INTRODUCTION	35
8.2	TIN WHISKER PROPENSITY MEASUREMENT PROCEDURE FOR BRASS LEADFRAMES	35
8.3	TIN WHISKER PROPENSITY MEASUREMENT RESULTS FOR BRASS LEADFRAMES	36
8.4	TIN WHISKER PROPENSITY MEASUREMENT PROCEDURE FOR COPPER LEADFRAMES	38
8.5	TIN WHISKER PROPENSITY MEASUREMENT RESULTS FOR COPPER LEADFRAMES	38
8.6	TIN WHISKER PROPENSITY MEASUREMENT DISCUSSION.....	40
9	CONCLUSIONS :	40
10	REFERENCES	42
11	ACKNOWLEDGEMENTS.....	42

1 INTRODUCTION

The electronics industry worldwide has begun the move to eliminate lead from its manufacturing processes. Driven by impending European legislation and by consumer preferences for environmentally friendly products, industry has already made great strides towards finding alternative alloys for solder (SnPb) and for Pb-containing printed circuit boards finishes. However, the greatest obstacle to a complete Pb-free process is that of component termination finishes.

At NPL, a previous successful studio project assessed the processability of palladium nickel (PdNi) leadframe finishes. The recent rises in the cost of palladium has reduced some of the attractiveness of this finish. Between 1997 and 2000, the palladium price quadrupled. It is currently at around 3 times the 1997 price. Thus plating chemistry suppliers have begun to make available alternative plating chemistries based on fusible finishes. Many of these new coatings have not previously been widely utilised in the electronics industry and they will therefore require characterisation to gain consumer confidence.

The most attractive chemistry from a manufacturing point of view is pure tin. This is easier to electroplate than an alloy combination, but it is reported to suffer from the spontaneous growth of single crystal whiskers under certain conditions. The proposed lead-free alternative alloys (tin silver (SnAg), tin bismuth (SnBi) & tin copper (SnCu)) are more difficult to deposit at the correct eutectic composition due to the low fractions of the alloying elements and the precision required in composition. Moving these alloy compositions a few percent away from the optimum can result in a very significant increase in melting point.

The aim of this project was to investigate the options available and benchmark them with a series of tests, which will assess the processability of the alternative Pb-free termination finishes, both pre- and post-plated in a lead-free soldering environment. Pre-plated leadframes are plated prior to component moulding with a finish which is both wire-bondable and solderable. Post plated leadframes have to be plated initially with silver in selected areas to allow wire-bonding and subsequently plated after component moulding with a solderable finish on the component leads. Figure 1 shows typical flow charts for the manufacture of components using pre-plated and postplated leadframes. The project partners were Alpha Metals, Consumer Microcircuits, Enthone OMI (UK) Ltd., European Space Agency, Handy & Harman, Lucent Technologies, Matra Bae, Micrometallic, Motorola, Shipley Ronal, and Schloetter.

The component manufacturer partner supplied leadframes or encapsulated leadframes (SOIC16W format), which were plated with varying finishes by the plating chemistry supplier partners. These platings included the fusible coatings Sn, SnAg, SnCu, SnBi and the non-fusible coating of gold on palladium (PdAu). The component manufacturer partner then incorporated these lead-frames into standard SOIC16W components. The resulting components were characterised for solderability, plating ductility, tin whisker propensity and moisture ingress. Components were also assembled on to PCBs and process yield was measured by visual inspection. The PdAu finish was also tested for wirebondability.

Variants within each plating group resulted in fifteen different finishes. These were provided by the five suppliers of plating chemistries that participated in this project. A further pure Sn finish was also obtained in limited quantities from a commercial source.

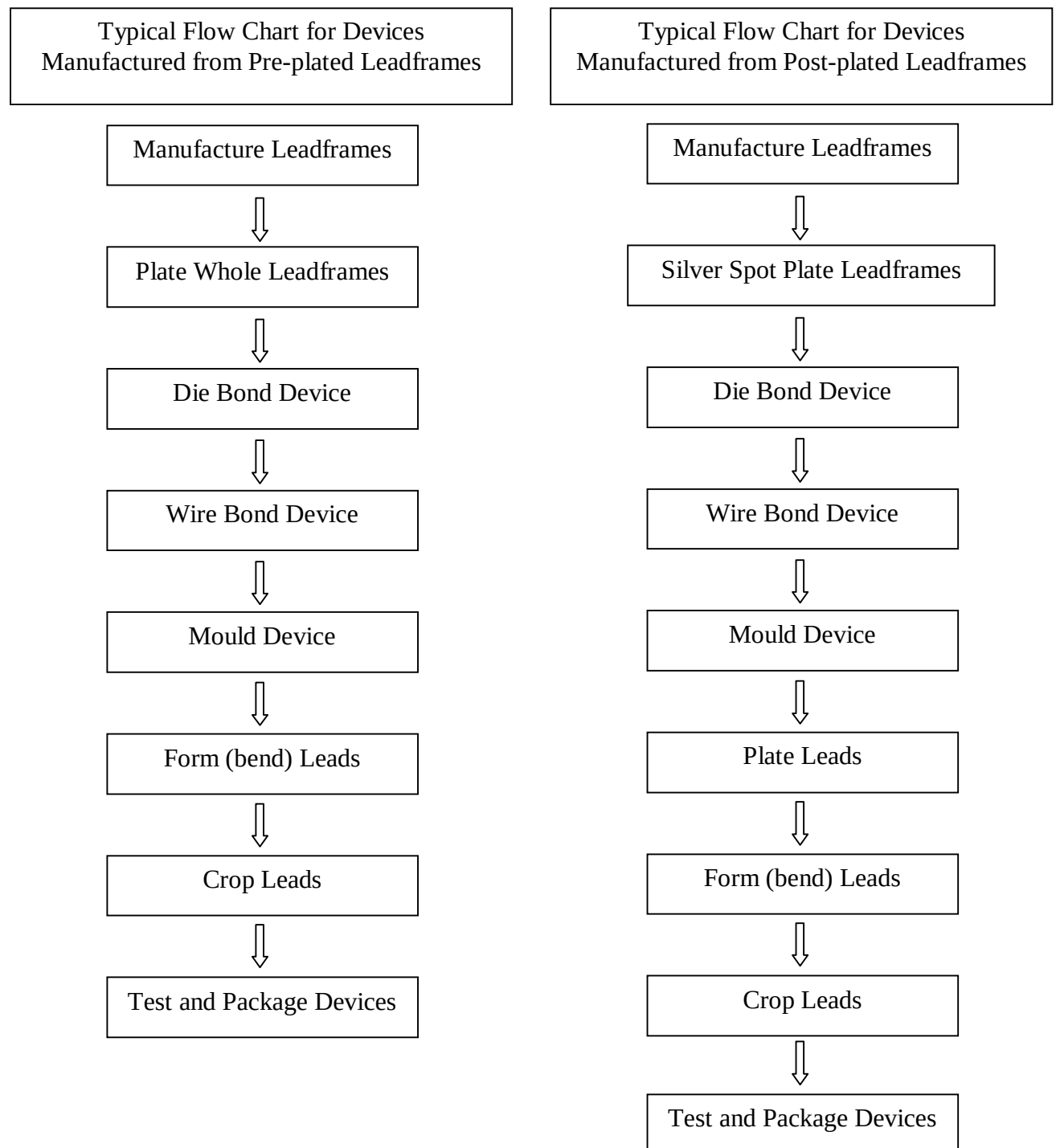


Figure 1 : Typical Process Flow Charts for Component Manufacture

2 FINISHES INVESTIGATED

2.1 PURE Sn FINISHES

Four plating chemistry partners provided a pure tin finish each. Sn2 is a redundant chemistry specifically added to the programme as a finish thought likely to whisker. Finish Sn6 was not supplied by a partner but sourced outside the project. Complete components were supplied for this finish and they were therefore not encapsulated by the component manufacturer partner. Thus six tin finishes were incorporated into the project as a whole although only four were available in sufficient numbers to be incorporated into process yield evaluation.

Sn1	Partner's matt tin process
Sn2	Redundant tin process
Sn3	Partner's satin tin process
Sn4	Partner's matt tin process
Sn5	Partner's matt tin process
Sn6	Commercial matt tin process

2.2 TIN BISMUTH FINISHES

Three SnBi finishes were supplied by three different partners. These were nominally of a 95%Sn/5%Bi composition. These finishes were designated SnBi1, SnBi2 & SnBi3.

2.3 TIN COPPER FINISHES

Three SnCu finishes were supplied by three different partners. These were nominally of a 99%Sn/1%Cu composition. These finishes were designated SnCu1, SnCu2 & SnCu3.

2.4 TIN SILVER FINISHES

Three SnAg finishes were supplied by three different partners. These were nominally of a 96.5%Sn/3.5%Ag composition. These finishes were designated SnAg1, SnAg2 & SnAg3.

2.5 GOLD/PALLADIUM FINISH

The final finish incorporated into the programme was a multilayer noble metal finish of Au on Pd on Ni. This finish was the only finish to be preplated to the leadframe prior to encapsulation. All other finishes were plated after encapsulation. This finish was designated Au1.

3 PLATING DUCTILITY INSPECTION USING SCANNING ELECTRON MICROSCOPY

3.1 PLATING DUCTILITY INSPECTION PROCEDURE

To ascertain the plating ductility, components from each of the finishes was examined using SEM (scanning electron microscope) techniques. Each sample was secured onto a stub with a conductive paste and examined in a SEM. Images were taken of the heel where the greatest stresses were found. The area of interest is shown in Figure 2. The magnification used was x150.

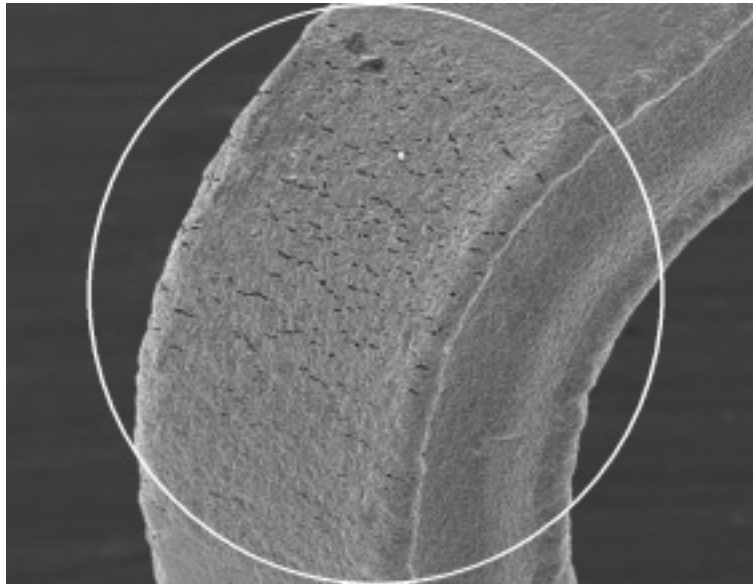


Figure 2: Areas of interest for plating ductility analysis.

3.2 RESULTS

SEM micrographs of the heel bend region are shown in Figures 3 to 18.

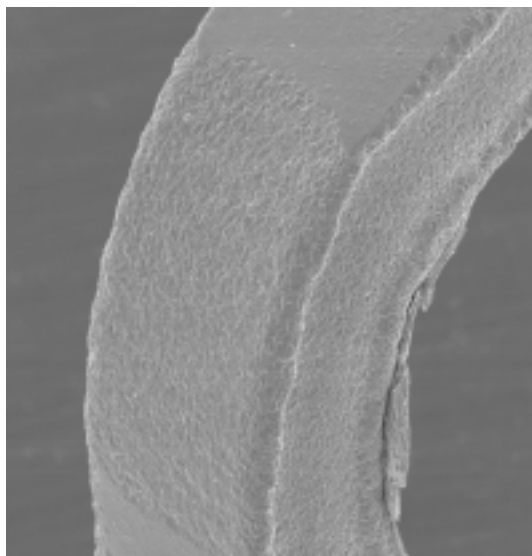


Figure 3: Sn1 finish (x150)

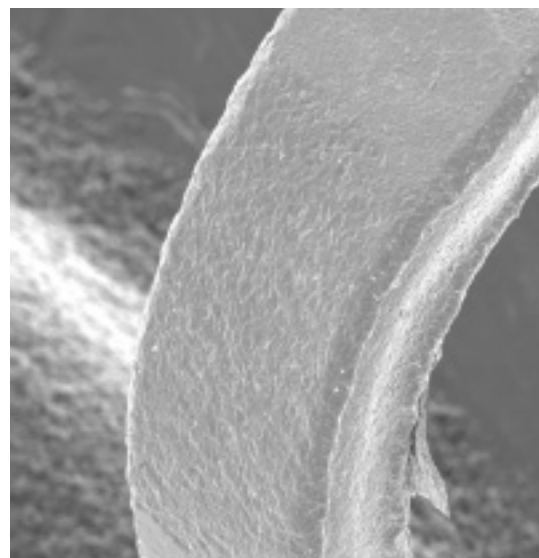


Figure 4: Sn2 finish (x150)

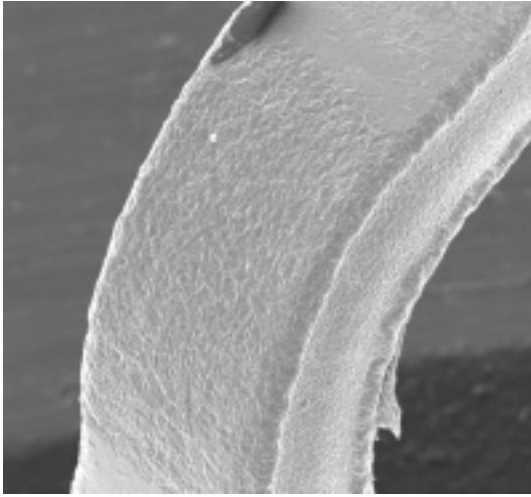


Figure 5: Sn3 finish (x150)

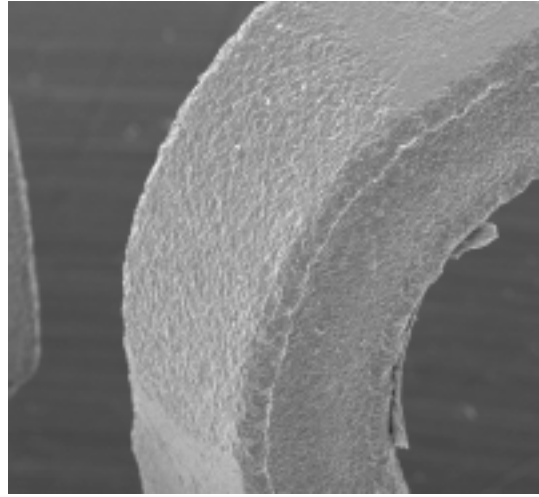


Figure 6: Sn4 finish (x150)

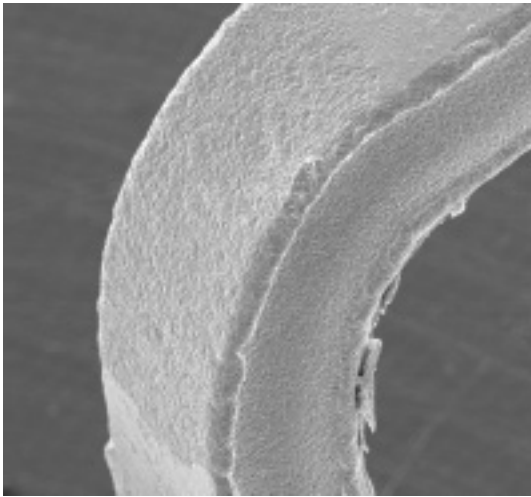


Figure 7: Sn5 finish (x150)

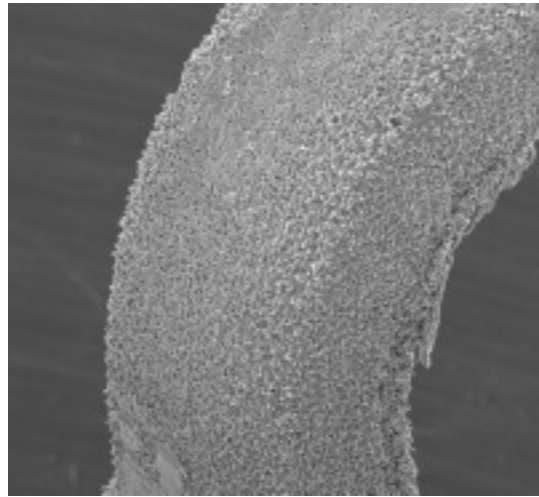


Figure 8: Sn6 finish (x150)

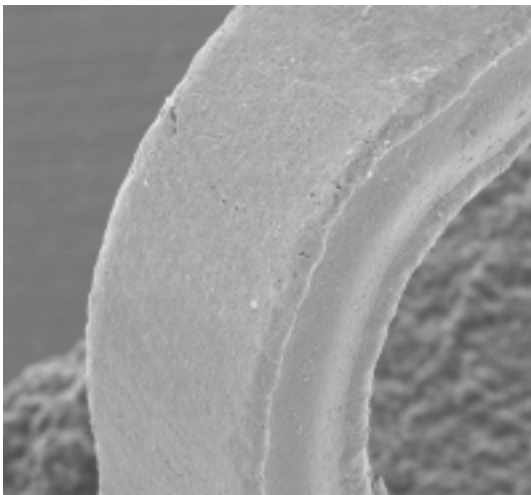


Figure 9: SnBi1 finish (x150)

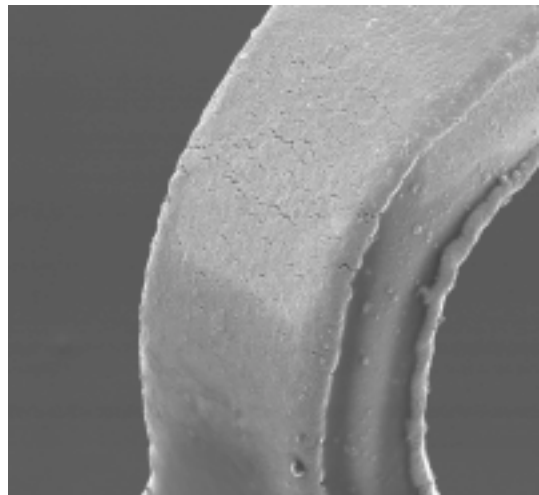


Figure 10: SnBi2 finish (x150)

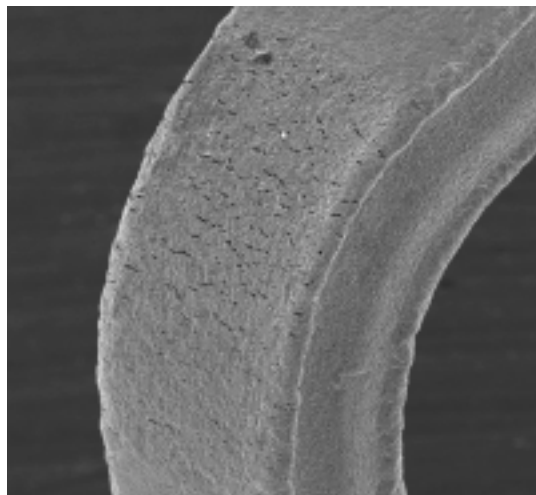


Figure 11: SnBi3 finish (x150)

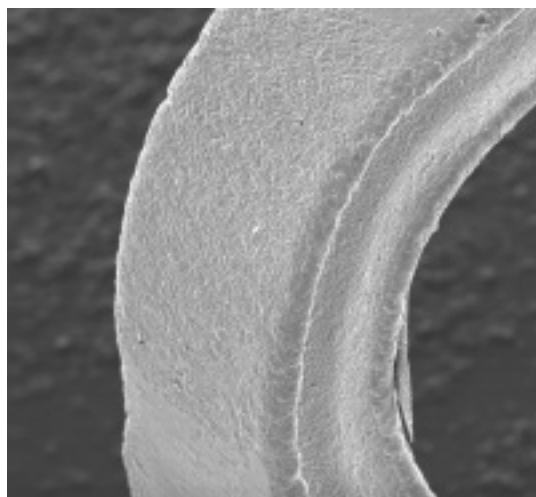


Figure 12: SnCu1 finish (x150)

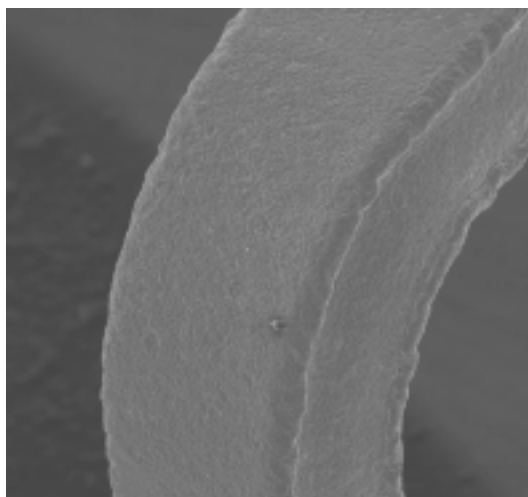


Figure 13: SnCu2 finish (x150)

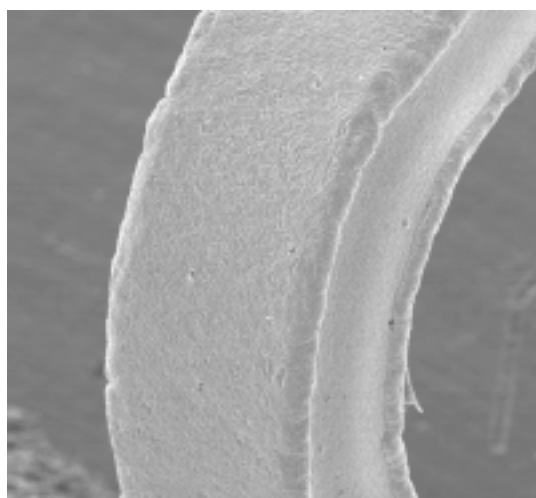


Figure 14: SnCu3 finish (x150)

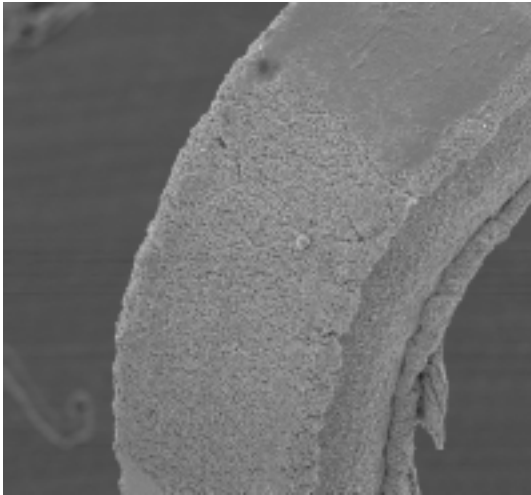


Figure 15: SnAg1 finish (x150)

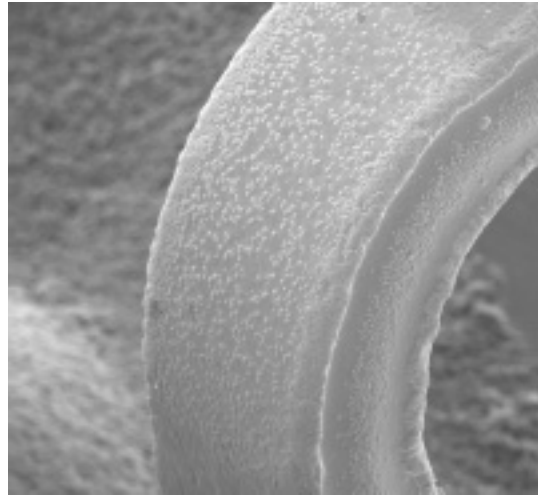


Figure 16: SnAg2 finish (x150)

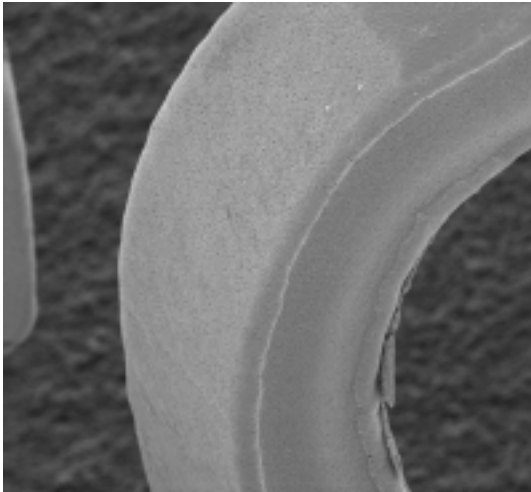


Figure 17: SnAg3 finish (x150)

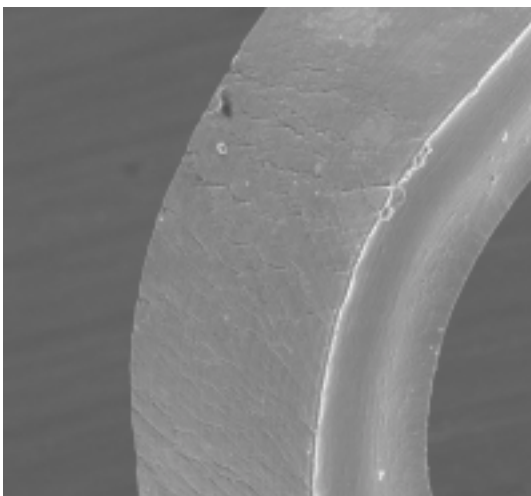


Figure 18: Au1 finish (x150)

3.3 PLATING DUCTILITY INSPECTION DISCUSSION

The results highlighted the varying degrees of deformation/ cracking of the coating around the heel bend areas. It was evident that some of the plating finishes displayed a degree of cracking around the heel area. Of the different finishes used, SnBi1, SnBi2, SnBi3, SnAg1 and Au1 exhibited the worst cracking in the heel area. All Sn, SnAg1, SnAg3, SnCu1 and SnCu3 had de-bonded regions of the coating from the component lead on the inside bend of the heel. Sn6 and SnAg1 showed a definite increase in surface roughness, within the heel area.

4 WIRE BOND PULL STRENGTHS

The tensile strength of gold wire bonds between die and substrate for Au1 leadframe type was investigated.

WIRE BOND PULL STRENGTHS EXPERIMENTAL PROCEDURE

Testing was undertaken with a Farco biaxial tensile test machine. Four of the bond wires interconnecting a single die and leadframe were tensile stressed to failure in the vertical axis, producing a value for the ultimate tensile stress (UTS). This was repeated using 17 components giving a total of 68 tests. Figure 19 shows a typical sample and the wire bond test sites.

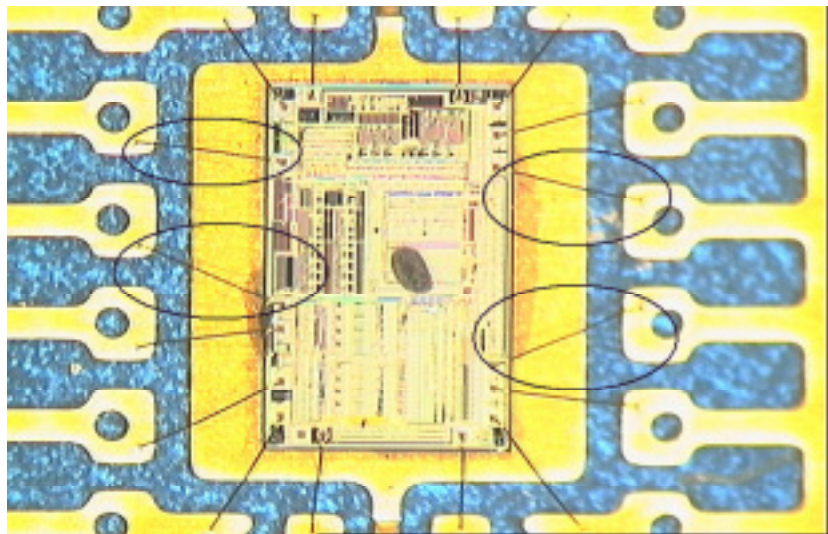


Figure 19: Stereomicroscope image of die showing test sites.

WIRE BOND PULL STRENGTH RESULTS

The average, and standard deviation of the ultimate tensile strengths for the samples are given in Figure 20.

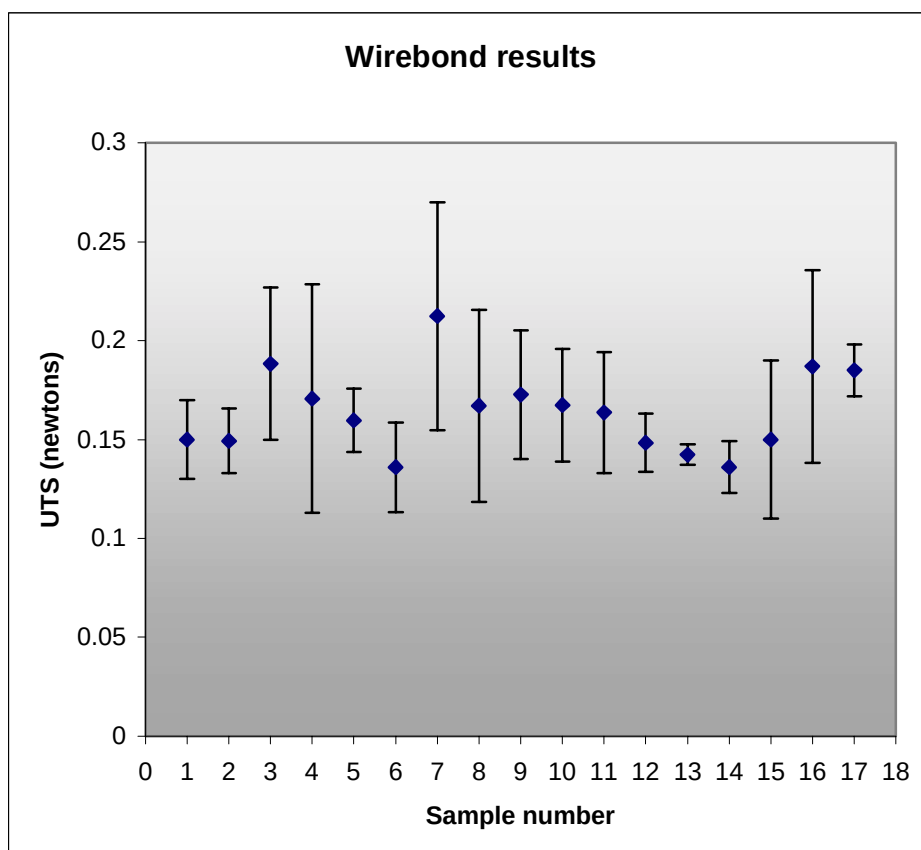


Figure 20. Average UTS for Au wire bonds.

WIRE BOND PULL STRENGTH DISCUSSION

Results in figure 20 show marginal differences in UTS between components. A range of values is to be expected, for the four gold wire bonds since where the hook engaged on the wire and at what angle the wire was connected on the die can vary. The average force for all wire-bond pull tests was found to be 0.163 ± 0.004 Newtons. This compares favourably with the values achieved in a previous NPL project on noble metal component finishes (Ref 1) as shown in Figure 21.

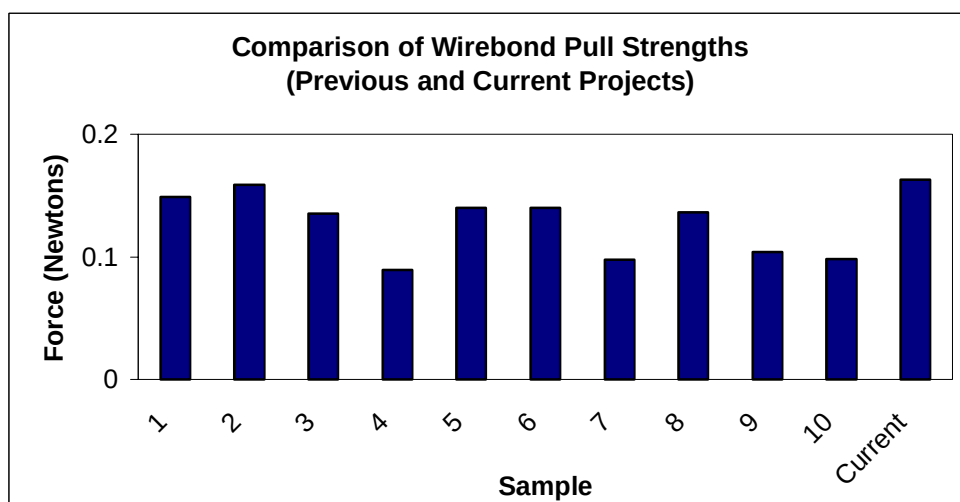


Figure 21 : Wirebond Pull Strength Comparison

5 SOLDERABILITY MEASUREMENT

5.1 SOLDERABILITY MEASUREMENT PROCEDURE

Fully moulded components in a SOIC16 package were used and all 16 lead-free finishes were tested. The components were tested as received, and after ageing at 155⁰ C for 4 and 16 days. The samples at the three ages were tested with two fluxes and three lead-free alloys for solderability. These were:

Fluxes:

- 'A' = 0.5% halide activated pure rosin
- 'B' = VOC free, water soluble no-clean

Solder Alloys:

- | | | |
|----------------|--------------|--------------------------|
| • SnAgCu (SAC) | 95.5/3.8/0.7 | m.pt. 217 ⁰ C |
| • SnCu | 99.3/0.7 | m.pt. 227 ⁰ C |
| • SnAgBi | 93.5/3.5/3.0 | m.pt. 210 ⁰ C |

The solderability testing was carried out using a Multicore MUST II. The test conditions were in accordance with the IEC standard 68-2-69, and the instrument was used in the solder globule mode. The test temperature was 40⁰ C superheat. Superheat is defined as the soldering temperature above the melting point of the test alloy (i.e. 257⁰C for the SAC alloy). The following conditions were used:

- 200mg solder pellet
- immersion speed = 1 mm/s
- immersion depth = 0.2 mm
- no pre-heat
- data were acquired over a 5 second period
- leads were dipped at an angle of 45⁰
- three leads from each of two components were tested for each finish/flux/alloy/age combination

The test results are therefore an average value from 6 leads.

Figures 22-33 show the wetting force and time results for each alloy/flux combination for all finishes and all three ages when tested at 40⁰ C superheat. For wetting force results good solderability is indicated by high forces, and for wetting time good solderability is indicated by quick times. Ideally after ageing these values shouldn't have changed. For Flux A the force is typically 0.8mN in the as-received condition, and this corresponds to 0.4mN/mm, taking into account gullwing lead perimeter. This value is near the maximum possible and shows the excellent solderability of these samples. For flux B the as received value is approximately 0.26mN/mm, still acceptable but lower, reflecting the weaker flux. These values are typical of SnPb finishes.

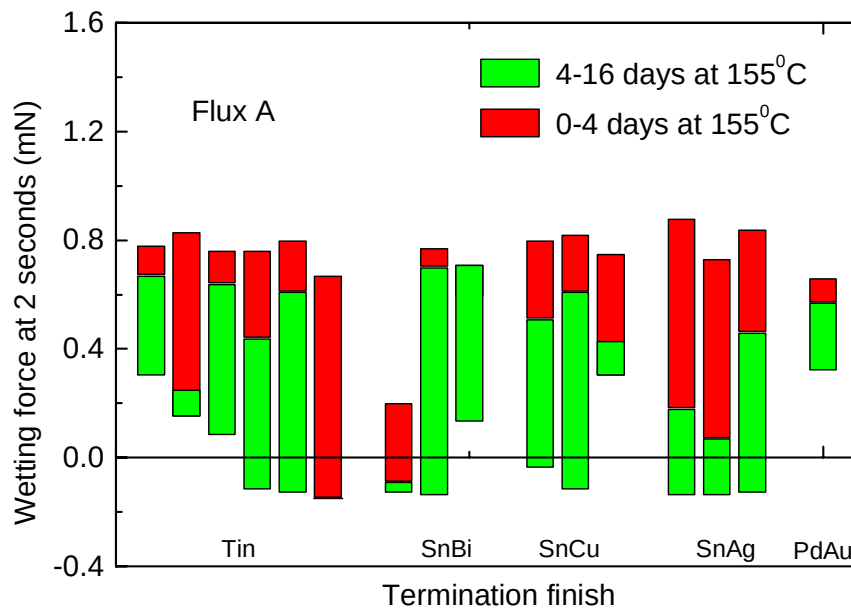


Figure 22. Wetting force for SAC and flux 'A'

The top of the red box represents the value at 0 days, the bottom of the box represents the value after 4 days ageing, and the bottom of the green box is the value after 16 days ageing.

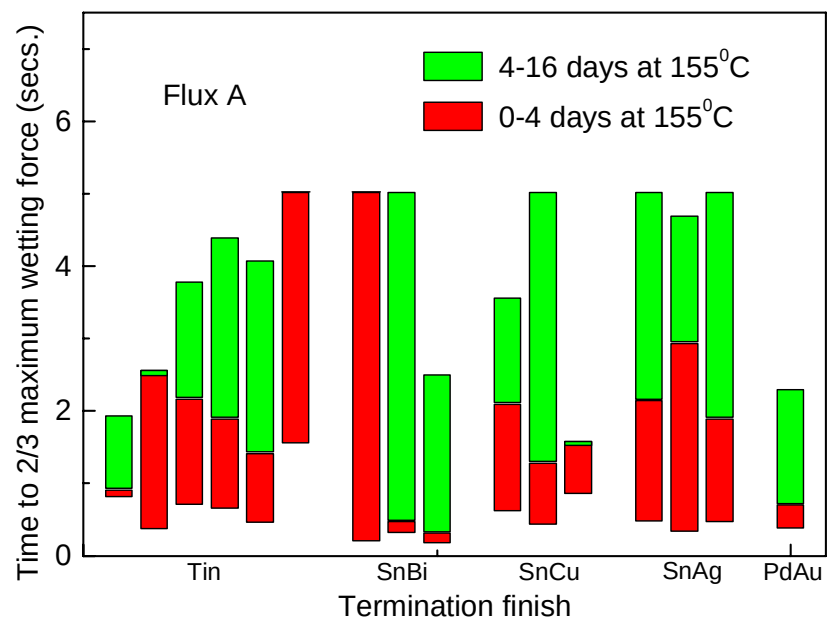


Figure 23. Wetting time for SAC and flux 'A'

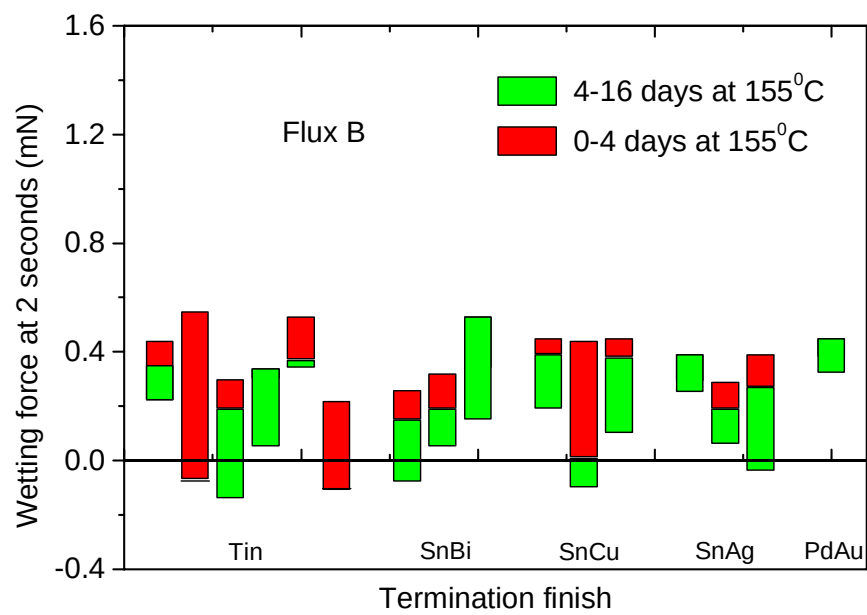


Figure 24. Wetting force for SAC and flux 'B'

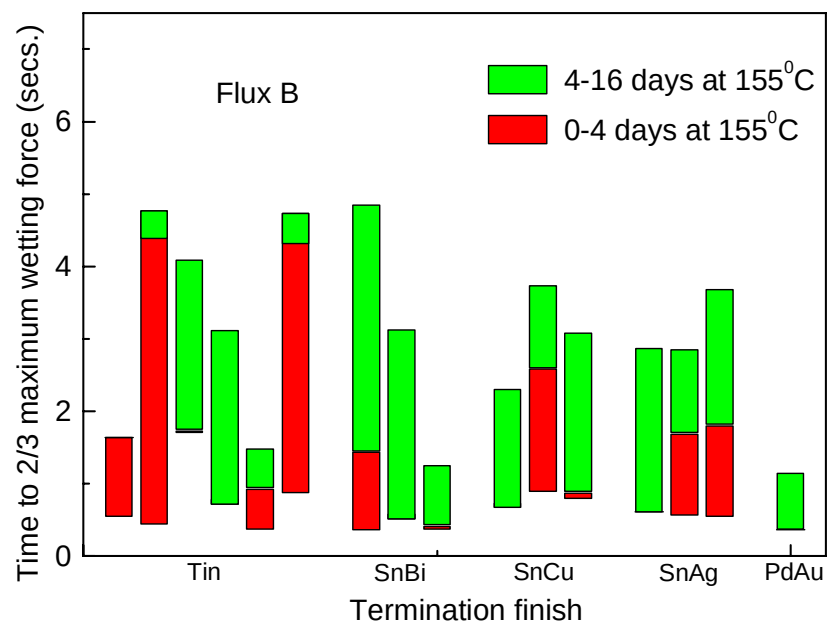


Figure 25. Wetting time for SAC and flux 'B'

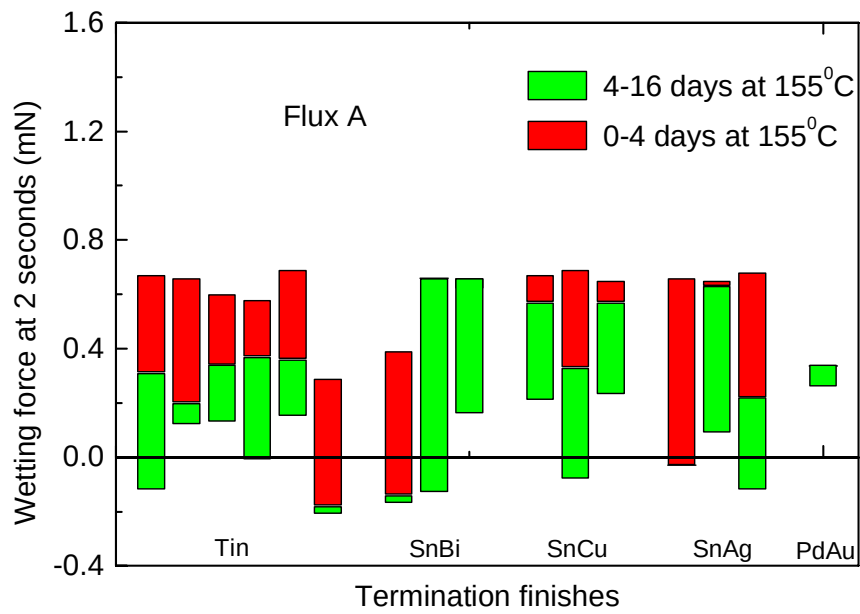


Figure 26. Wetting force for SnCu and flux 'A'

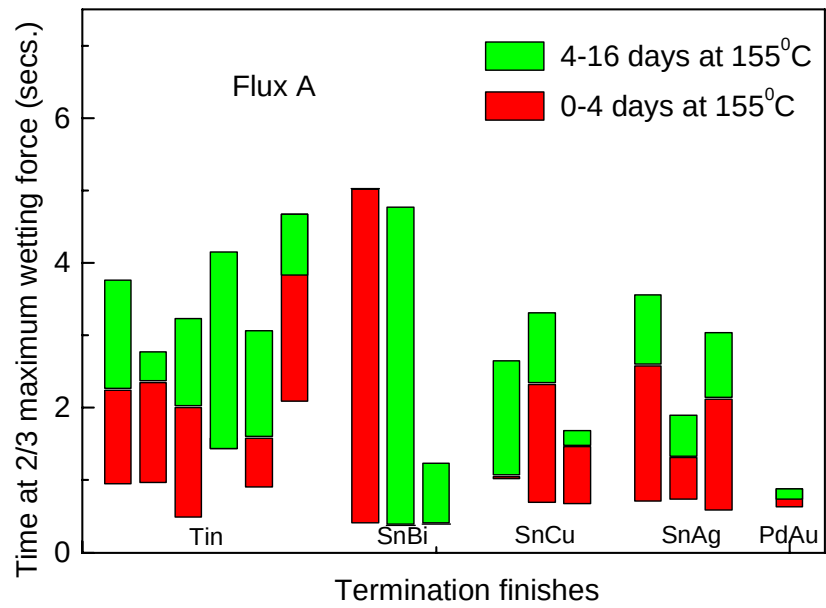


Figure 27. Wetting time for SnCu and flux 'A'

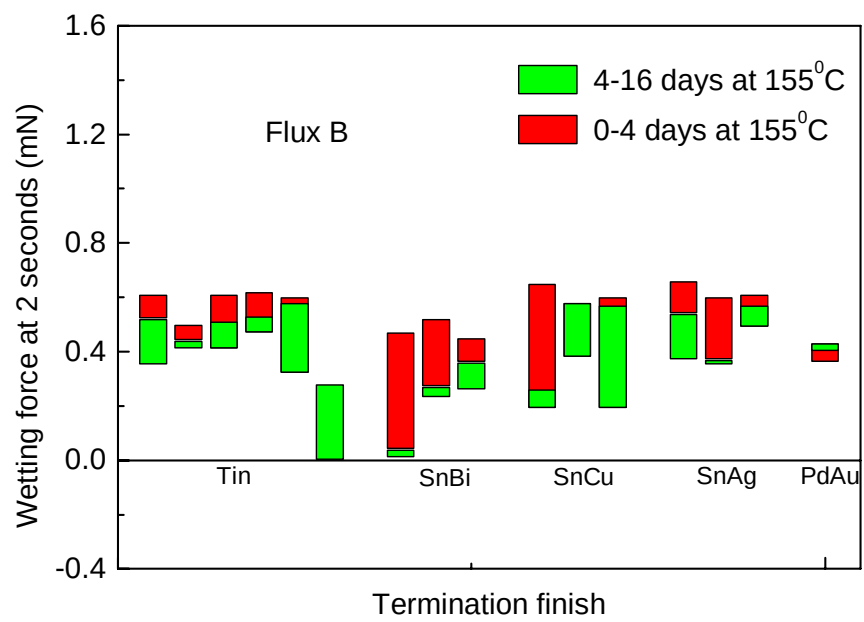


Figure 28. Wetting force for SnCu and flux 'B'

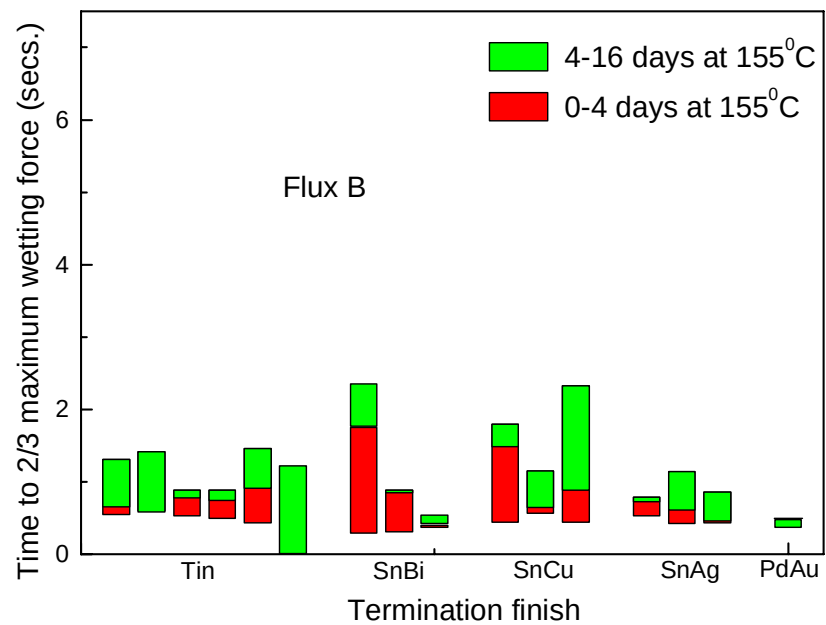


Figure 29. Wetting time for SnCu and flux 'B'

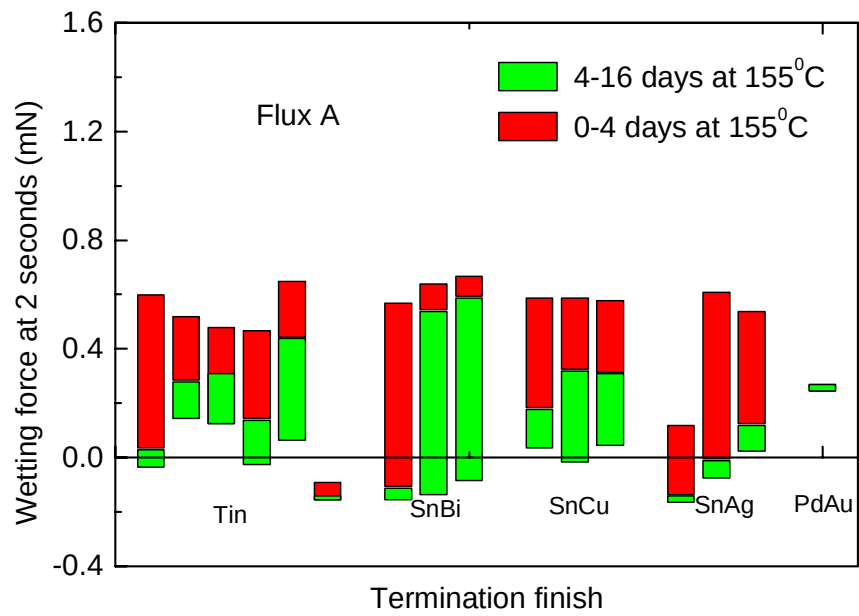


Figure 30. Wetting force for SnAgBi and flux 'A'

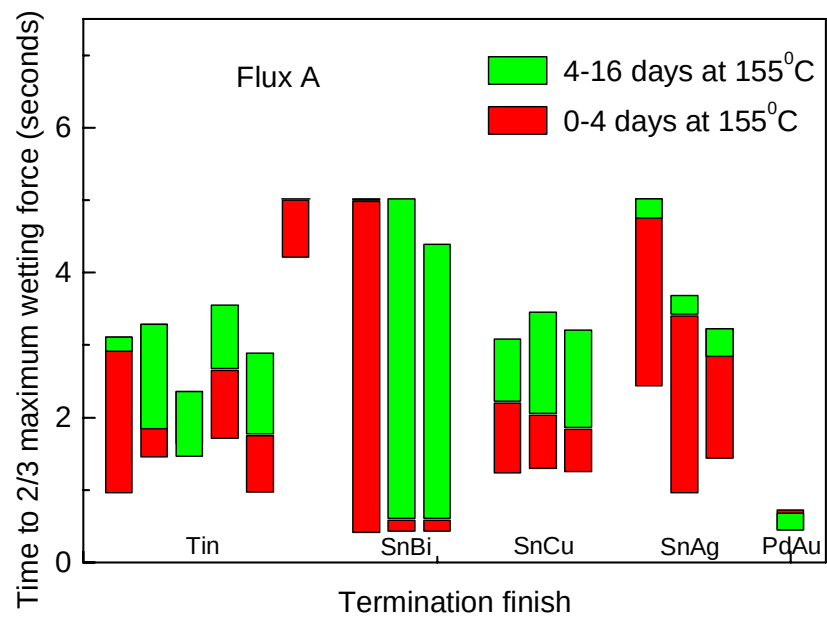


Figure 31. Wetting time for SnAgBi and flux 'A'

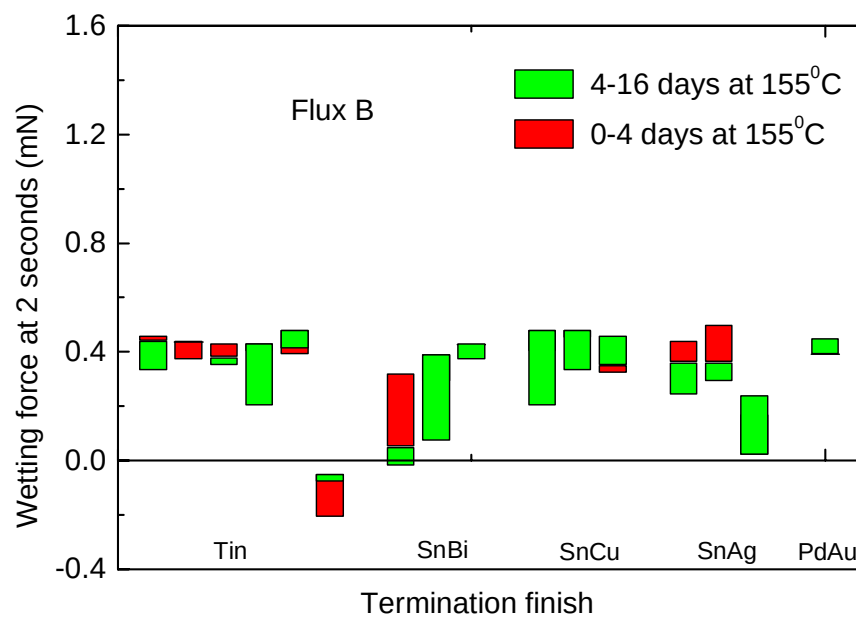


Figure 32. Wetting force for SnAgBi and flux 'B'

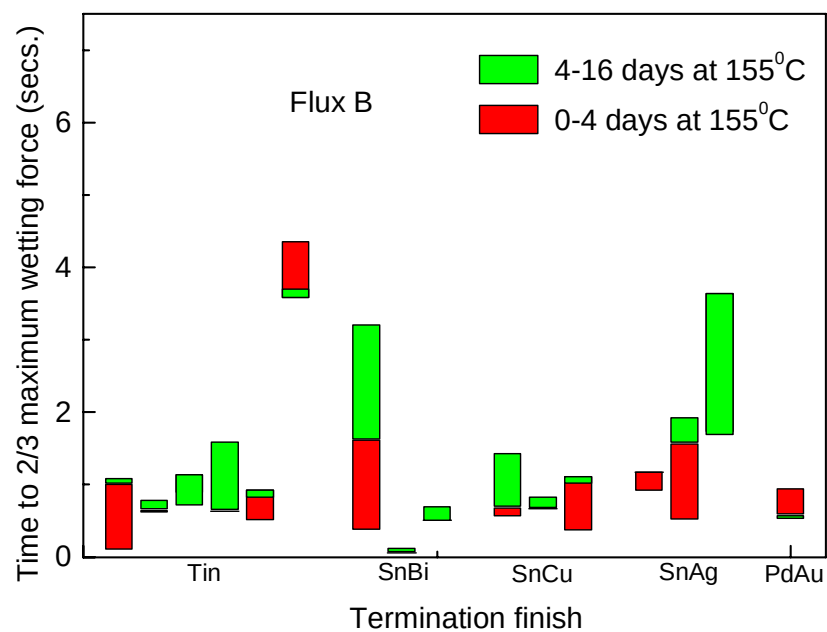


Figure 33 : Wetting time for SnAgBi and flux 'B'

The effect of flux performance with component ageing for all termination finishes and alloys is shown in Figure 34.

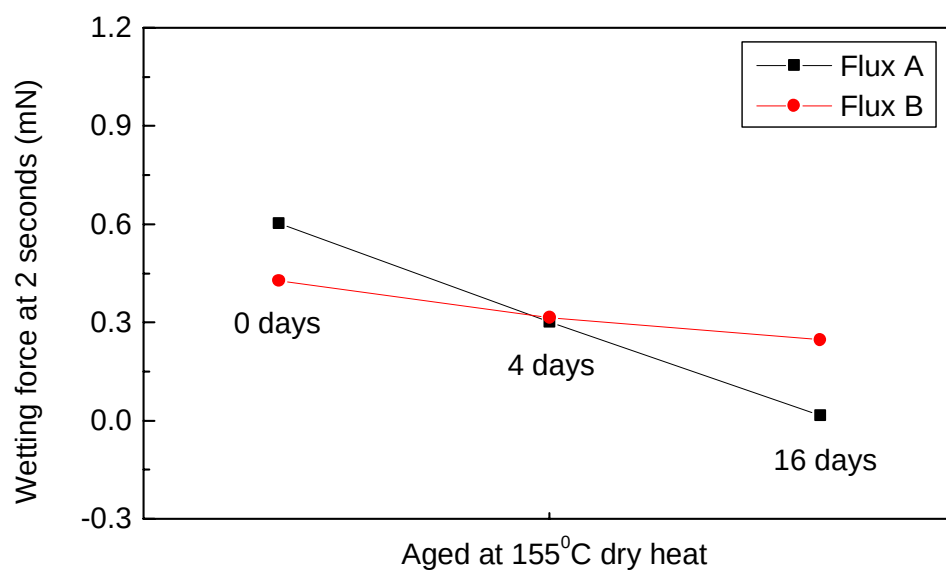


Figure 34. Flux performance with ageing

The effect of ageing on wetting force for all termination finishes as a function of alloy and flux is shown in Figure 35.

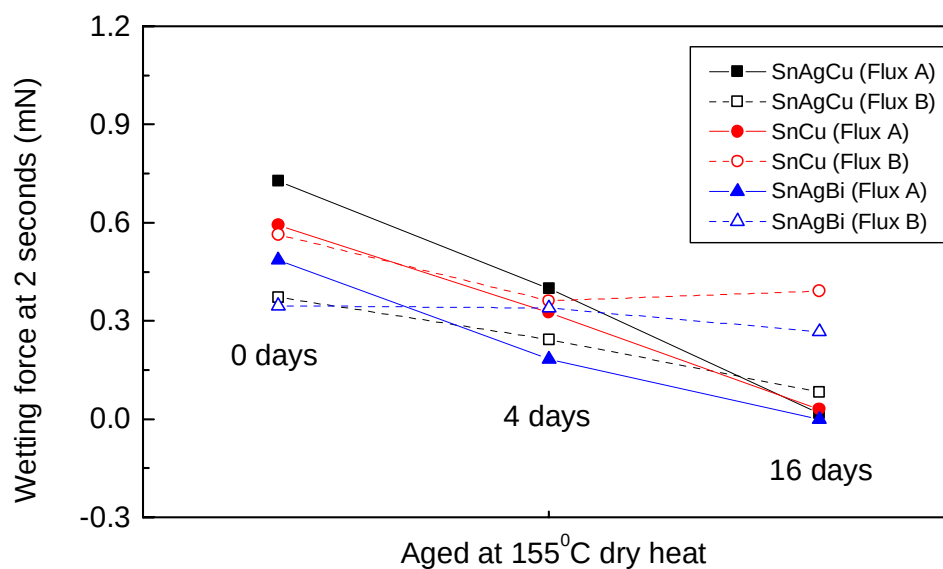


Figure 35. Effect of ageing on all termination finishes

The effect of ageing on wetting force for each alloy as a function of termination finish and flux is shown in Figures 36 – 38.

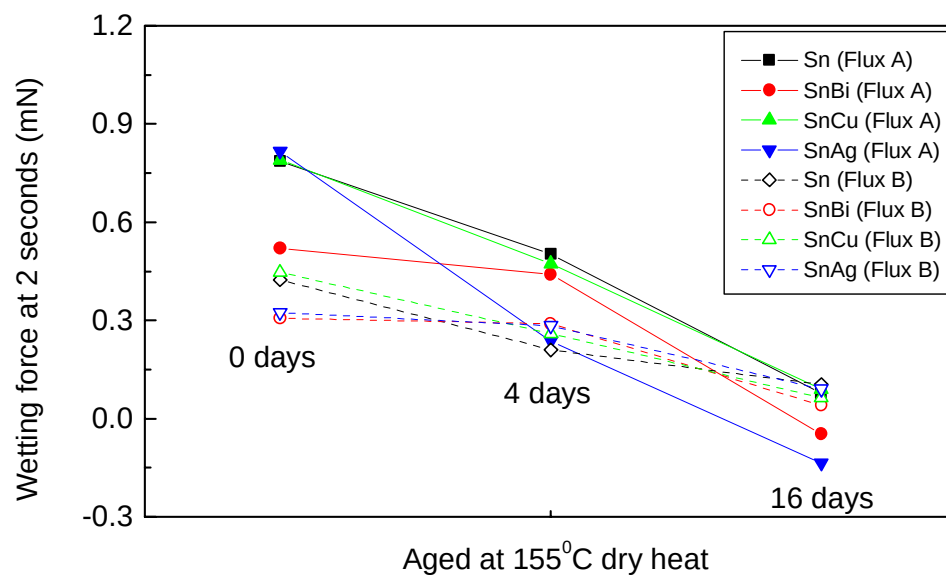


Figure 36. Effect of ageing when using SAC alloy

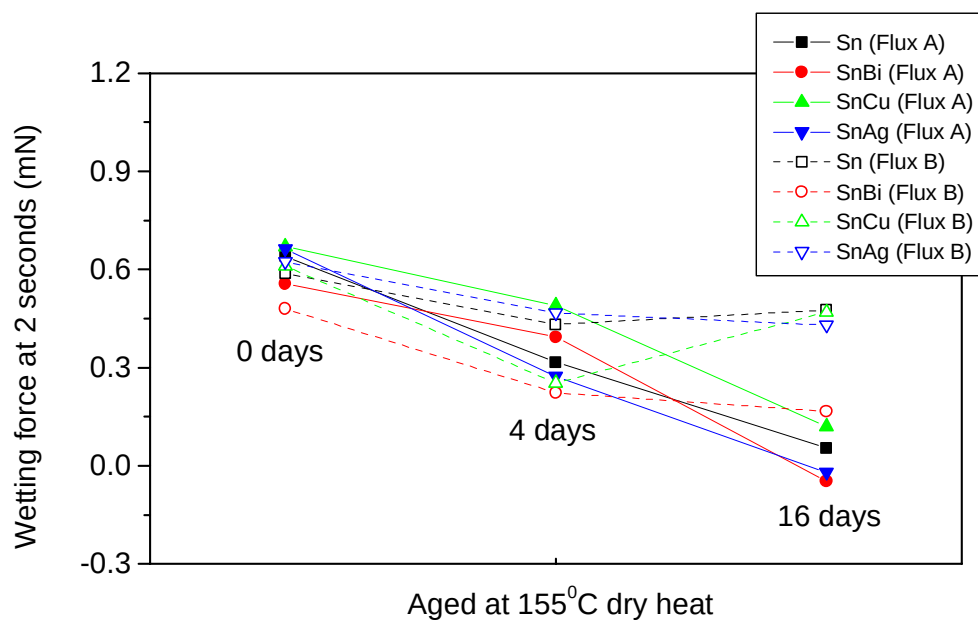


Figure 37. Effect of ageing when using SnCu alloy

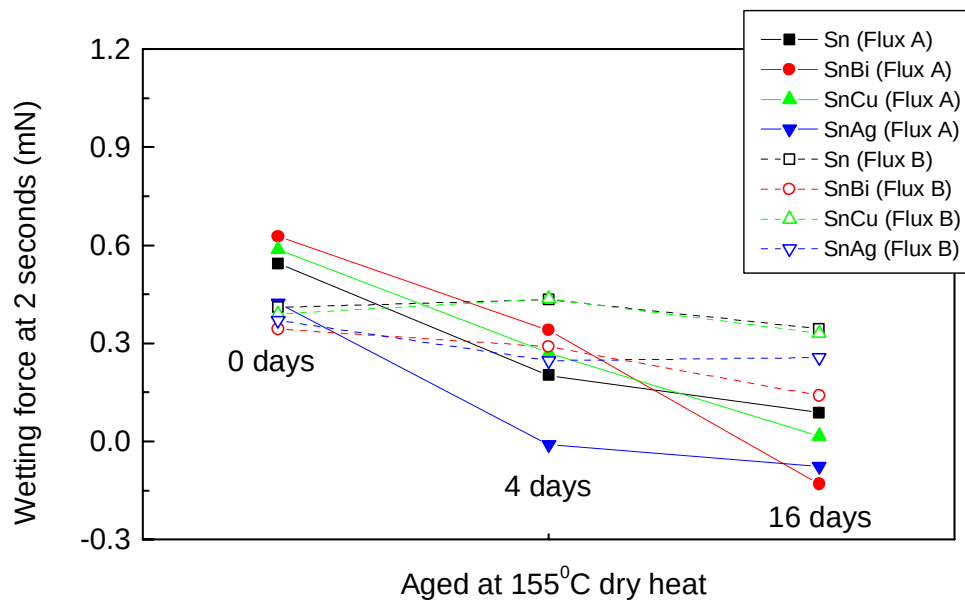


Figure 38. Effect of ageing when using SnAgBi alloy

The effect of ageing on wetting force for all alloys as a function of termination finish and flux is shown in Figure 39.

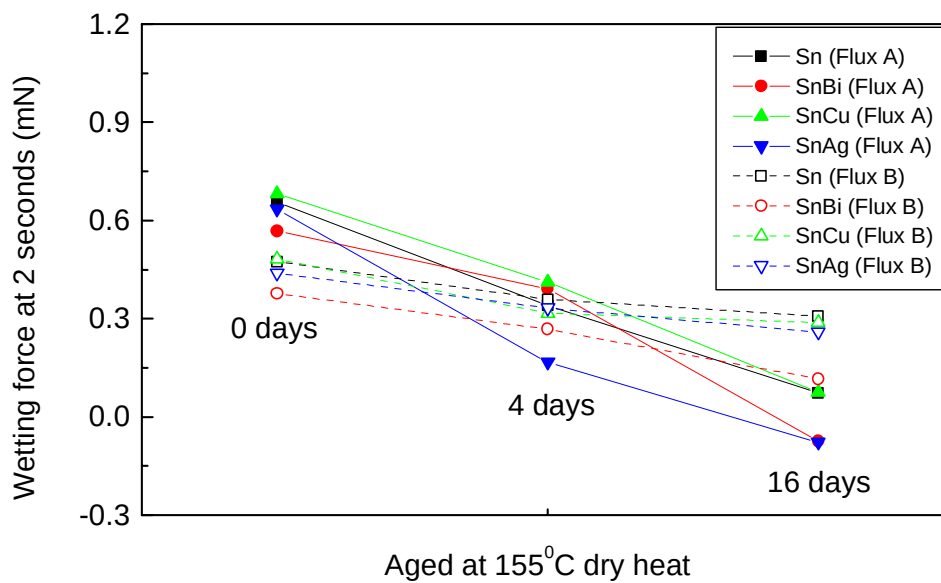


Figure 39. Effect of ageing of the individual finishes for all solder alloys and the two fluxes

The effect of ageing on PdAu finish as a function of alloy and flux is shown in Figure 40.

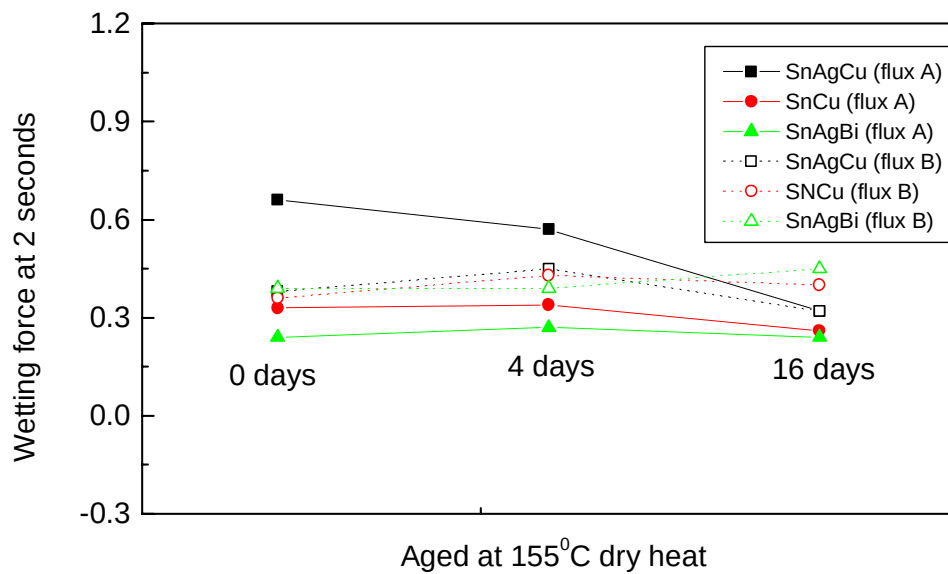


Figure 40. Effect of ageing on PdAu finish

5.2 DISCUSSION OF SOLDERABILITY RESULTS

The results from Figures 22-33 show that the wetting forces for the as received (unaged) components are similar for all finishes when using any one flux (either A or B). Good solderability is apparent for any finish/alloy combination on unaged components for both fluxes. When using flux 'A', the wetting forces of the unaged components are higher by approximately 0.2 mN compared to flux 'B'. After four days ageing, the wetting forces are similar for both fluxes. The solderability with Flux 'B' only shows a small decrease with ageing, with the wetting forces still acceptable after 16 days ageing. However, when using flux 'A', although the initial solderability on the unaged components was better than for flux 'B', the solderability deteriorates and is unacceptable after 16 days ageing. This is shown clearly in Figure 34.

The results in Figure 35 consider the effect of the solder alloy averaged over all the surface finishes, but for the two fluxes. The effect of the two fluxes is still apparent in these results. The effect of the alloys is more confused. With Flux A the SAC alloy is clearly the best, but with Flux B the SAC performs the poorest and SnCu is the best.

Figures 36-39 show the effect of the solder alloy is shown for the surface finishes and again for the two fluxes. The results show that with Flux B there was a similar response from all three alloys and no strong effect from ageing. With Flux A there was a significant influence of ageing, and the SAC alloy performed slightly better than the other two alloys. From these figures there does not appear to be any difference between the surface-finishes. This is summarised in Figure 40 where all the solder alloys are averaged. There is a suggestion that the SnAg did not perform as well as the others and the pure tin was slightly better, but really they are all very similar.

The results from Figure 40 show that there is little change in solderability for the PdAu finish with ageing. In general, as before, flux 'B' gives more consistent results with little difference observed between the solder alloys. The solderability of the SAC alloy with flux 'A' is noticeably better compared to the other two alloys, except after 16 days aging.

6 MOISTURE INGRESSION MEASUREMENTS

6.1 MOISTURE INGRESSION MEASUREMENT PROCEDURE

Components manufactured from the 16 lead-free finishes were assessed for moisture ingress using weight gain measurements. The components were dried at 125⁰ C for 24 hours, and weighed. The dried components were placed in an humidity chamber at 40⁰ C/93% for 24 hours, and weighed again.

6.2 MOISTURE INGRESSION MEASUREMENT RESULTS

Increase in mass for each component termination finish, as a % increase in weight, is shown in Figure 41. Finishes 1-15 had a mean weight increase of 0.135 % $\pm$ 0.015% compared to only 0.080% for finish 16.

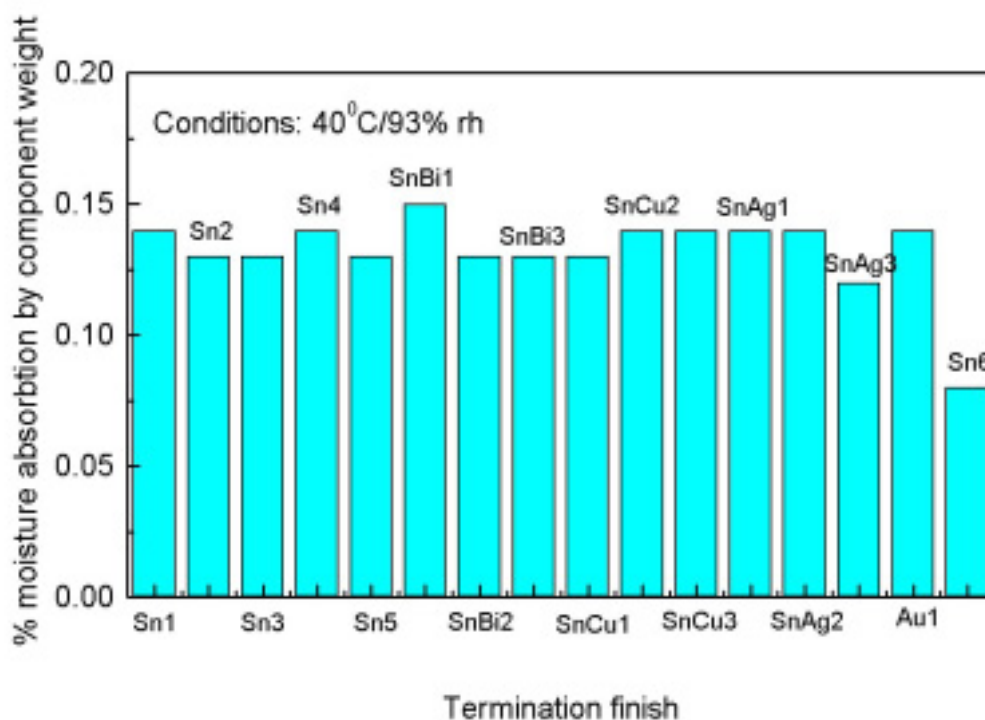


Figure 41. Weight gain (%) for 16 finishes components

6.3 DISCUSSION OF MOISTURE INGRESSION RESULTS

The results show that there is very little difference in weight gain as a result of moisture ingress between finishes 1-15. Finish Sn6 was encapsulated by an alternative

manufacturer and had a smaller weight gain than the other finishes. This suggests that the dominating issue in moisture take-up with these samples was the encapsulating resin used, rather than the lead finish.

7 PROCESS YIELD MEASUREMENT

7.1 PROCESS YIELD MEASUREMENT PROCEDURE :

Samples were made to demonstrate the suitability of the various plated component lead finishes when applied to a standard assembly process. These were manufactured by Matra BAe using their normal single sided surface mount (SM) assembly process. The test assembly utilised a simple single sided FR4, 80mm x 80mm printed circuit board (PCB) with an immersion gold on an electroless nickel finish and photo-imaged solder resist. This is shown in Figure 42. Each assembly contained 25 components of a single leadframe finish. Twenty assemblies were manufactured for each leadframe finish.

The manufacturing process utilised a Tin/Silver/Copper (SAC) solder paste printed through a 150 micron chemically etched stainless steel stencil. The components were autoplaced and reflowed through the same profile in a nitrogen atmosphere. Maximum reflow temperature was 234°C and the maximum molten solder time (time above 217 °C) was 37 secs. The profile is shown in Figure 43.

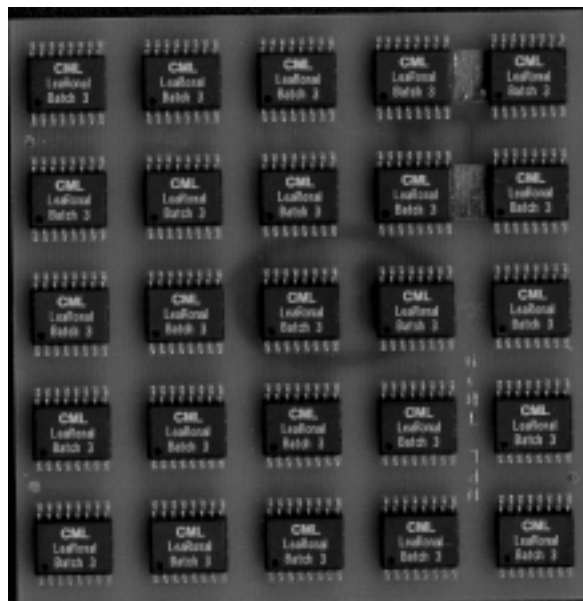


Figure 42 : Process Yield Test Assembly

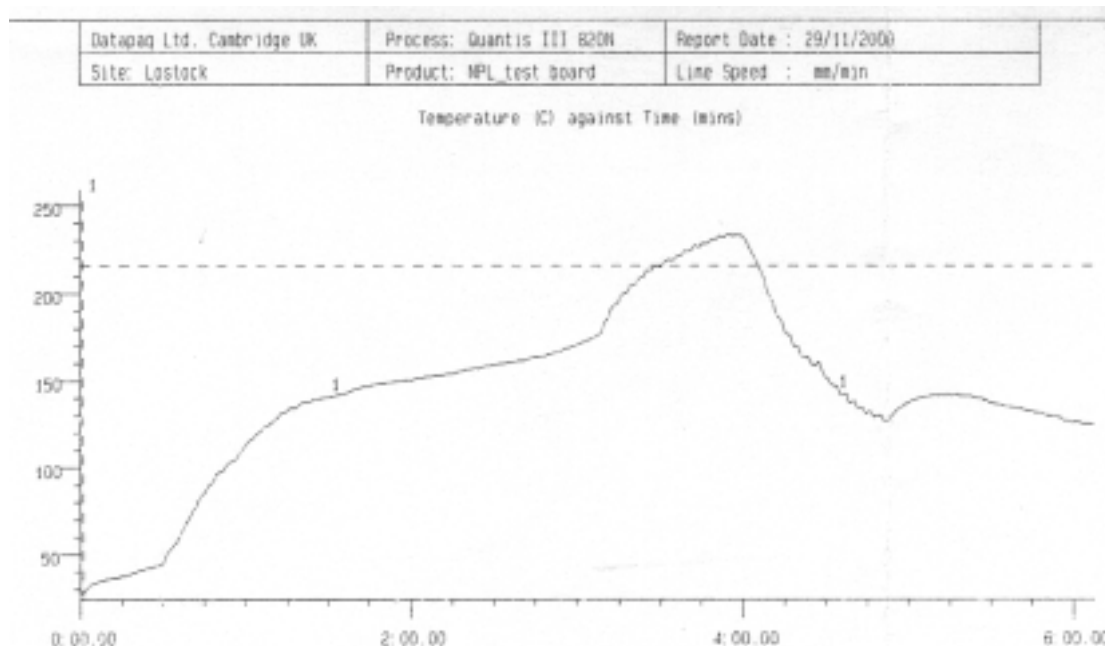


Figure 43 : SAC reflow profile used

After assembly, the resulting solder joints were visually inspected 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 based on the scoring system shown in Figure 44. Using the IPC visual inspection guidelines (reference 2), a joint failure would be scored below a 2 on this scoring system. There were insufficient samples available for finish Sn3 for process yield measurement to be undertaken.

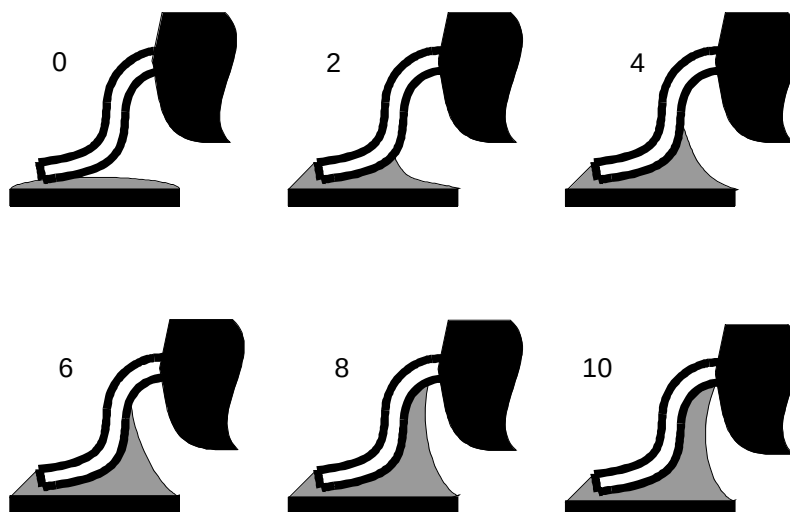


Figure 44 : Schematic representation of solder joint scores used in visual inspection

7.2 PROCESS YIELD RESULTS :

The range of joint scores recorded for each of the lead-free finishes are shown in Figures 45 to 58.

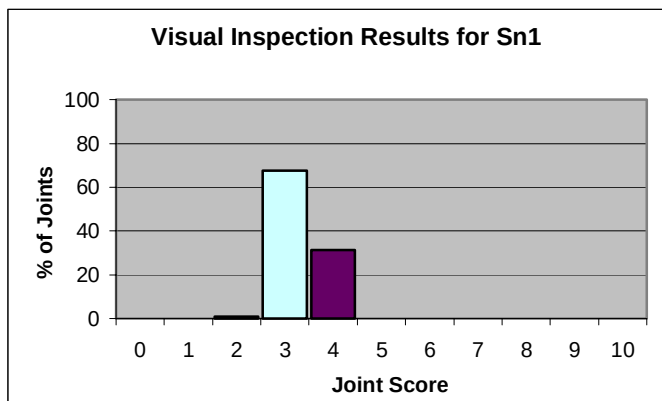


Figure 45 : Joint scores for finish Sn1

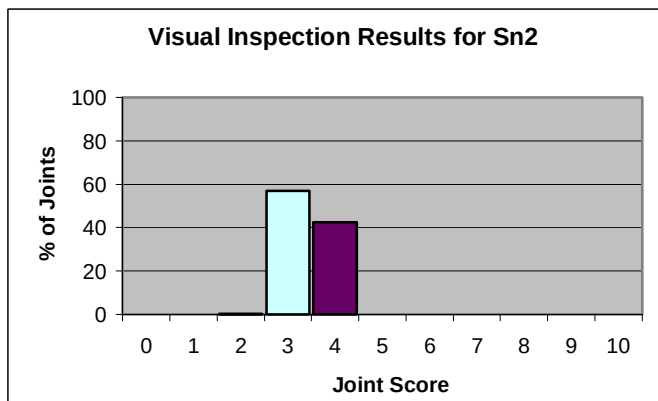


Figure 46 : Joint scores for finish Sn2

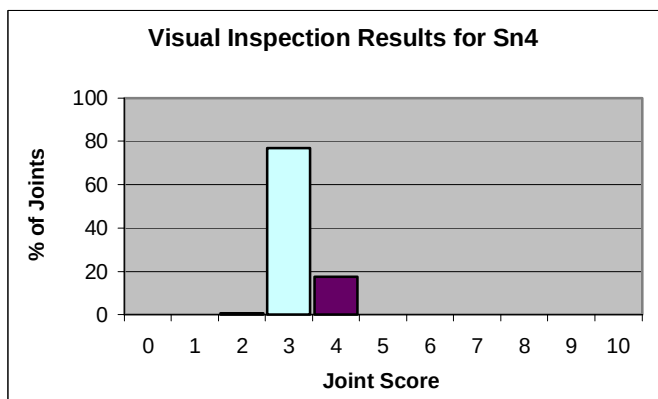


Figure 47 : Joint scores for finish Sn4

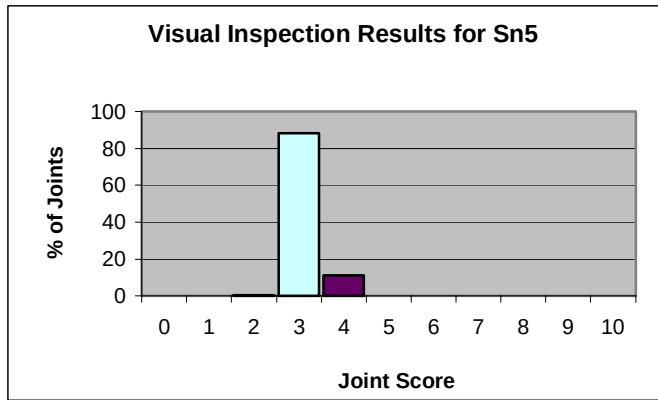


Figure 48 : Joint scores for finish Sn5

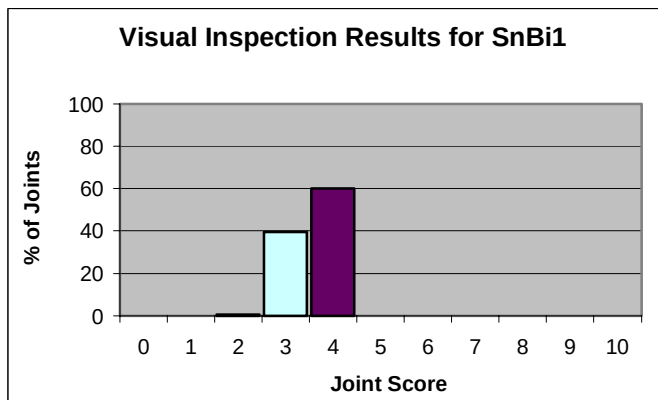


Figure 49 : Joint scores for finish SnBi1

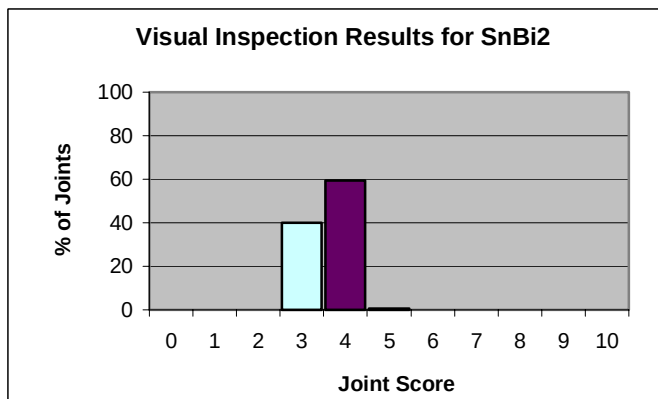


Figure 50 : Joint scores for finish SnBi2

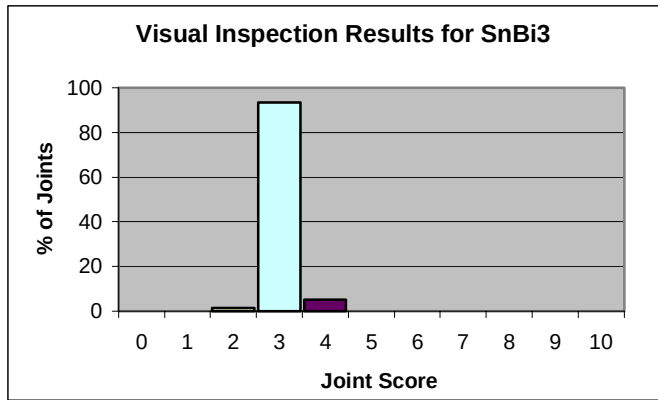


Figure 51 : Joint scores for finish SnBi3

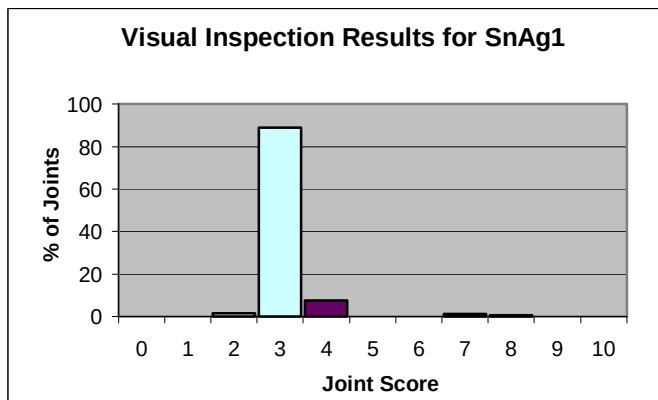


Figure 52 : Joint scores for finish SnAg1

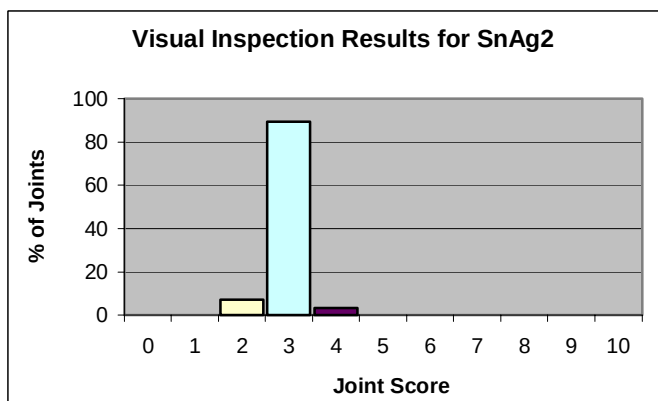


Figure 53 : Joint scores for finish SnAg2

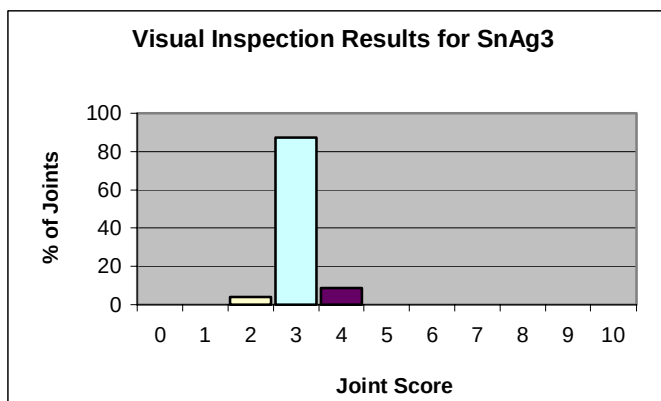


Figure 54 : Joint scores for finish SnAg3

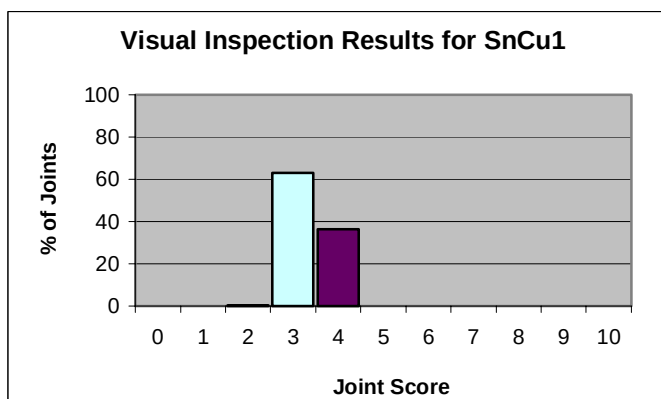


Figure 55 : Joint scores for finish SnCu1

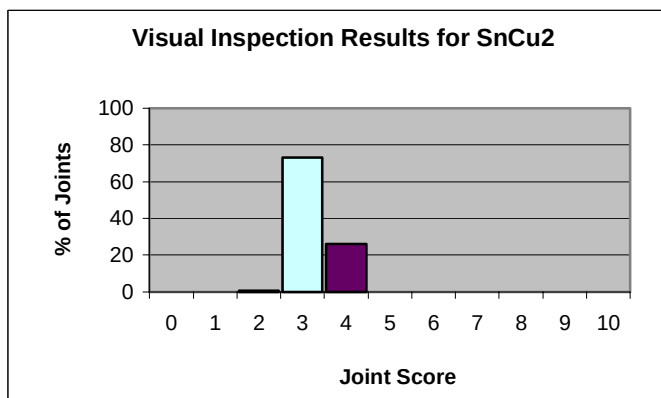


Figure 56 : Joint scores for finish SnCu2

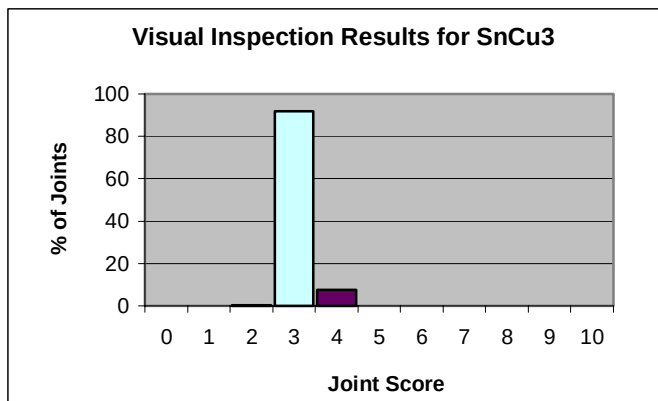


Figure 57 : Joint scores for finish SnCu3

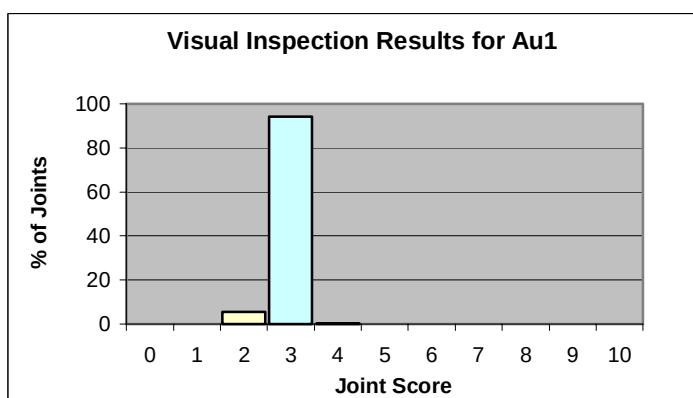


Figure 58 : Joint scores for finish Au1

7.3 DISCUSSION OF PROCESS YIELD RESULTS :

In total, only two joints failed visual inspection out of 28,000 inspected. This low incidence of failures makes meaningful calculations of parts-per-million defect rates for individual finishes impossible. For all the finishes a combined defect rate of approximately 70ppm was achieved. Figures 59 to 63 show typical solder joints for each of the finishes.

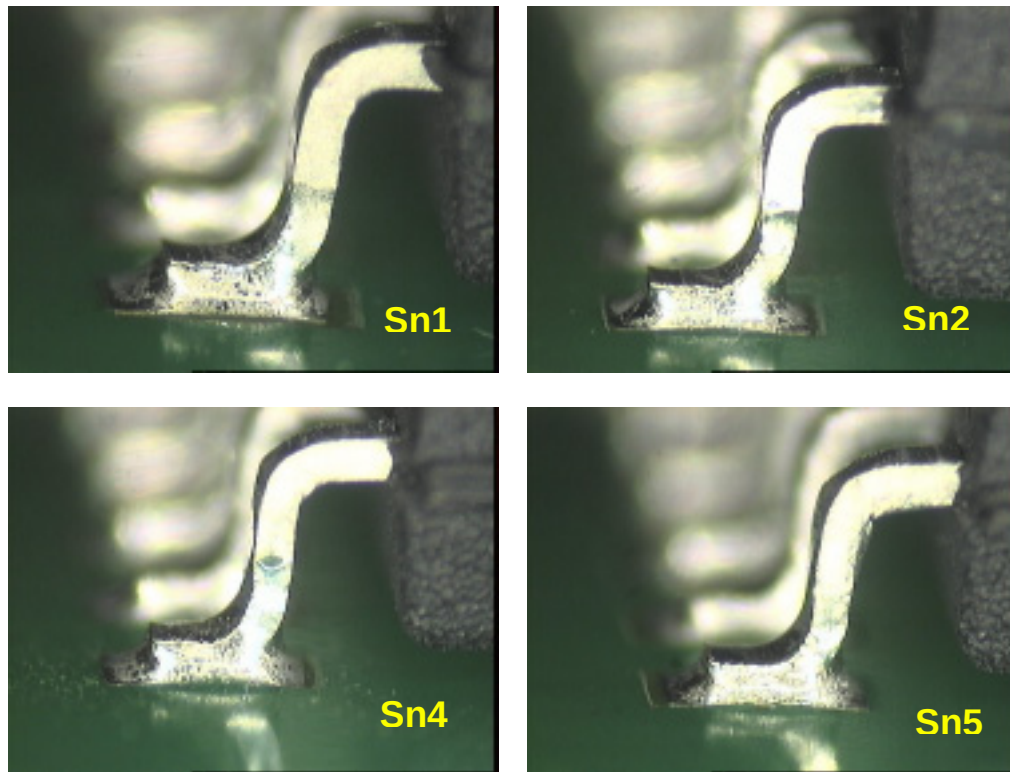


Figure 59 : Typical Joints for the Four Sn Finishes

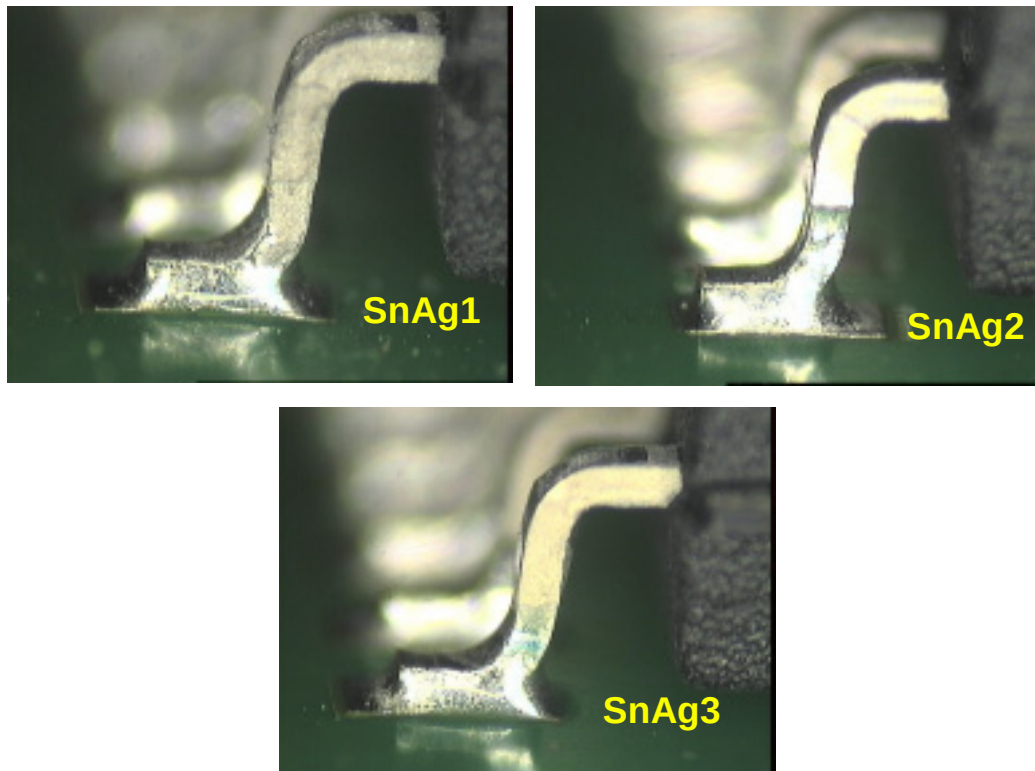


Figure 60 : Typical Joints for the Three SnAg Finishes

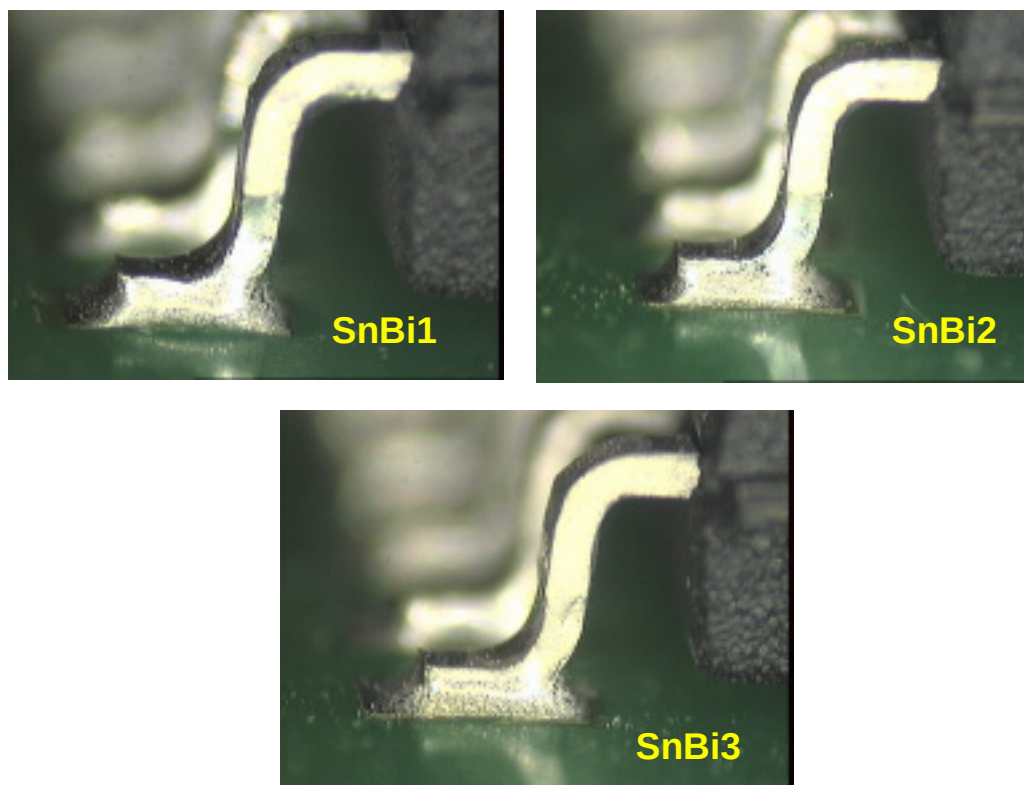


Figure 61 : Typical Joints for the Three SnBi Finishes

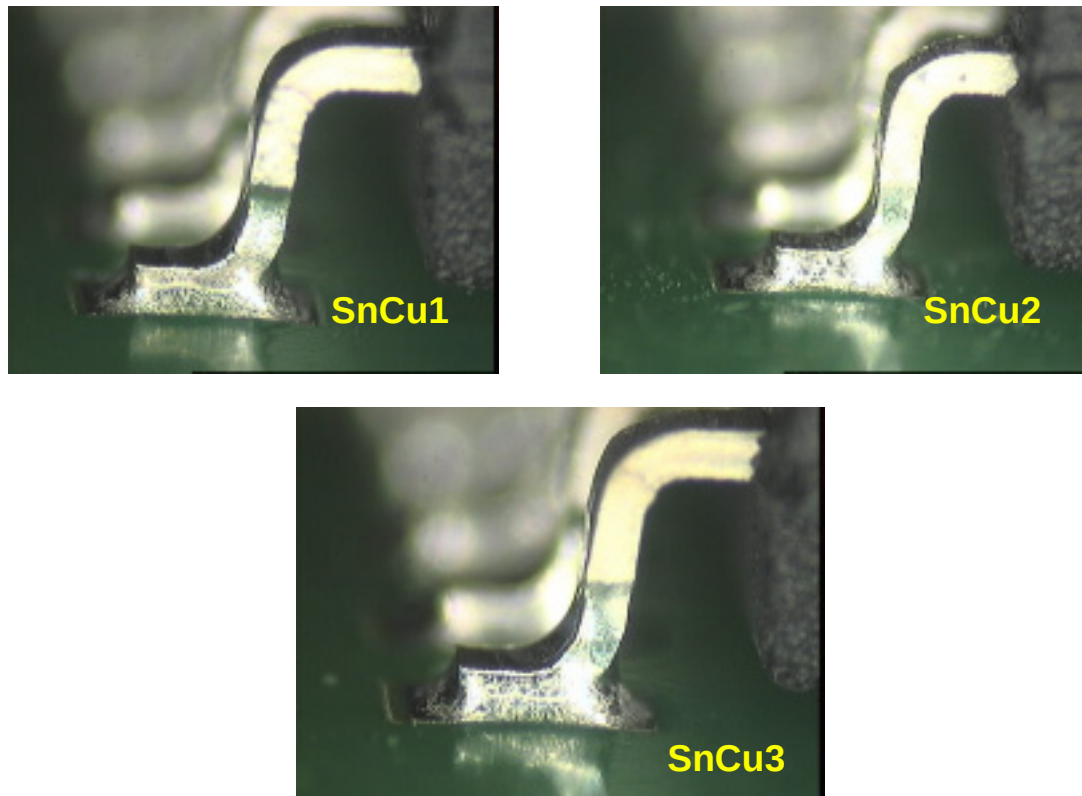


Figure 62 : Typical Joints for the Three SnCu Finishes

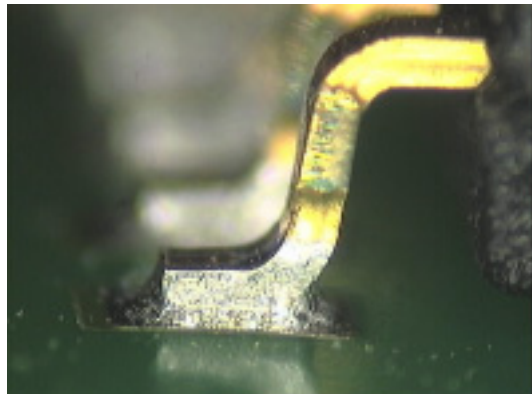


Figure 63 : Typical Joint for Au1 Finish

All finishes provided acceptable process yield with this assembly process. Comparisons of results for each alloy type are shown in Figures 64 to 67. A comparison of all lead-free finishes is shown in Figure 68. All the finishes exhibited similar average visual inspection scores, all above the minimum acceptable score of 2.

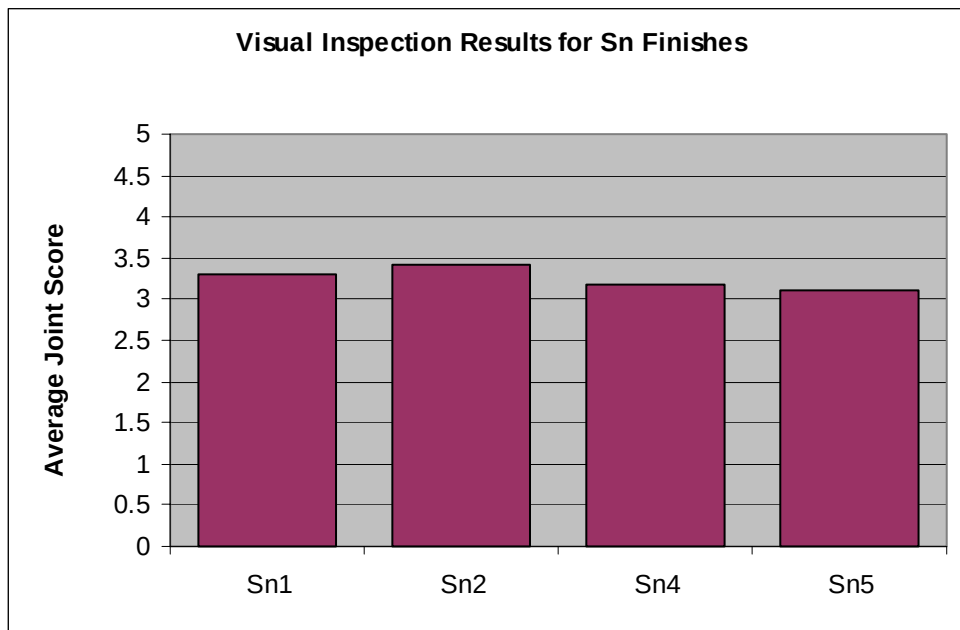


Figure 64 : Comparison of Average Scores for Sn Finishes

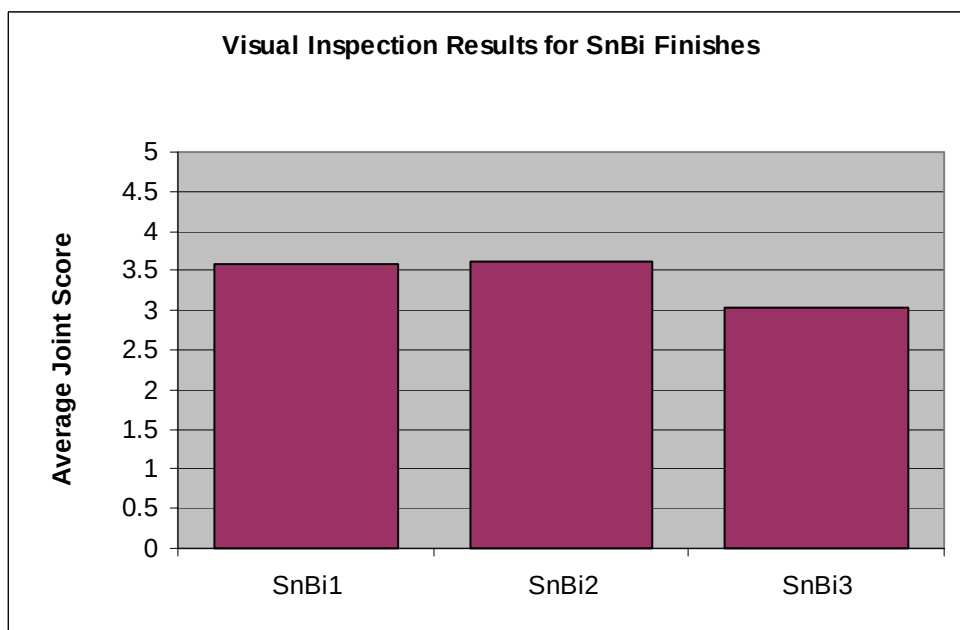


Figure 65 : Comparison of Average Scores for SnBi Finishes

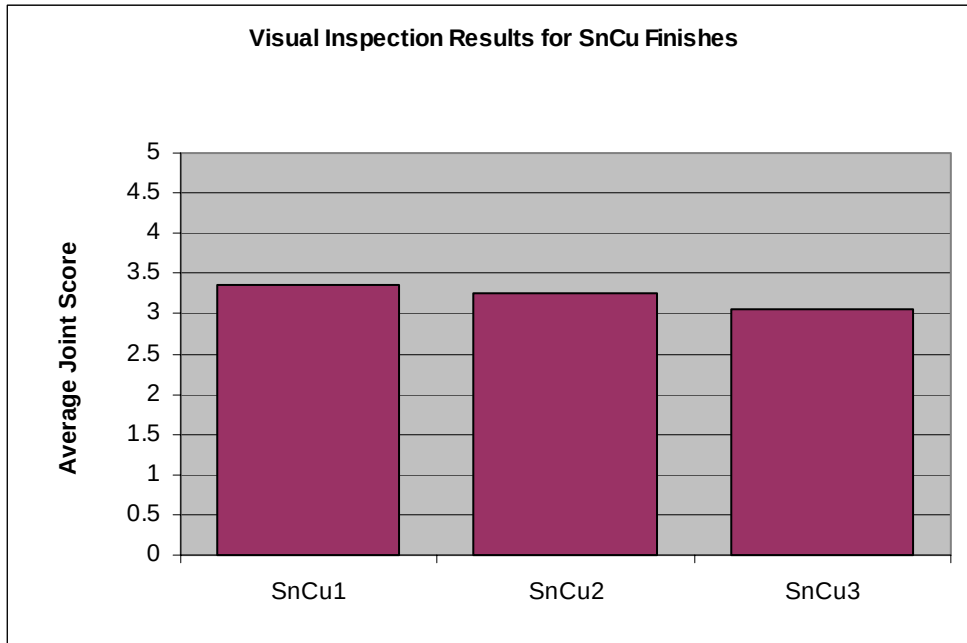


Figure 66 : Comparison of Average Scores for SnCu Finishes

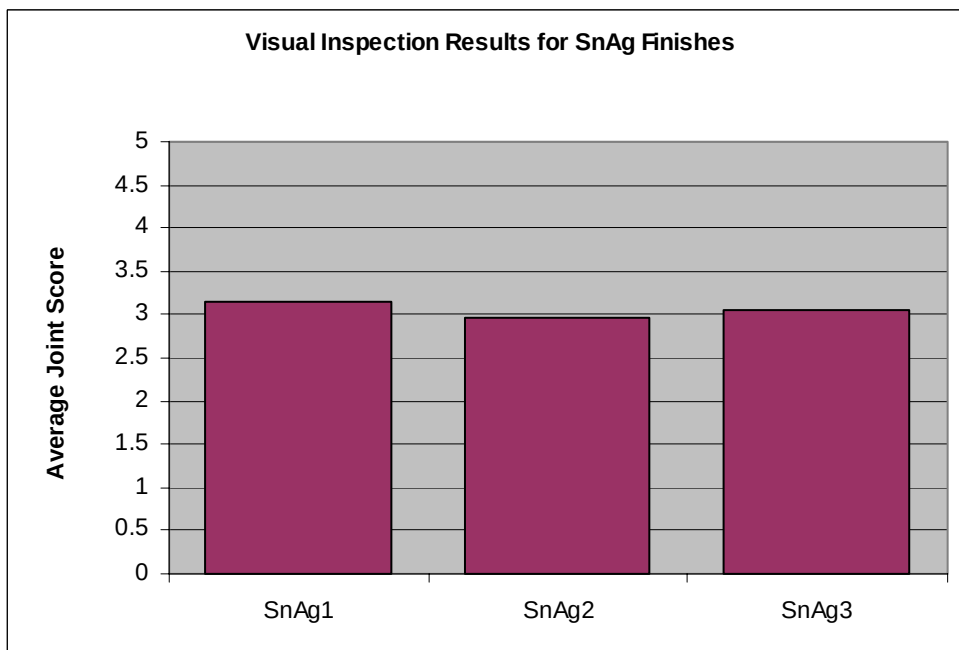


Figure 67 : Comparison of Average Scores for SnAg Finishes

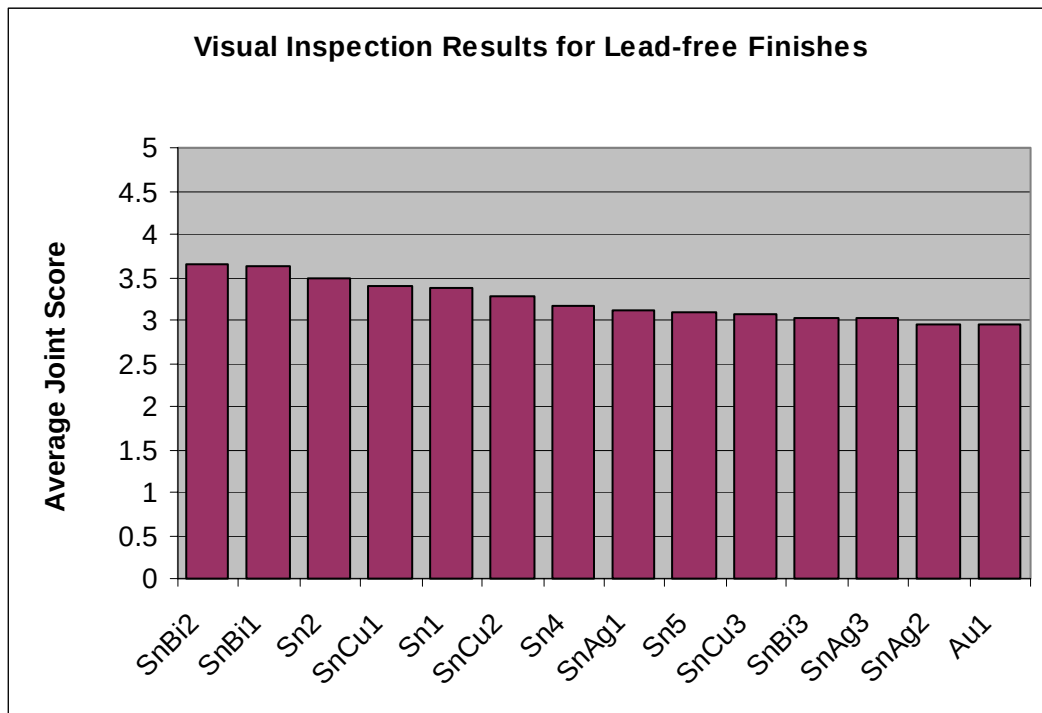


Figure 68 : Comparison of Average Scores For All Finishes

Figure 68 shows a comparison of the average joint inspection scores for each finish. Whilst there is very little difference between the finishes, and it should be noted that visual inspection is a subjective process, some conclusions can be drawn. Two of the three SnBi finishes give the highest two scores. The Sn finishes generally appear in the top half of the results, whilst the SnAg finishes appear in the lower half of the results. SnCu results are spread evenly. It should be noted that these results represent a snapshot of an individual reflow process. Using a different paste or reflow process could significantly alter the order of the results.



Figure 69: Example of SnAg1 solder joint where plating has reflowed

For the vast majority of the solder joints, the plated lead finish did not reflow during the soldering operation. However, for a small number of the SnAg1 components, reflow of the plating did occur and this led to a significantly higher visual inspection score in the region of 7 or 8 instead of 3 or 4 for these individual joints. An example of such a joint is shown in

Figure 69. Increasing the maximum temperature of the reflow profile may result in a greater degree of reflow in the plated terminations, resulting in a higher average visual inspection score and a possible higher process yield. However, higher reflow temperature may result in reliability problems with temperature sensitive components. With the plating on the brink of reflowing or not, this may produce some unforeseen effects influencing process yield.

8 TIN WHISKER PROPENSITY MEASUREMENT

8.1 INTRODUCTION

Post plated and preplated components with all finishes were evaluated for tin whisker growth. The lead frame salvage from the final crop operation were also evaluated (Figure 70). The components and lead frame salvage were subjected to various different environments at different time intervals to ascertain the conditions that were necessary to initialise tin whisker formation and sustain growth. Once the optimum temperature and humidity condition was found, this was used to characterise and benchmark whisker susceptibility.

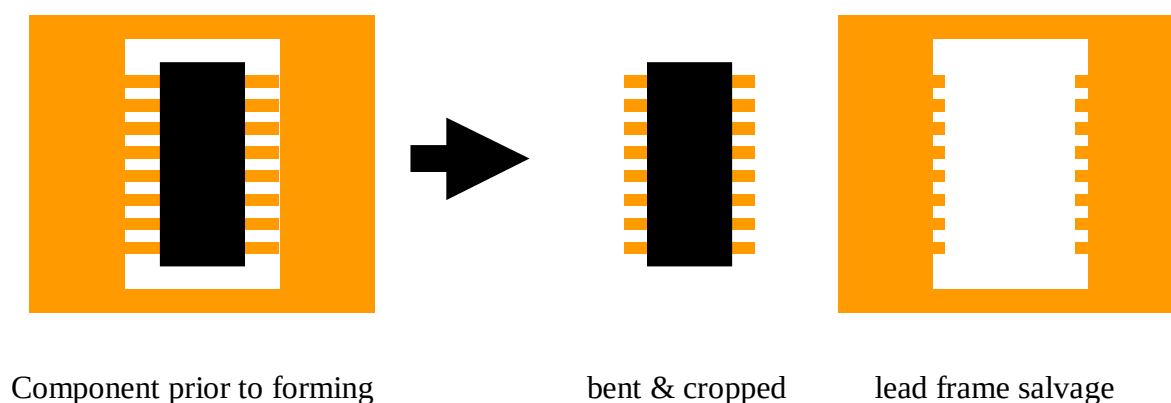


Figure 70 : Component bend and crop operation

8.2 TIN WHISKER PROPENSITY MEASUREMENT PROCEDURE FOR BRASS LEADFRAMES

In the first phase of the experiment a redundant Sn chemistry was used on brass leadframes. Three types of plating were investigated and designated SnABrass, SnBBrass and SnCBBrass. SnBBrass and SnCBBrass were the same chemistry, but SnCBBrass has a nickel barrier layer on the brass. These samples were subjected to 28 days of ageing at the following conditions:

- 1) 85°C/85%RH
- 2) 40°C/95%RH
- 3) 50°C/95%RH
- 4) 50°C dry.

After ageing the encapsulated leadframes were mounted onto stubs and examined for whiskers using a SEM. The whisker density was recorded as a ranking from 0 to 5, and defined over an area of 150 by 150 μ m, the ranking is defined in Table 1.

Table 1: Whisker density definition

Ranking	0	1	2	3	4	5
Number	0	1 to 4	5 to 8	9 to 11	12 to 15	>15

The size of whiskers was also recorded with a ranking from 0 to 3, these are defined in Table 2.

Table 2: Whisker size

Ranking	0	1	2	3
Size (μ m)	0	< 15	15 to 30	> 30

The type of whisker was also recorded and characterised as follows: straight, hooked, spiral, columnar or nodular.

8.3 TIN WHISKER PROPENSITY MEASUREMENT RESULTS FOR BRASS LEADFRAMES

The brass leadframes were exposed to the four environmental conditions detailed above. Whiskers were produced with all the conditions specified above to varying degrees. Table 2 contains all the details.

Table 3. This table contains all the whiskering details of the leadframes used.

Condition	Plating Type	Nickel Barrier	Whisker		
			Type	Size	Density
85°C/ 85%RH	SnABrass		Columnar	1	2
	SnBBrass		Kinked	2	2
	SnCBrass	✓	None	0	0
40°C/ 95%RH	SnABrass		Straight	1	1
	SnBBrass		Hooked	2	3
	SnCBrass	✓	None	0	0
50°C/ 85%RH	SnABrass		Columnar	2	3
	SnBBrass		Straight	3	5
	SnCBrass	✓	None	0	0
50°C	SnABrass		Hooked	1	1
	SnBBrass		Columnar	1	1
	SnCBrass	✓	None	0	0

Figures 71 to 73 are micrographs that show some examples of the whiskers that were found on the brass-plated leadframes. The optimum condition for whisker growth was 50°C/85%RH, and produced both the greatest density of whiskers and the largest size of whisker.

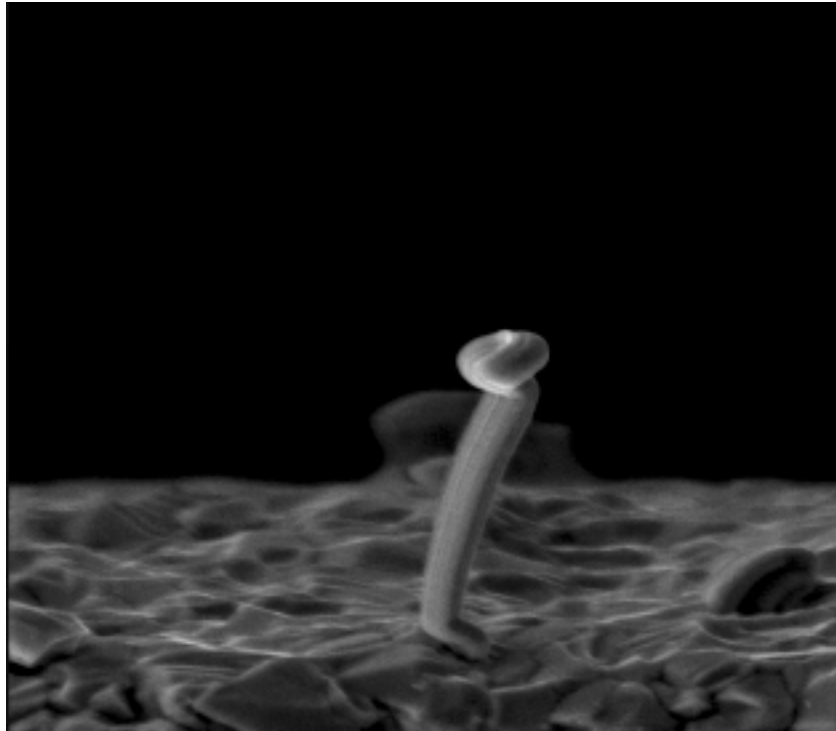


Figure 71. Tin whisker seen after 28 days, 40°C/95%RH on SnBBrass leadframe.

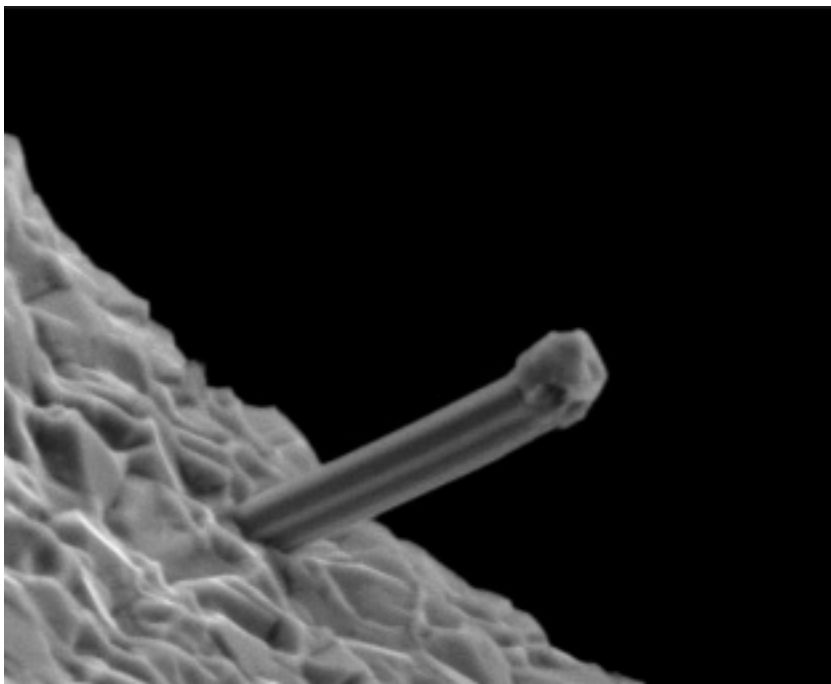


Figure 72. Tin whisker seen after 28 days, 40°C/95%RH on SnABrass leadframe.

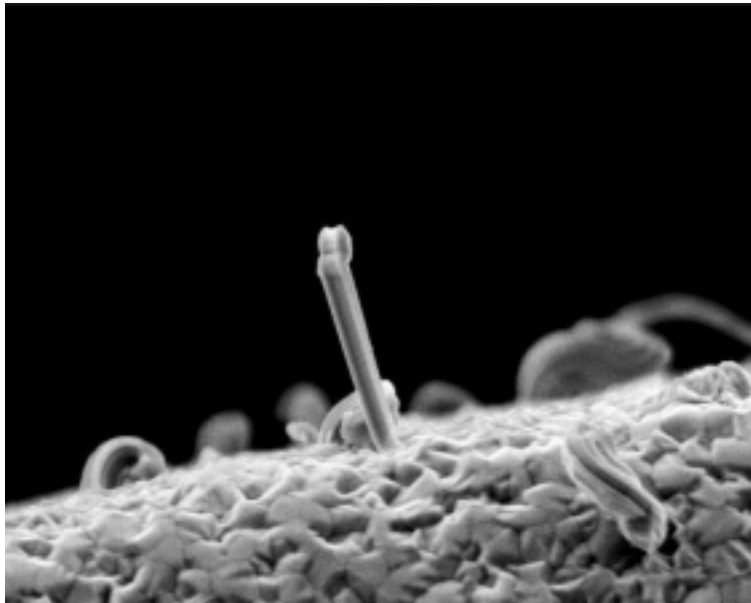


Figure 73. Tin whisker seen after 28 days, 50°C/85%RH on SnBBrass leadframe.

8.4 TIN WHISKER PROPENSITY MEASUREMENT PROCEDURE FOR COPPER LEADFRAMES

In this phase of the project both components and lead-frame salvage plated with all sixteen lead-free alternatives (Sn1, Sn2 etc..) were aged for a period of 56 days under the most favourable condition for whisker growth earlier i.e. 50°C/85%RH.

8.5 TIN WHISKER PROPENSITY MEASUREMENT RESULTS FOR COPPER LEADFRAMES

The whiskering test on the components did not produce any whiskers on any of the finishes. Some whiskers were found on the lead frame salvage, and the results are detailed in Table 4.

Table 4. Whiskering results for lead frame salvage and different plating finishes.

Sample Details	Whisker		
	Type	Size	Density
Sn1	None	0	0
Sn2 (redundant chemistry)	Straight	1	1
Sn3	None	0	0
Sn4	None	0	0
Sn5	None	0	0
Sn6	None	0	0
SnBi1	None	0	0
SnBi2	None	0	0
SnBi3	None	0	0
SnCu1	None	0	0
SnCu2	Straight	3	1
SnCu3	None	0	0
SnAg1	None	0	0
SnAg2	None	0	0
SnAg3	None	0	0
Au1	None	0	0

Figure's 74 and 75 illustrate whiskers that were found on two different plating types used on leadframes, Sn2 (redundant chemistry) and SnCu2.

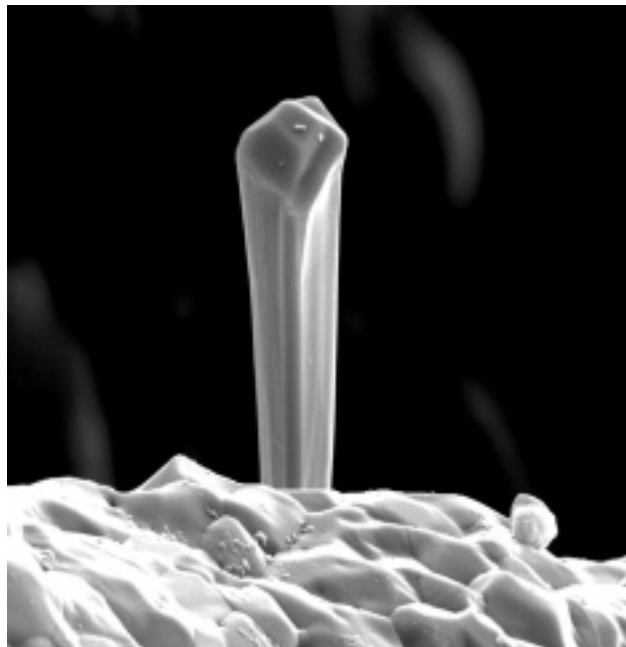


Figure 74. Sn2 leadframe tin whisker. (x4000), 7 um size.

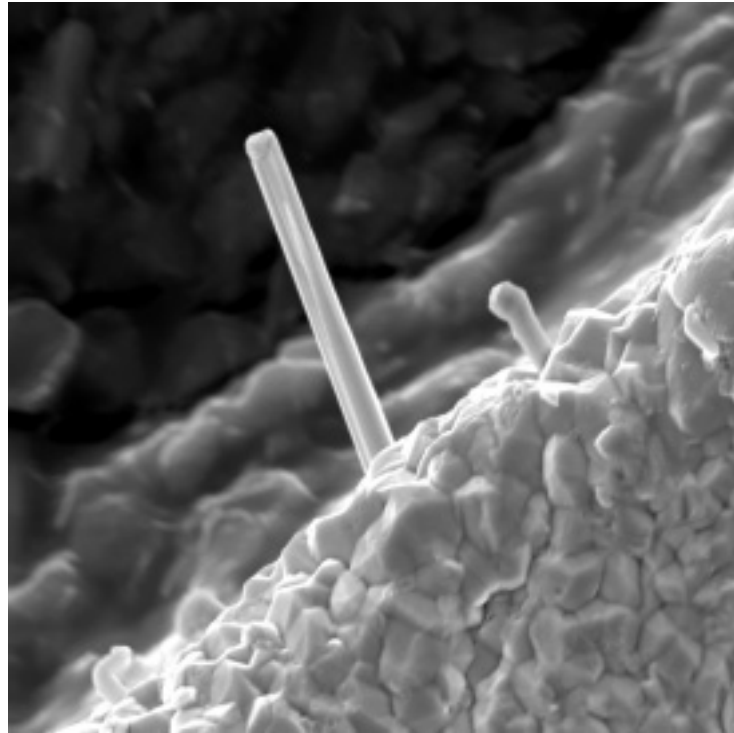


Figure 75. SnCu2 leadframe tin whisker. (x1500), 40 μm size.

8.6 TIN WHISKER PROPENSITY MEASUREMENT DISCUSSION

Initial trials showed that samples plated with redundant Sn chemistry on brass leadframes (SnA and SnB) had a propensity to whisker, with SnB producing larger whiskers that were more numerous in number. SnC samples produced no whiskering under any condition tried. This will be due to the presence of the nickel barrier layer inhibiting diffusion from the brass.

The second phase of the whisker propensity experiment showed that for all plating finishes used none had the propensity for whiskering/ nodular growth on components after accelerated ageing at 50°C/85%RH. However, when the lead-frame salvage were examined two finishes Sn2 and SnCu2, both produced a few (1 to 5) whiskers. The majority of these were found in the tooling holes of the frames, indicating that applied mechanical force had played a part in whisker formation. On Sn2 whiskers were typically 7 μm long, and on the SnCu2 the whiskers were up to 40 μm in length.

9 CONCLUSIONS :

The performance of four types of lead-free finishes has been evaluated and compared to a palladium gold alternative. These four types, Sn, SnAg, SnCu and SnBi were assessed for plating ductility, solderability, moisture ingress, process yield and tin whisker propensity. The PdAu finish was also assessed for wirebondability.

Generally, the lead-free finishes performed well. Inspection of the heel bend area revealed a number of finishes which exhibited cracking in the heel region. Previous projects have shown that this can adversely effect solder joint yield as the cracked area can have poor solderability

and inhibit the solder rise up the heel (ref 1). However, as can be seen from Figure 76, there appears to be no relationship between heel cracking and reduced joint scoring.

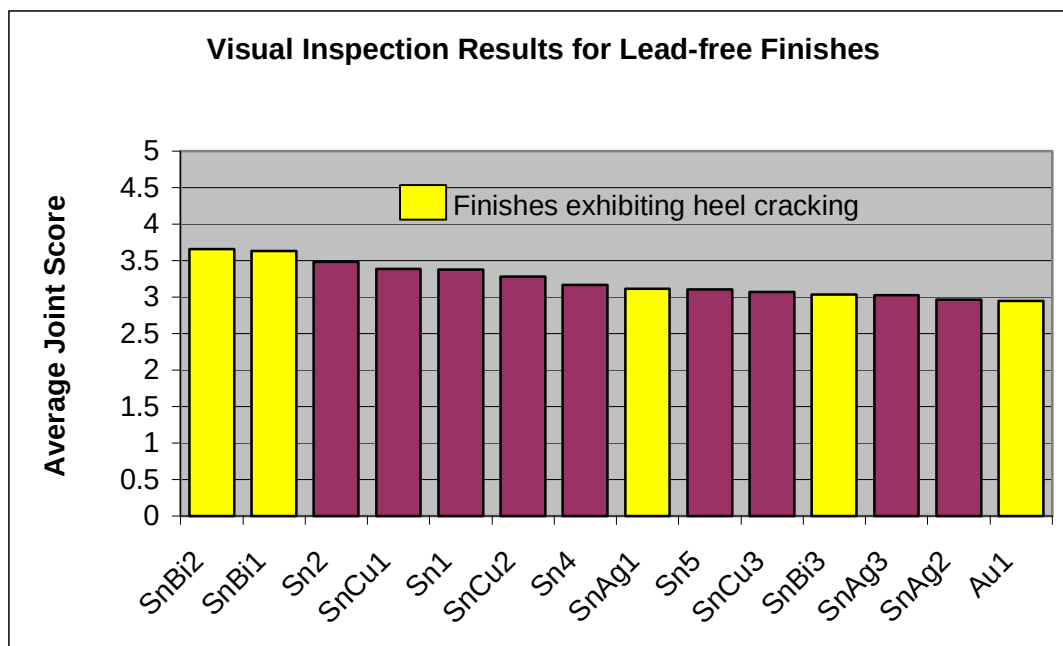


Figure 76 : Visual inspection results with those finishes exhibiting heel cracking highlighted

The solderability of the finishes was also measured with 2 different fluxes and 3 different lead-free alloys. All the finishes exhibited similar acceptable solderability with both fluxes in the as-received condition but solderability was better on aged components for the VOC-free water-soluble flux, then for the 0.5% halide activated rosin flux.

All the lead-free finishes in this comparison exhibited acceptable and similar visual inspection scores. There was very little discernible difference between all the finishes using this assembly process. There were only two failed solder joints out of a total of 28,000 joints inspected. The plating on a limited number of one of SnAg components did reflow during soldering resulting in higher visual inspection scores for these individual joints.

When testing for the propensity to tin whisker, the use of humidity was found to increase the likelihood of whiskers being generated. Using this test, the matt or satin Sn finishes supplied by the project partners did not show any signs of whiskering during a 56 day test at 50°C/85%RH. The finish supplied using redundant chemistry did whisker but only on lead frame salvage, not on built components. Whiskering also occurred on one of the SnCu plated samples, again only on lead frame salvage not on components.

It is clear overall from this work that all the finishes performed very similarly. Since the new tin finish did not whisker here, it would be unreasonable to reject the Sn finishes on this basis for future component plating. Since the two component alloy finishes present a challenge to achieve the specified composition the pure tin finish offers clear advantages in terms of cost and quality. On this basis and the performance the pure tin would be the optimal finish of choice.

10 REFERENCES

- (1) Improving the Processability of Noble Metal Component Termination Finishes :
M Wickham, M Dusek, L Zou & C P Hunt : NPL Report CMMT (A)199
- (2) IPC-A-610 Revision C January 2000 : Acceptability of Electronic Assemblies

11 ACKNOWLEDGEMENTS

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Schloetter
Shipley-Ronal Ltd