

The Use of Shear Testing and Thermal Cycling for Assessment of Solder Joint Reliability

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ABSTRACT:

This report presents an evaluation of the use of short-term thermal cycling as a method for assessing solder joint reliability. Three techniques (shear testing, and electrical continuity measurements, complemented with microstructural investigations) have been employed. Comparative data have been acquired using a test assembly and a matrix of conditions - three components termination styles, two pcb finishes, and three solders including one leading lead-free candidate. Test data were obtained following thermal exposure (-55 to +125°C) for up to 2000 cycles. A comparison of the results from the shear tests with those from the currently recognised non-destructive reliability assessment method (electrical continuity using DC techniques), demonstrated a strong, alloy depended, correlation. This could offer the promise of shear testing as a sensitive test for joint reliability. Whilst the pre-cycling results demonstrated some differences in reliability of joints on the two board finishes, those after cycling indicated that the results were insensitive to the board finish. The work also confirmed that (a) in BGAs the solder balls lying under the periphery of the silicon die are most likely to fail, and (b) since ceramic resistors fail from early stages of accelerated testing, they constitute a good component for assessing solder joint reliability.

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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

The use of shear testing for evaluation of accelerated thermocycling is a method that has recently been used for reliability assessment and lifetime prediction [1]. This method is based on the assumption that solder joint strength reduction is a main failure mechanism for electronics in the field. Thermal cycling accelerates the development of cracks and structural changes that will weaken a solder joint. The measurement of the solder joint strength will therefore be a function of this microstructural damage. Since electronics assemblies are manufactured from various materials with different thermal coefficients of expansion (TCE), shear strains are placed on the various components in the assembly as it is taken through a thermal cycle. Temperature cycling during service induces stresses due to the TCE differences between the mounted component and base substrate. It is a function of the materials used in assemblies that this strain is relieved in the solder joint, which becomes damaged as a consequence of continual cycling. This is shown schematically in Figure 1.

A conventional method for assessing reliability is to use electrical continuity measurements. This method provides a technique in which a large number of joints can be monitored. However, the technique is dependent on a complete electrical failure occurring before any detection is registered. This can be a severe handicap when over 5000 cycles may be required to reach a failure. ***An alternative approach being developed at NPL is to expose the assemblies to a limited number of cycles and evaluate the solder joint damage using a shear testing technique,*** which is described later. To enhance the failure rate, known “weak links” have been selected. These are components in which the TCE mismatch is high, and in this study we have used 2512-type ceramic resistors and large BGAs. These “weak link” components are the most likely to suffer solder joint failure on commercial products.

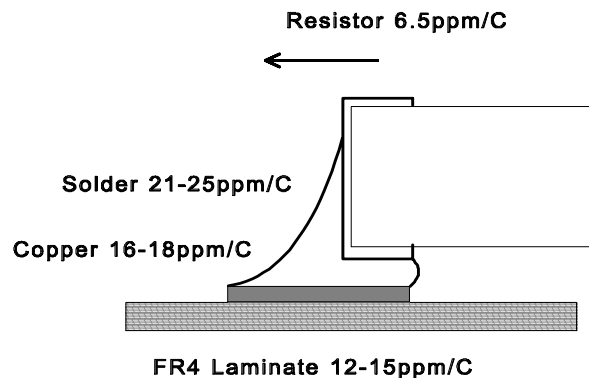


Figure 1. TCE (X-axis) mismatches in SM assemblies

2 EXPERIMENTAL

2.1 ASSEMBLY AND MATERIALS

The substrate material used in the study was FR4 epoxy laminate with two different surface finishes, bare Cu with OSP (organic solderability preservative) and AuNi. These surface finishes are commonly available.

There were three different solder alloys used in the experiment as shown in Table 1. The lead-free alloy, SnAgCu is currently the most promising candidate replacement for SnPb solder [1].

Table 1. Solder alloys used in the experiment

Solder	Composition	Melting point [°C]
A	Sn63Pb37	183
B	Sn95.8/Ag3.5/Cu0.7	217
C	Sn62/Pb36/Ag2	~ 179

Components used on the representative assembly were chip resistors of two sizes, SOICs with gull wing leads, and daisy chained BGAs.

Chip resistors: These components were used, since their rigid alumina bodies have a significantly different TCE from the PCB base material, and hence are more prone to fail from stress accumulation in the solder joints. The other advantage of using SM chip resistors as test devices is the simplicity in joint failure detection. High resistance or an open circuit is easily recognised by direct current measurement (DC). There are currently two different termination finishes commercially available and used as resistor termination materials, Sn and SnPb.

SOIC: The attachment design here was based on the gull wing. This is probably the most common type of lead attachment used in SM components, e.g. SOIC, QFP, SOT, SM connectors etc. The focus of attention was the heel of a solder joint, this being an indicator of wetting acceptability and hence was utilised for visually inspection purposes. As this type of lead attachment is compliant, the reliability of this type of solder attachment was considered high, providing that proper wetting characteristics were achieved [2]. SOIC components with gull wing leads are widely available with different surface finishes some of them being lead-free. There were two termination finishes used in this experiment, SnPb (10/90) and NiPd.

BGA: The last type of SM solder joint explored was a solder bump of the BGA. The bump or ball type of attachment method is a space-saving option of solder attachment especially for high-density packages. The solder bumps tested in this experiment were made from the identical solder to that used in soldering other components to the boards. All the BGA components were re-balled due to the unavailability of a commercial lead-free version at the time of manufacturing the assemblies. Using this method all the BGAs had the same characteristics.

Re-balling procedure:

- 1) De-balling of a BGA - wicking of original solder bumps with a fluxed Cu braze.
- 2) Cleaning of a BGA - package was cleaned with IPA to remove flux residues and provide a flat surface suitable for printing operations.
- 3) Printing of first layer - 150 μm stainless steel stencil was used to print the first layer of corresponding solder paste on a BGA package.
- 4) Reflow of first layer into bumps.
- 5) Printing of second layer - second layer of solder paste was printed on the first layer of bumps. The first layer of bumps significantly helps alignments of component and stencil.
- 6) Reflow of second layer - the primary first layer of bumps and second printed layer are reflowed and consequently contribute to the bump volume.
- 7) Printing and reflowing of the third and fourth layer - printing and reflow operation were repeated for solder bump volume increase (Figures 2 and 3).
- 8) Protecting re-balled package from ambient humidity before final PCB reflow operation.

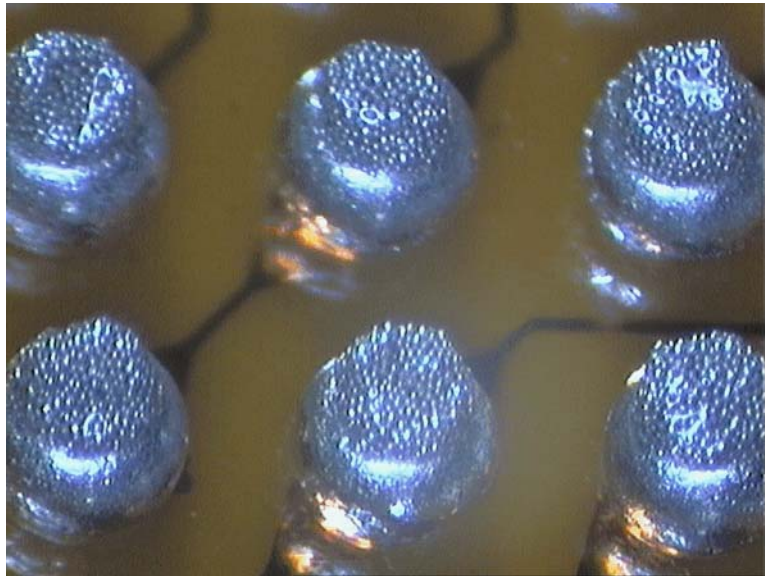


Figure 2. Re-balling of BGAs



Figure 3. Re-balling of BGAs, side view

Table 2 illustrates a full matrix of material and joint type combinations used in these experiments. There are three distinguishable stages of material combinations: conventional leaded assembly, lead-free transitional assembly, and completely lead-free assembly, where there is no Pb contained within the solder or component terminations.

Components:

- BGA672 1 mm pitch
- BGA256 1 mm pitch
- BGA484 1 mm pitch
- SOIC 1.27 mm pitch
- 2512-type resistors
- 0805-type resistors
- 40-way connector

Table 2. Combinations of materials and component types in the experiment

	OSP (Cu) Board	AuNi Board
Lead-Free Solder	Sn Resistors	Sn Resistors
	PdNi SOIC	PdNi SOIC
	SnAgCu BGAs	SnAgCu BGAs
	AuNi Connectors	AuNi Connectors
	SnPb SOIC	SnPb SOIC
	SnPb BGA	SnPb BGA
	SnPb Resistors	SnPb Resistors
Lead Solders	Sn Resistors	Sn Resistors
	PdNi SOIC	PdNi SOIC
	SnAgCu BGAs	SnAgCu BGAs
	AuNi Connectors	AuNi Connectors
	SnPb SOIC	SnPb SOIC
	SnPb BGA	SnPb BGA
	SnPb Resistors	SnPb Resistors

There were 24 pcbs used in the experiment, 12 with Cu OSP and 12 with AuNi surface finish. All three types of components were assembled and reflowed in an air convection reflow oven. Temperature profiles were chosen according to the solder alloy used. Temperature zones were set to ensure a proper reflow of the assemblies.

Table 3 lists the total number of components mounted on testing boards.

Table 3. List of all components used

Component	Frequency
BGA672	11
BGA484	42
BGA256	31
R0805 Sn	115
R0805 SnPb	95
R2512	210
SOIC14 PdNi	126
SOIC14 SnPb	126

The PCB layout, shown in Figure 4, was a single sided 1.6 mm thick FR4 board with Cu tracks 35 μm thick. The design incorporates 20 off 0805-type resistors, 20 off 2512-type resistors, four PBGAs and 12 SOICs. Resistors and PBGAs were joined to the connectors for continuity measurements. Table 4 illustrates the description of the various tests performed on the pcbs.

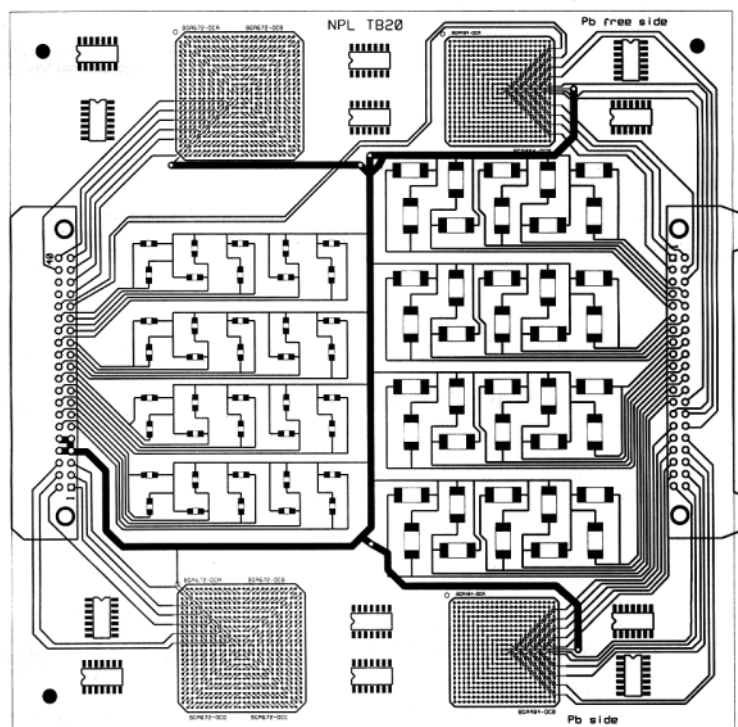


Figure 4. Test pcb layout, size 152 x 152 x 1.6 mm

Table 4. Component types and testing methods

Component	Failure detection
Resistors 2512 and 0805	Continuity measurement, shear testing, microsectioning
SOIC14	Visual inspection
BGA256 BGA484 BGA672	Continuity measurement

The solder joints were thermally cycled according to the profile in Figure 5 selected on the basis of being representative of what industry currently uses. There were two temperatures set points, -55 °C and 125 °C, with 5 minutes dwells. The 5 min dwell was defined as the time during which the temperature in the oven was within $\pm 5^{\circ}\text{C}$ of the set value.

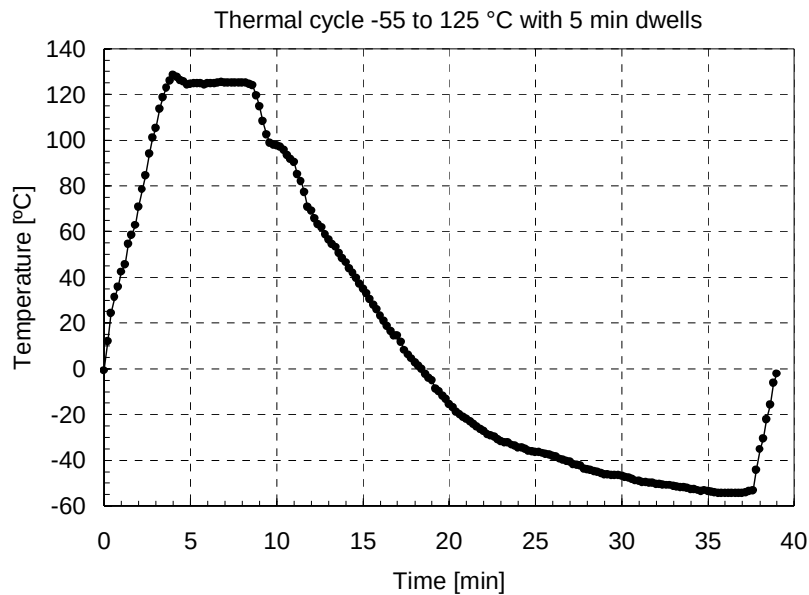


Figure 5. Temperature cycle load used

2.2 MICROSECTIONING

2.2.1 Specimen preparation.

The components used in microsectioning were the 2512-type resistors from the assembly detailed above. The Table below specifies the number of thermal cycles at which samples were taken for microsectioning.

Solder Type	SnPb	SnAgCu	SnPbAg
	0	0	0
Thermal Cycles	500	500	500
	2000	2000	2000

Samples were cut out individually from the boards using a liquid-cooled conventional diamond saw. This method of cutting was employed to ensure that the soldered joints did not heat to a level that would have affected the joint properties.

Once cut, the components were cleaned using conventional IPA (iso-propyl alcohol) to ensure that any residue present from the cutting stage had been sufficiently cleaned from the joint region. The samples were mounted in a cold curing epoxy.

2.2.2 Metallography.

Once cured, the samples were removed from their respective moulds to be ground and polished, using silicon carbide of 120 to 4000 grit paper on an automated machine, and polished with diamond-containing pastes/sprays 15 to 0.25µm in size. Diamond impregnation

of the cloth was kept to a maximum in order to ensure that the best cutting rate of the surface had occurred. Final polishing of the samples was achieved by hand using a gamma aluminide powder suspended in lapping fluid, as this was noted to give the best finish.

Some of the samples were etched. Etching of the lead-containing solder systems was accomplished using a solution containing 2 ml hydrochloric acid and 98 ml industrial methylated spirits. With this solution a polish-etch technique was achieved using 0.25 μm diamond paste as the polishing medium. The lead-free alloy was etched using 2 ml nitric acid, 2 ml hydrochloric acid and 96 ml distilled water.

A standard Olympus optical bench microscope was used with Polaroid instant colour film (Polaplan 100) at magnifications of 200x-500x.

2.3 SHEAR TESTING

The components tested were the 2512-type resistors soldered onto the test boards. Samples were examined after: 0, 443, 500, 1000, 1700 and 2000 cycles.

2.3.1 Specimen Preparation

The boards used were cut into smaller sections containing two or three components for testing. The method by which the boards were cut was a conventional water-cooled diamond saw. The smaller sections of board were cleaned to remove any contaminants/residues from the cutting process and dried using compressed air.

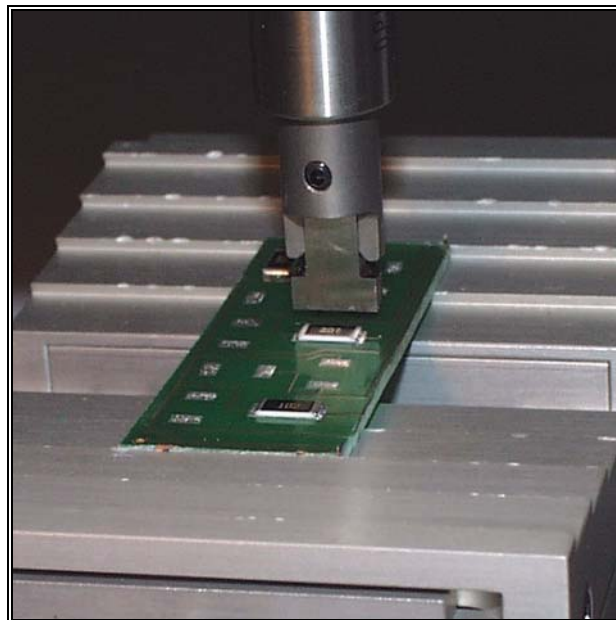


Figure 6. Shear test jig and push-off tool.

Figure 6 shows the experimental arrangement of the board placed within the jig ready for testing. As the jig was mounted on a movable X-Y table it was re-positioned so that the shear-test tool was directly behind the component (as shown). For each test the push-off tool was used at a pre-set height (centre of component) of 80 μm and a defined speed of 200 $\mu\text{m/s}$. The end of a typical test is shown in Figure 7.

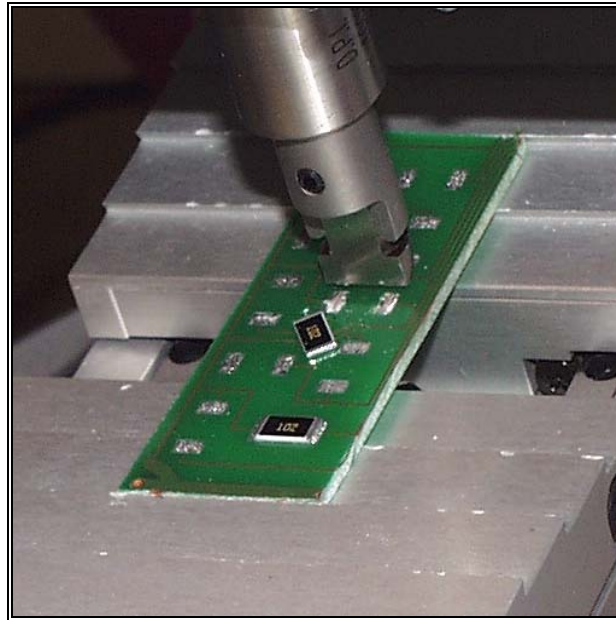


Figure 7. Typical joint break after failure

The 2512-type resistors were tested in this manner. For each thermal cycled board 4 resistors were tested in order to produce an average of the joint strength.

3 RESULTS

3.1 MICROSECTIONING

Typical photomicrographs are presented in Figures 8-20.

- 1) Figures 8-12. Five photomicrographs relating to the SnPb solder alloy joint combination. Figure 8 shows the joint region relating before thermal cycling, Figure 9 after 500 thermal cycles, and Figure 10 after 2000 thermal cycles. Figure 11 and 12 are photomicrographs taken at a higher magnification of 500x after 500 and 2000 thermal cycles respectively.
- 2) Figures 13-17. Five photomicrographs relating to the SnPbAg solder alloy. Figures 13 to 15 show the joint after three different thermal cycles 0, 500 and 2000 respectively. Figures 16 and 17 represent photomicrographs taken at a magnification of 500x after 500 and 2000 thermal cycles.

- 3) Figures 18-20. Three photomicrographs relating to the lead-free solder alloy, SnAgCu. Figures 18 to 20 illustrate the joint after the three different cycled conditions of 0, 500 and 2000 thermal cycles.

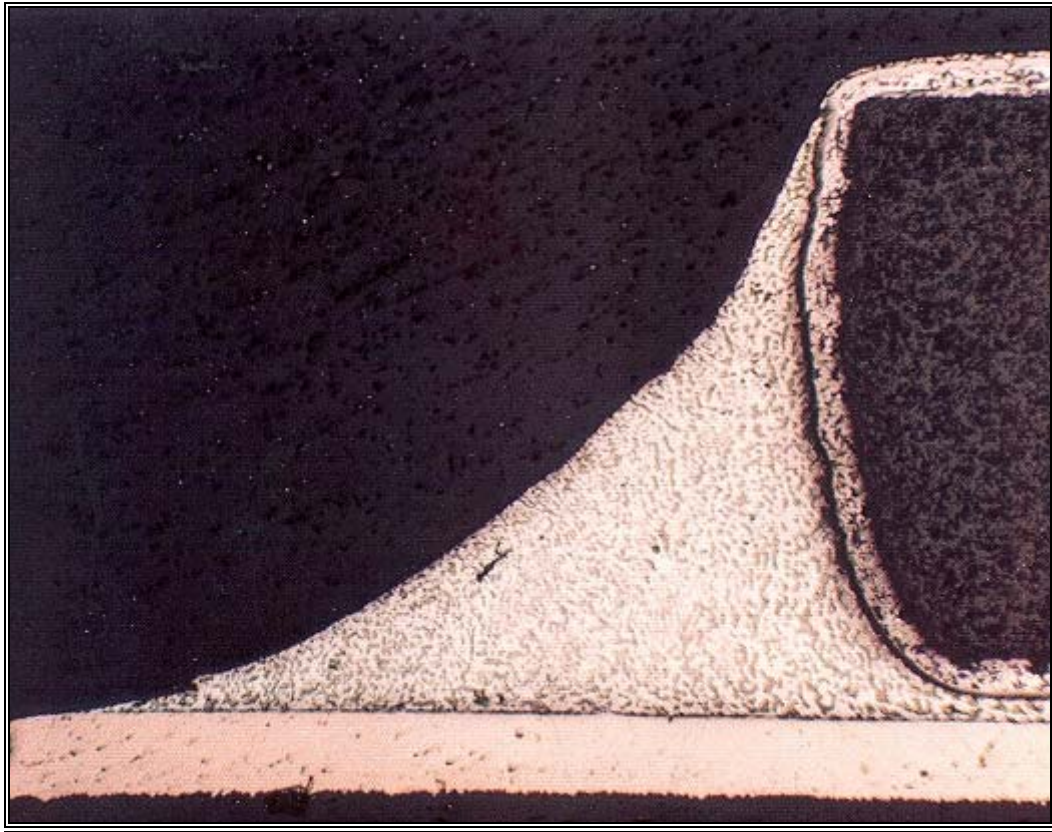


Figure 8. SnPb solder joint before thermal cycling (300x)

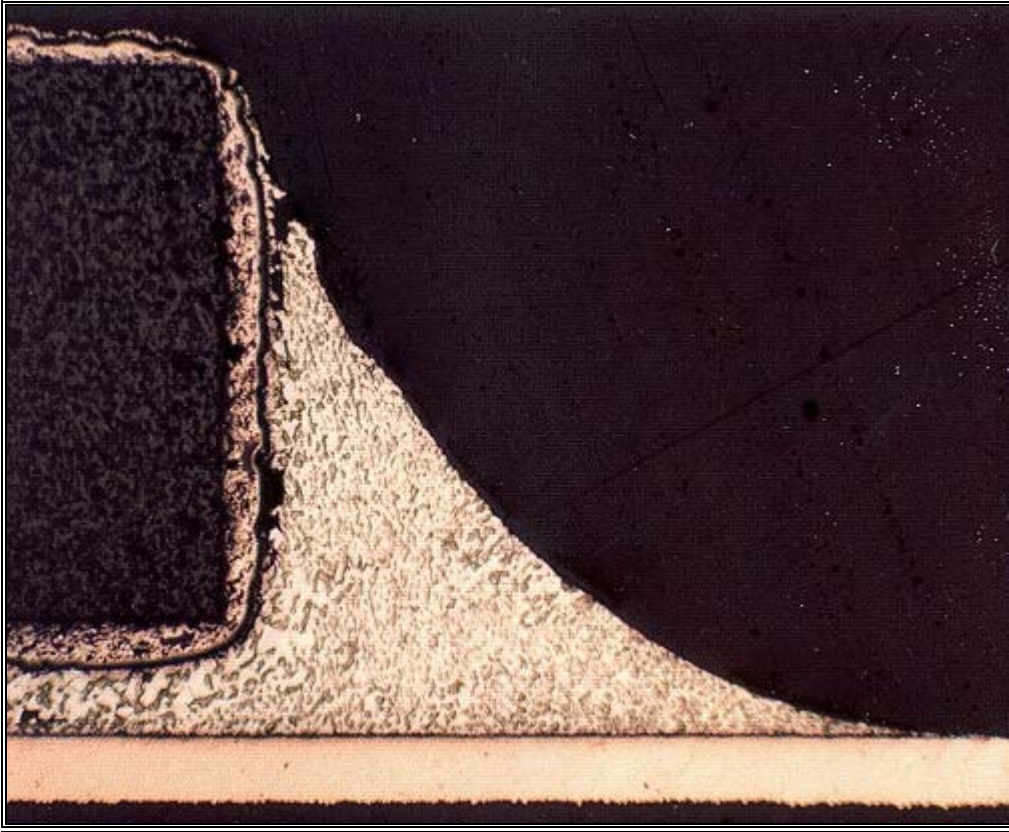


Figure 9. SnPb solder joint at 500 thermal cycles (260x)

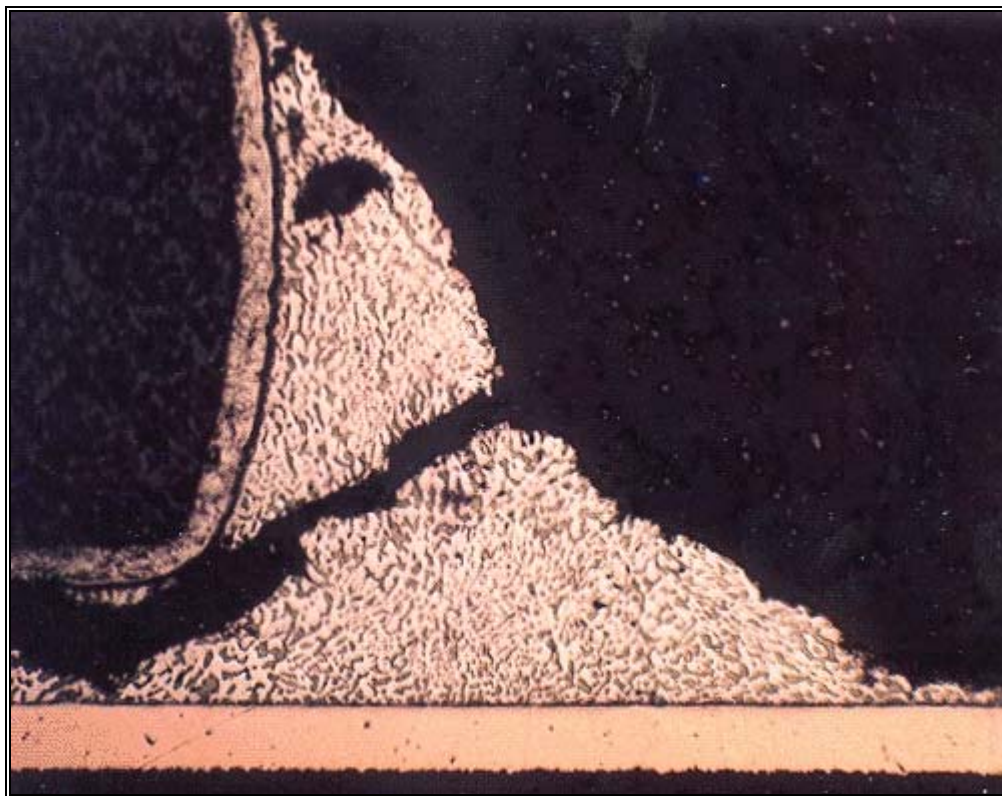


Figure 10. SnPb solder joint after 2000 thermal cycles (240x)

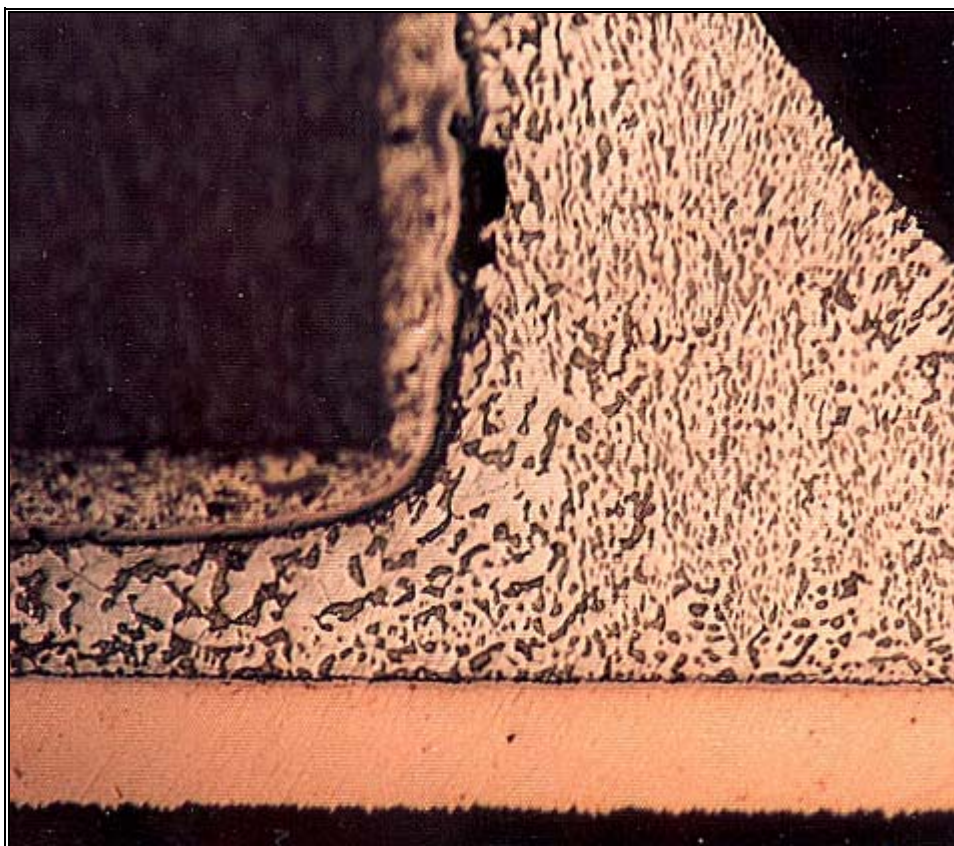


Figure 11. SnPb solder joint after 500 thermal cycles (500x)

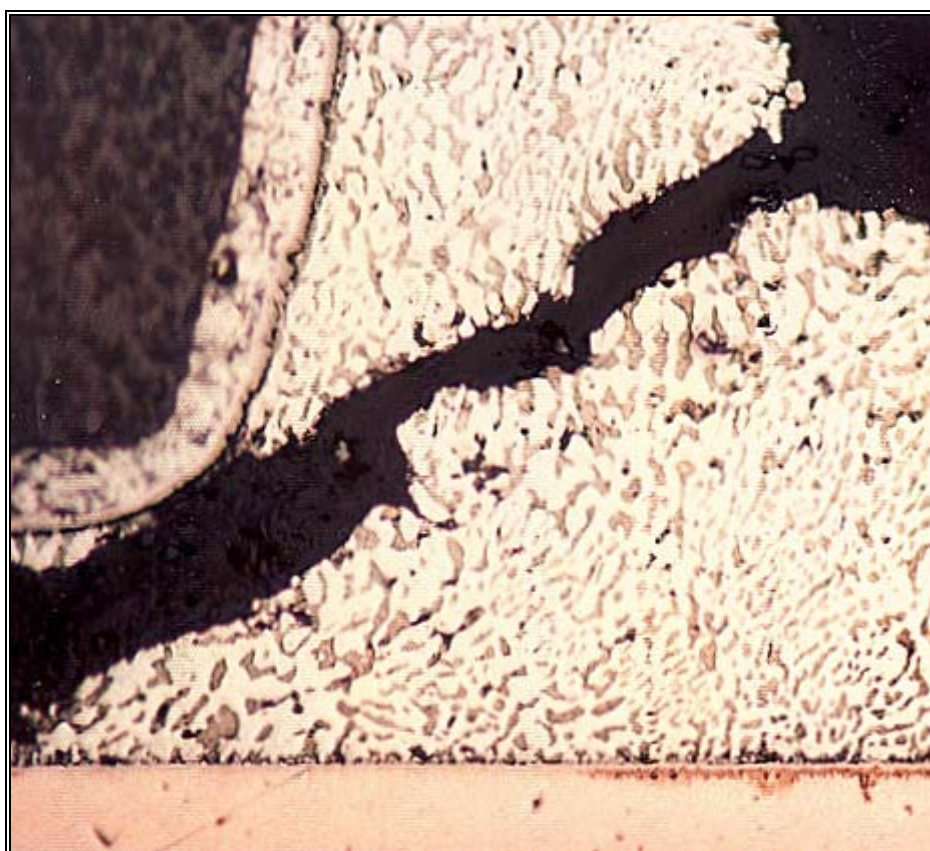


Figure 12. SnPb solder joint after 2000 thermal cycles (500x)

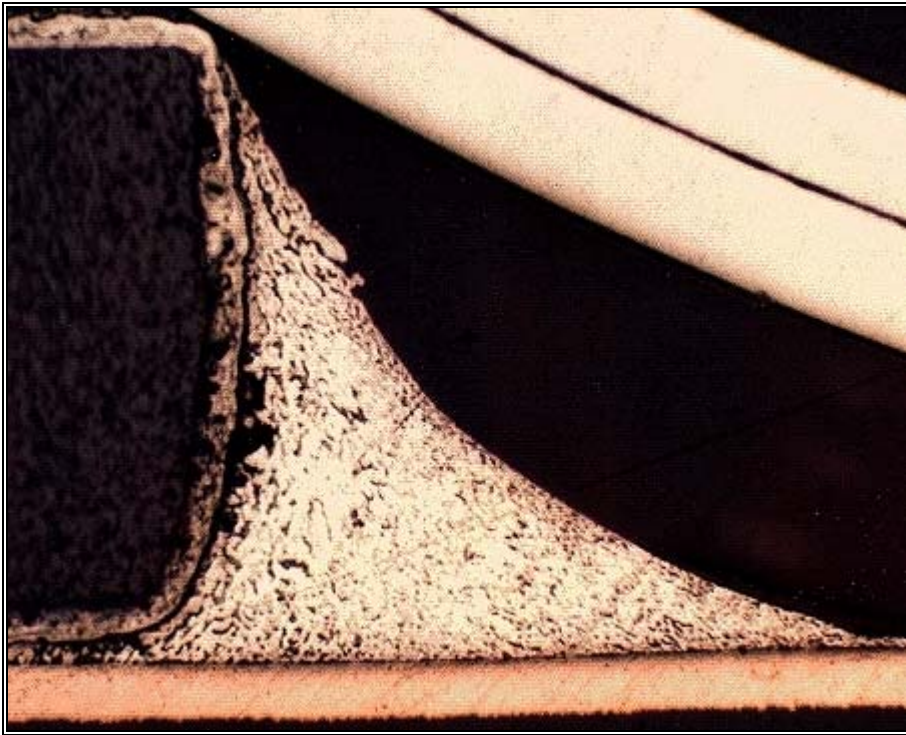


Figure 13. SnPbAg solder joint before thermal cycling (220x)

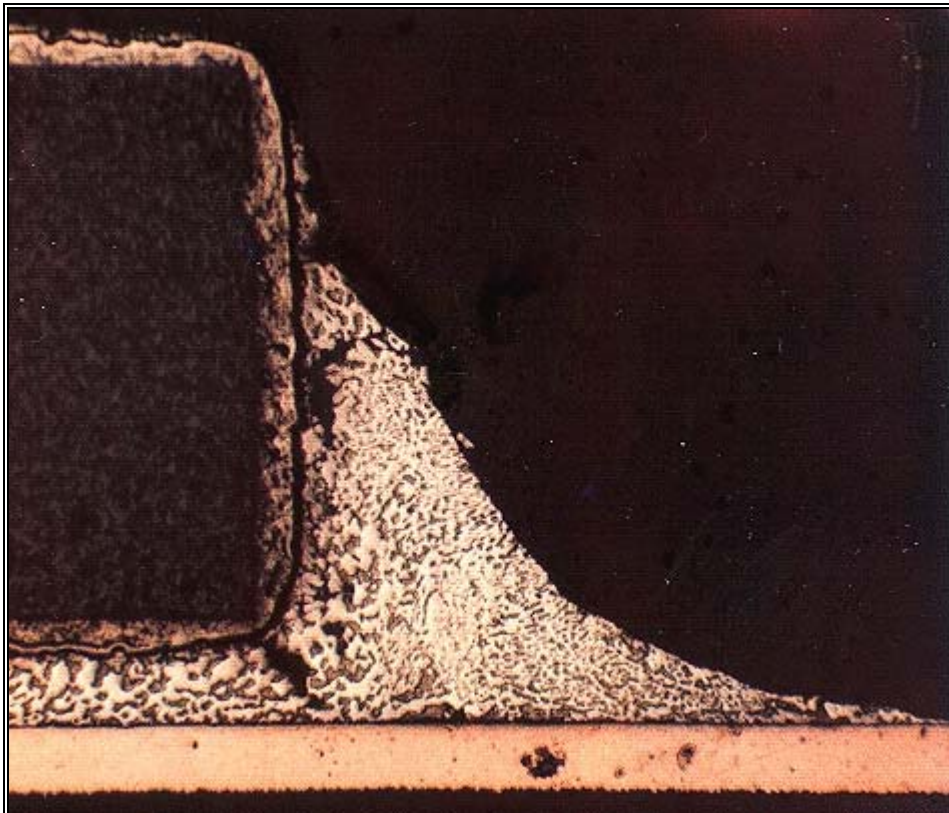


Figure 14. SnPbAg solder joint after 500 thermal cycles (220x)

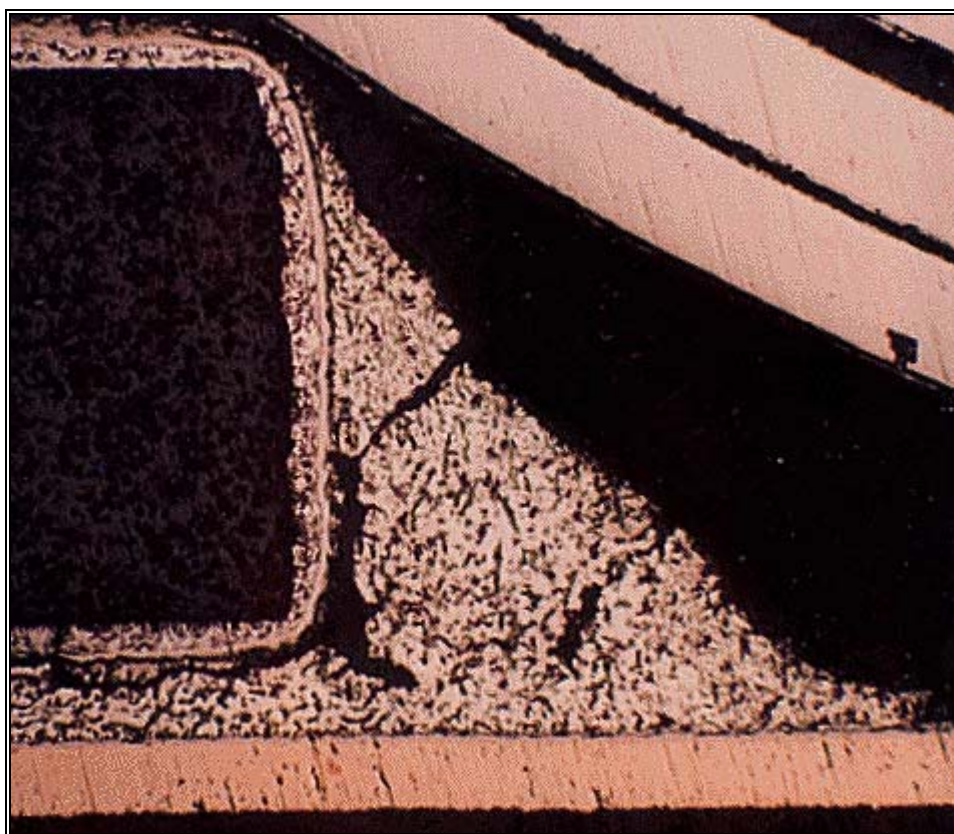


Figure 15. SnPbAg solder joint after 2000 thermal cycles (280x)

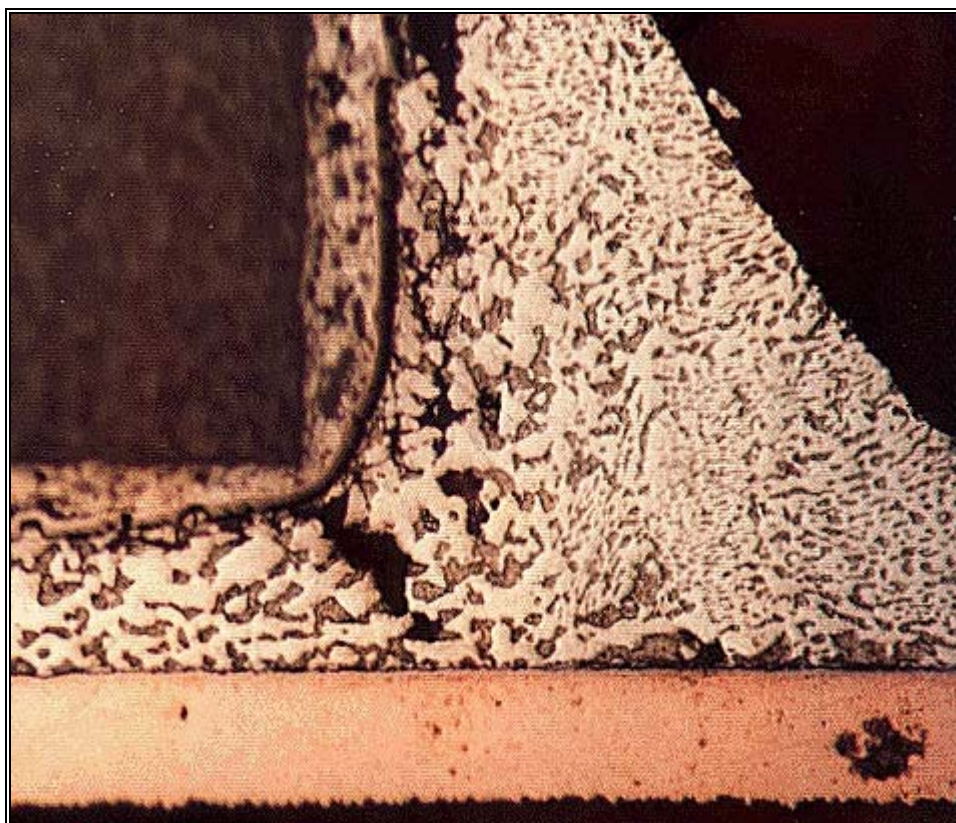


Figure 16. SnPbAg solder joint after 500 thermal cycles (500x)

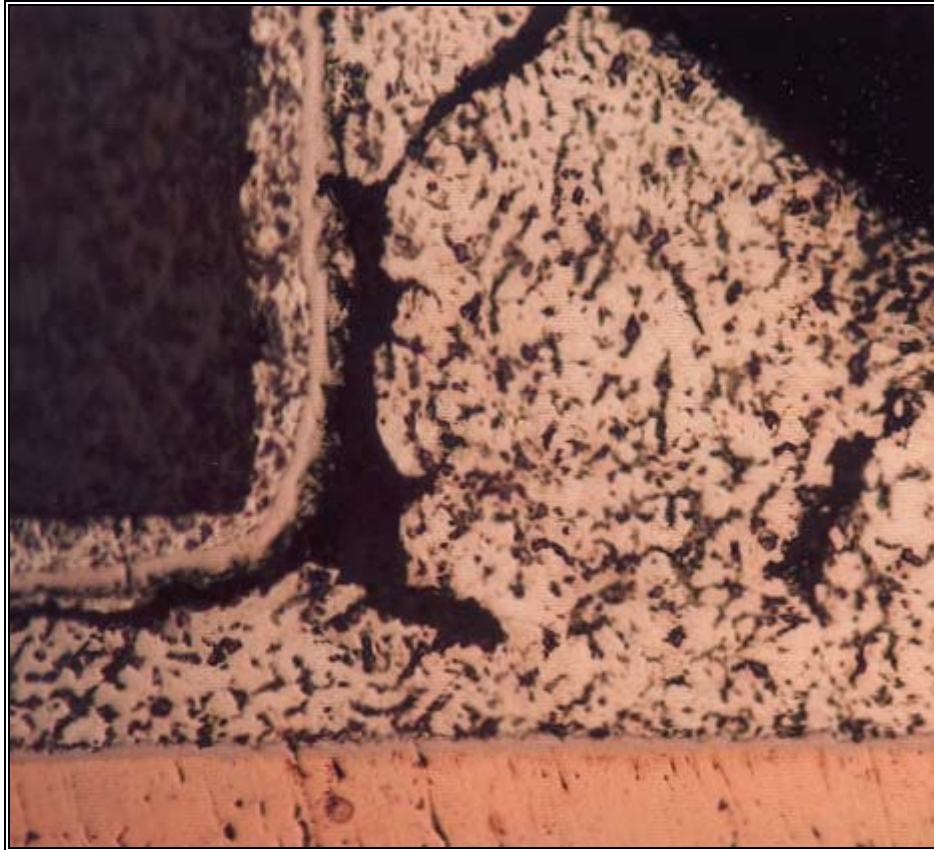


Figure 17. SnPbAg solder joint after 2000 thermal cycles (500x)

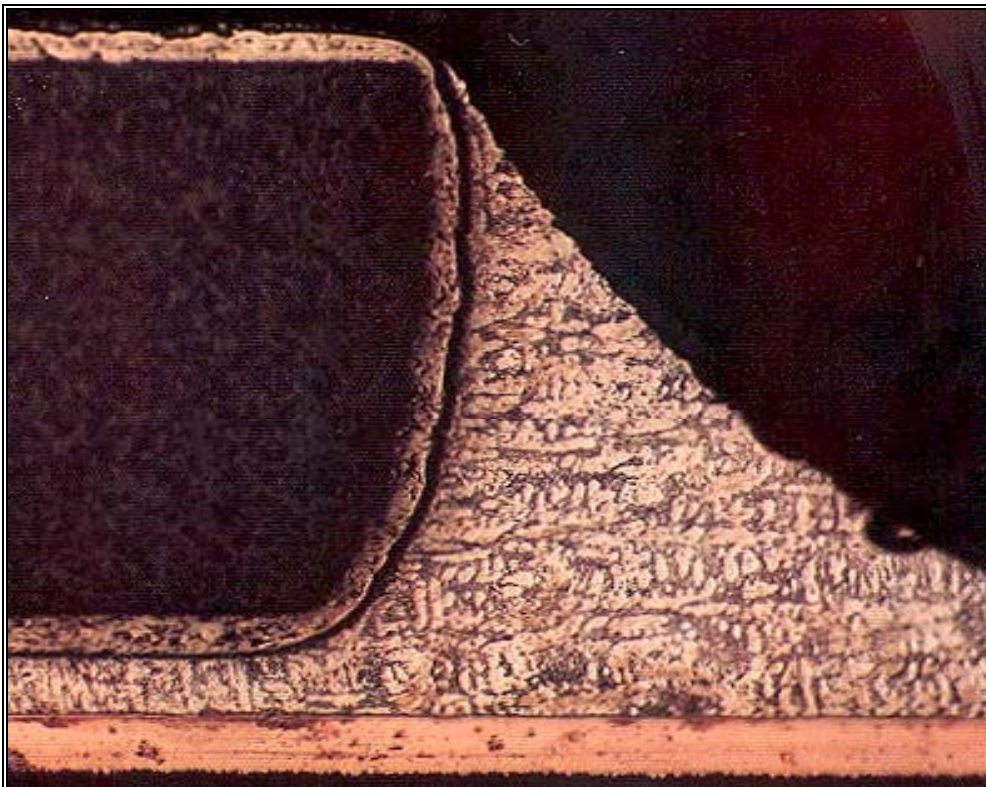


Figure 18. SnAgCu solder joint before thermal cycling (220x)

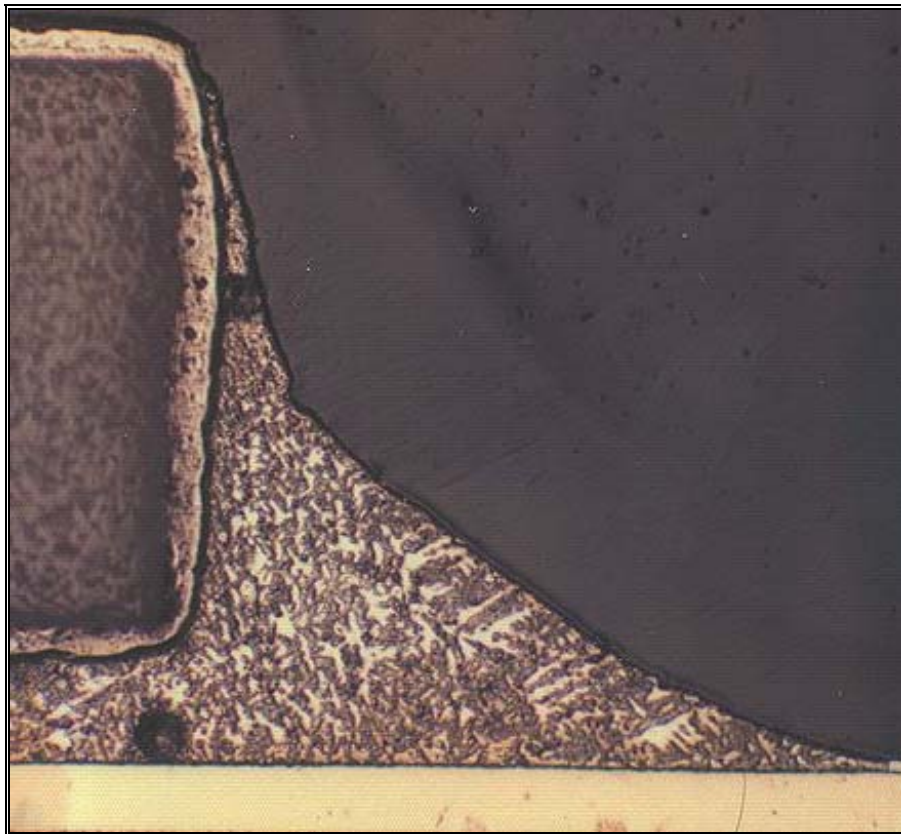


Figure 19. SnAgCu solder joint after 500 thermal cycles (220x)

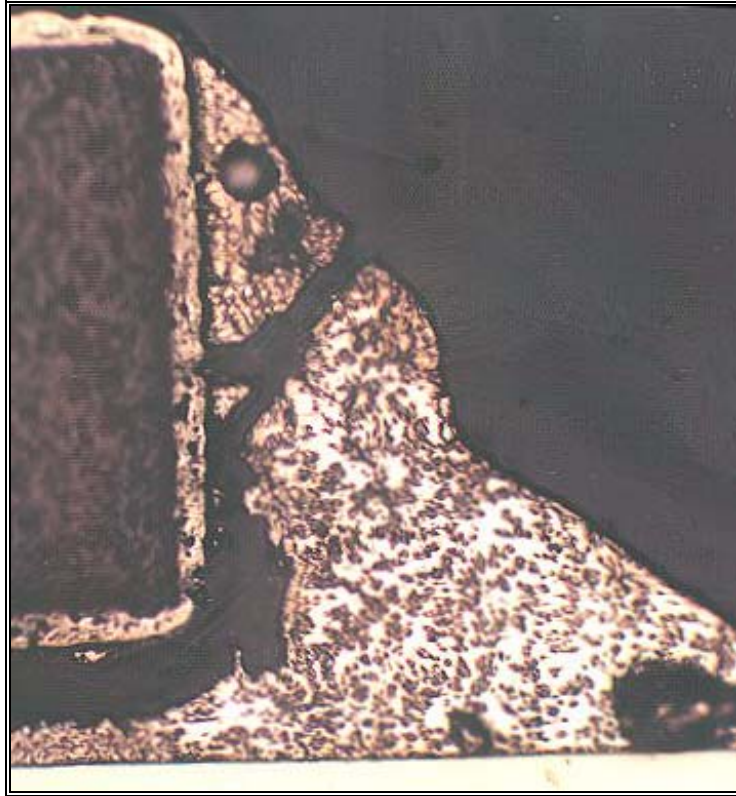


Figure 20. SnAgCu solder joint after 2000 thermal cycles (220x)

3.2 SHEAR TESTING

The results obtained from the shear tests are presented in Figures 21-26.

- Figure 21: SnPb solder with AuNi PCB finish.
- Figure 22: SnPb solder with Cu PCB finish.
- Figure 23: SnAgCu solder with AuNi PCB finish.
- Figure 24: SnAgCu solder with Cu PCB finish.
- Figure 25: SnPbAg solder with AuNi PCB finish.
- Figure 26: SnPbAg solder with Cu PCB finish.

Figure 21.

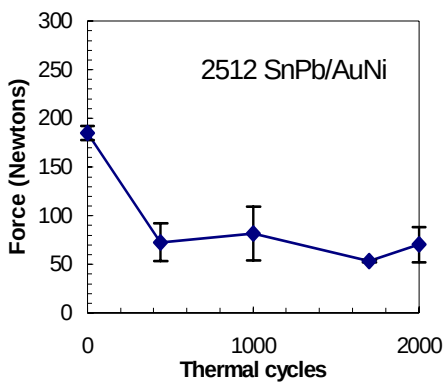


Figure 22.

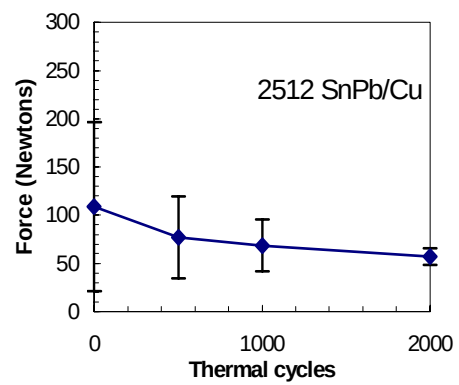


Figure 23.

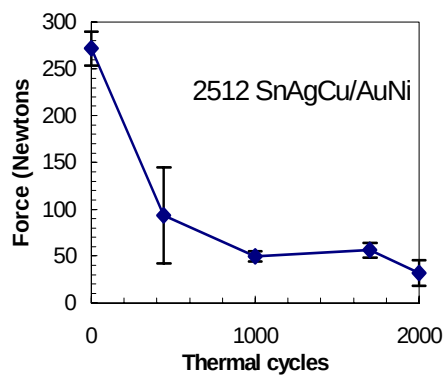


Figure 24.

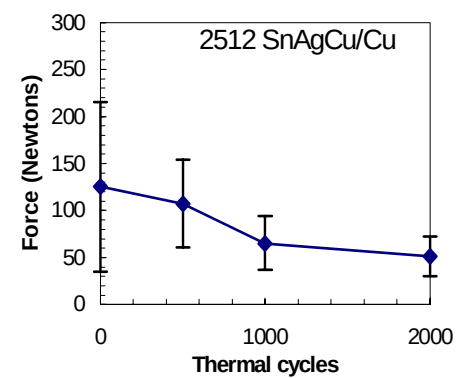


Figure 25.

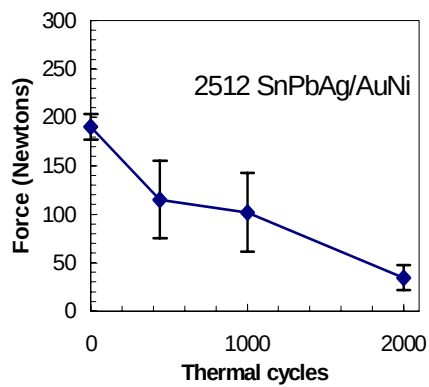
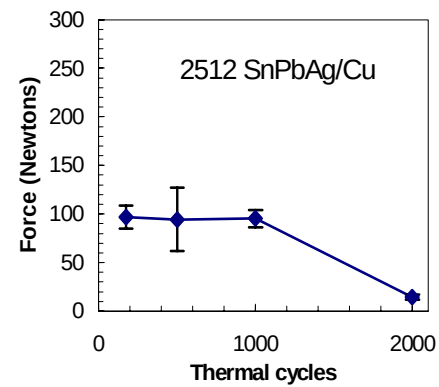


Figure 26.



3.3 CONTINUITY MEASUREMENT

Following manufacture of the pcbs, all the resistors and BGAs were electrically tested before thermal cycling. All the components exhibited an electrical resistance that was within the manufacturers tolerance of $\pm 5\%$. The resistance of each continuity loop was measured using the Voltage Method, in which a constant voltage of 1 V is applied across a device and the current through the device measured.

All the resistors were periodically measured at room temperature. Each board was connected through an 80-way switch bridge to the measuring equipment. If the resistance was by 5 % higher than the nominal value, it was classified as a failure and marked. From the failure analysis (Figure 27) a Weibull distribution was fitted to the failure rate and N_f , the median numbers of cycles for 50 % failure rate, calculated. The results for 2512-type resistors are shown in Figure 28.

On the X-axis there are three solder alloys combined with the two pcb finishes. The Y-axis is the number of cycles at which the failure rate equals 50 % (median number of cycles). The Y-error bars represent 200 cycles, an estimate of absolute error, as the period of testing was 200 cycles. The SnPb/Cu result have been normalised to this value at 100%. The other combinations of soldering alloys and pcb finishes are annotated as a percentage of this value in Figure 28.

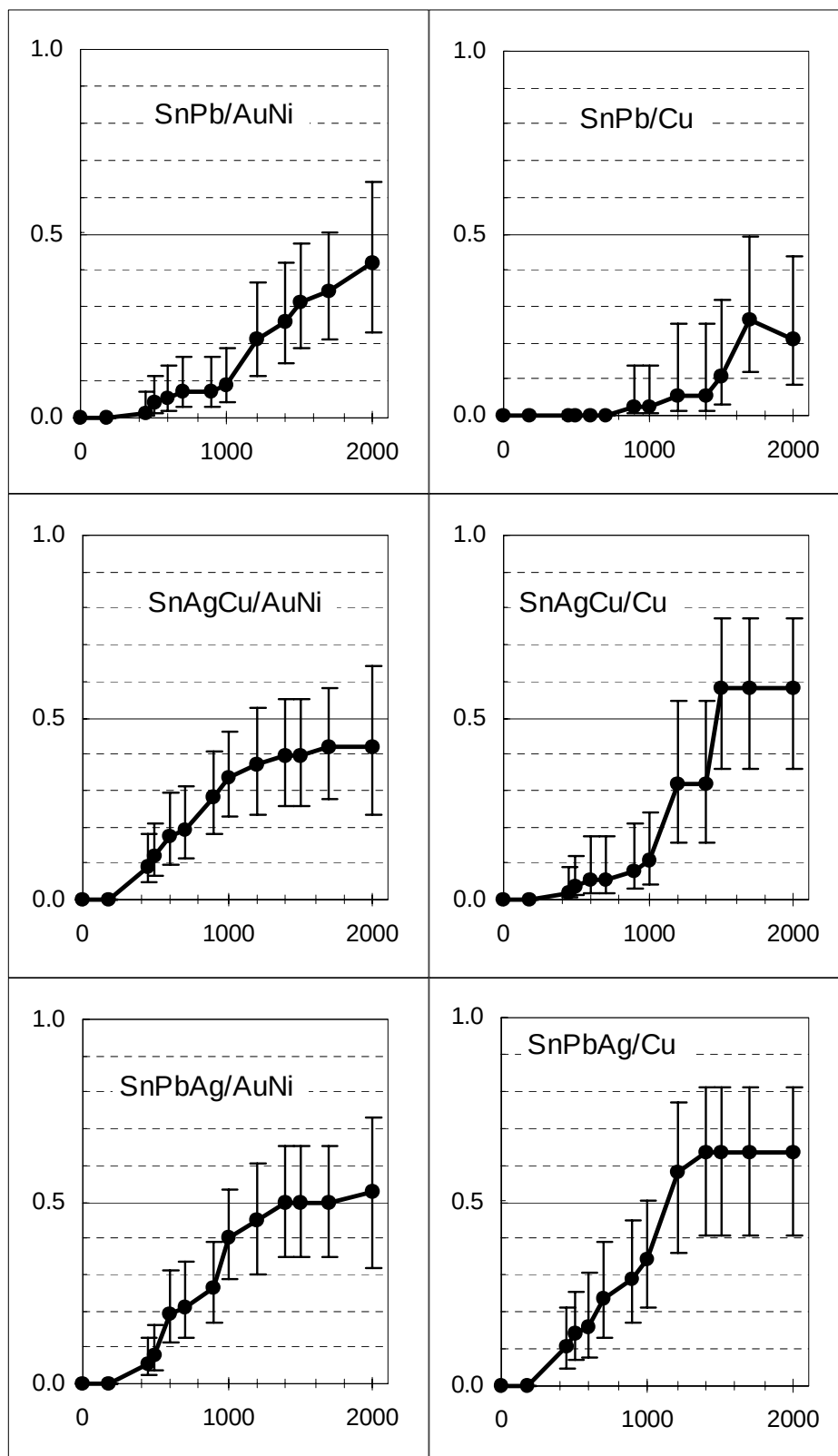


Figure 27. Failure rate for 2512-type resistors, Y-error bars are calculated from Binomial distribution [4] and they represent 95 % confidence interval

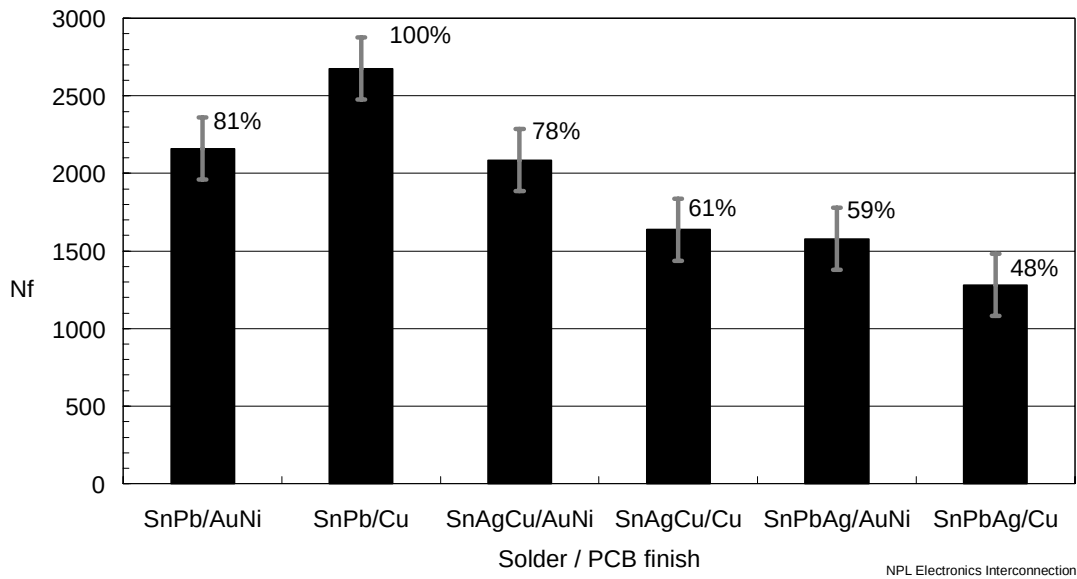


Figure 28. Comparison of solder joint reliability with two pcb finishes for 2512-type resistors

There were only a handful of failures of the 0805-type resistors, not enough for any useful analysis.

Reliability results for BGAs are shown in Figures 29, 30 and 31. The failure analysis for BGAs is different from that for the resistors, due to the limited availability of BGA samples. Hence the Weibull distribution was not fitted. The solder balls are grouped into square “rings”, with each ring daisy-chained separately as a closed loop with a 100 Ω resistor in series.

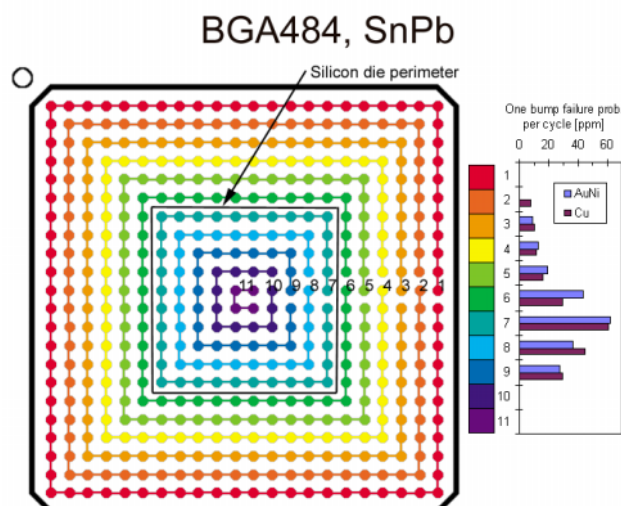


Figure 29. BGA layout and probability of failure of SnPb balls in different rings

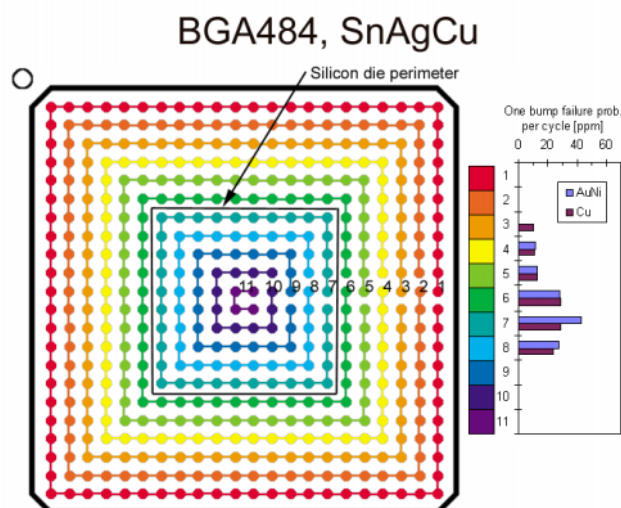


Figure 30. BGA layout and probability of failure of SnAgCu balls in different rings

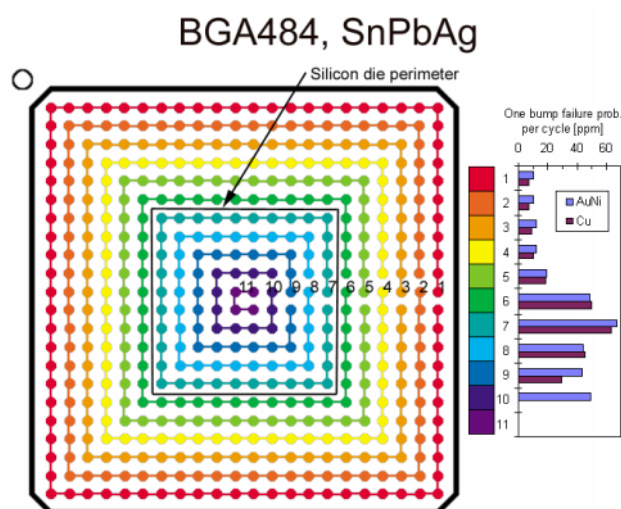


Figure 31. BGA layout and probability of failure of SnPbAg balls in different rings

The minimum number of cycles for each ring to fail was calculated and averaged, and then the **probability of failure** (Equation 1) for one solder ball in a ring, calculated. These results are plotted as the inset bar charts within Figures 29-31. The average number of cycles to fail, shown in Table 5, is marked as N_x , where x is the number of the ring on the component.

Equation 1 Probability of failure of one ball in x-th BGA ring

$$p_x = 1 - \sqrt[n_x]{1 - \frac{1}{N_x}}$$

Where:

p_x - probability of one ball failure [ppm unit in Table 5]

n_x - number of balls in x-th ring

N_x - number of cycles for x-th ring to fail

Table 5. Reliability of BGA484 as a failure probability per one cycle in x-th BGA ring

Solder/ PCB finish	SnPb/AuNi		SnPb/Cu		SnAgCu/AuNi		SnAgCu/Cu		SnPbAg/AuNi		SnPbAg/Cu	
Ring (x)	Nx	[ppm]	Nx	[ppm]	Nx	[ppm]	Nx	[ppm]	Nx	AuNi	Nx	[ppm]
Perimeter 1	-	0	-	0	-	0	-	0	1222	10	1700	7
2	-	0	1700	8	-	0	-	0	1222	11	2000	7
3	1700	9	1500	10	-	0	1500	10	1200	12	1700	9
4	1300	13	1400	12	1400	12	1500	11	1350	12	1700	10
5	1000	19	1200	16	1450	13	1500	13	1000	19	1050	18
6	522	44	775	29	818	28	800	28	470	48	454	50
7	451	62	457	61	648	43	972	29	415	67	441	63
8	980	36	800	45	1300	27	1500	24	807	44	786	45
9	1850	27	1700	29	-	0	-	0	1150	43	1700	29
10	-	0	-	0	-	0	-	0	1700	49	-	0
Centre 11	-	0	-	0	-	0	-	0	-	0	-	0

From the failure probability of one ball a failure probability for the whole component can be calculated using Equation 2, and this is shown in Figure 32 and Table 6. The higher the probability of failure the lower the component life-time.

Equation 2: The component reliability in 1st cycle for PBGA484

$$P = 1 - \prod_{i=1}^{11} (1 - p_i)^{n_i}$$

Where:

P - probability of a component failure in 1st cycle

p_i - probability of one ball failure in i-th ring

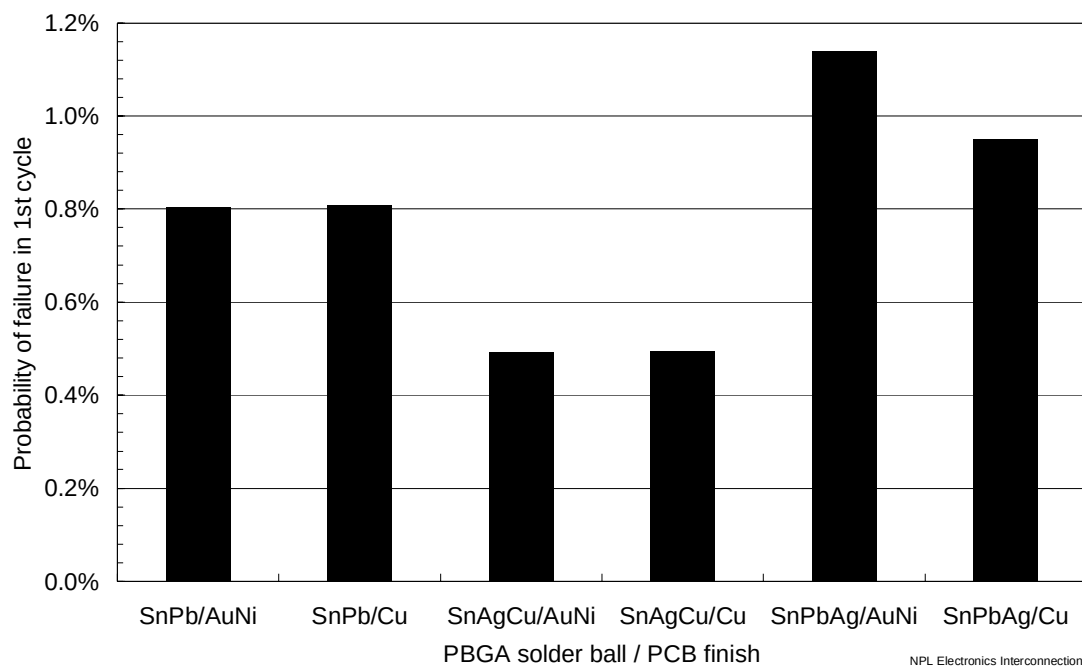
n_i - number of solder balls in i-th ring (Table 7)

Table 6. PBGA484 component probability of failure in 1st cycle

Solder/ PCB finish	Probability of failure
SnPb/AuNi	0.80%
SnPb/Cu	0.81%
SnAgCu/AuNi	0.49%
SnAgCu/Cu	0.49%
SnPbAg/AuNi	1.14%
SnPbAg/Cu	0.95%

Table 7. Number of solder balls in BGA484 rings

PBGA484 rings	Number of balls in a ring
1	84
2	76
3	68
4	60
5	52
6	44
7	36
8	28
9	20
10	12
11	4

**Figure 32. PBGA484 failure probability**

To estimate the number of cycles for the PBGA component to work without a failure, a prediction must be based on the binomial distribution, Equation 3. It is assumed that one ball reliability is a constant value. The calculation of the probability of functioning without a ball failure up to 500 cycles is shown in Figure 33.

Equation 3 Probability of PBGA package failing (Y axis in Figure 33) in N cycles

$$P(k) = \binom{N}{k} \times p^k \times (1-p)^{N-k}$$

Where:

P(k) - probability of BGA component failing in N cycles k-times only

N - number of cycles (X-axis in Figure 34)

k - number of failures during N cycles (in this case = 0)

p - probability of PBGA component failing in 1st cycle (result of Equation 2)

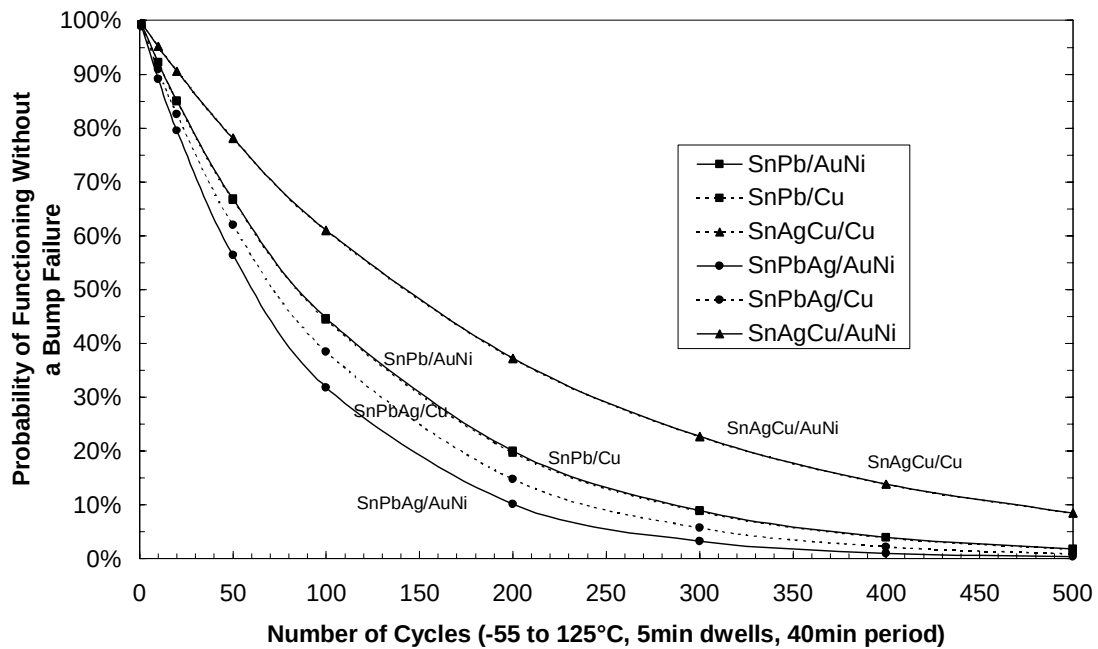


Figure 33 PBGA484 package reliability

4 DISCUSSION

4.1 METALLOGRAPHY

The microstructure of the solder joints undergoes significant morphology changes as the thermal exposure increases from 0 to 2000 cycles. In particular, after 2000 thermal cycles the joints exhibit regions where physical continuity is completely disrupted by the presence of cracks that start in and traverse the whole solder fillet. Grain coarsening and intermetallic growth also occur during cycling modifying the physical properties of the joint [5]. Additionally, the high local stress results in crack formation and ultimately joint failure. This coarsening effect can be seen to increase with thermal cycling.

For the SnPb joints subjected up to 2000 cycles (Figures 8, 9, 10, 11 and 12) the tin-rich and lead-rich phases have coarsened appreciably from the initial state. The eutectic equilibrium structure consisted of colonies of alternating lamellae of Pb-rich alpha-phase (face centred

cubic) crystal structure and Sn-rich Beta-phase (body centred tetragonal) platelets. Furthermore non-equilibrium conditions occur during thermal cycling which give rise to interfacial boundaries that alter the joint behaviour leading to weakness within the fillet. Closer examination of the PCB pad showed that intermetallic boundary layers were present between the solder and the resistor.

The two lead-containing solders used showed very similar microstructural changes after thermal cycling of the joints. Both had have very similar grain structures and modes of crack initiation/failure, and both solder joints exhibited a similar coarsening of the grains with early signs of joint degradation (see Figures 8 and 14). However, in spite of these obvious changes, these joints would still function in service without any noticeable problems after 500 cycles. After 2000 cycles (Figures 10 and 15) both joints had similarly degraded.

The microstructure of the SnAgCu alloy is illustrated in Figures 18 to 20. Joint failure had occurred after 2000 cycles and slight degradation of the microstructure was apparent after 500 cycles. The grain structure consisted of intermediate phases of Sn-Ag and Sn-Cu Binary systems. The eutectic containing alpha-Sn and 3.5% Ag was formed between the Sn-rich phase and Ag₃Sn intermetallic which consisted of fine grains within a Sn-rich matrix (dark phase). The microstructure changed over the cycled range with a higher presence of the eutectic phase after fewer cycles.

All the alloys failed in a similar way, with crack initiation and the greatest microstructural damage occurring under the resistor. There were significant microstructure differences between the lead-containing and lead-free alloys. However, the failure mechanism did not appear to be dissimilar at this microstructural level.

4.2 SHEAR TESTING

Figures 21-26 illustrate the general trend of a decrease in the ultimate shear strength of the joints on the 2512-type resistors as the number of cycles in increased. All the resistors tested had pre-cycling ultimate shear strength values that were higher those following cycling, confirming that the damage caused by thermal cycling reduces the joint strength. It is convenient to use the pre-cycling value as an indicator or baseline that can be used for comparison of the other values obtained.

The strongest joint strength that was given by the lead-free solder, SnAgCu (Figure 23), its pre-cycling value being over 250 N. The lead-containing solders, SnPb and SnPbAg had similar pre-cycling strengths of 190 N. The board finish appeared to be very influential on the initial strength. However following thermal cycling the effect of board finish does not appear to be significant. All the shear results show the general trend in reduction of joint strength with cycling. This functional dependence will be investigated further at again later, when its possible correlation with the continuity data will be explored.

4.3 CONTINUITY MEASUREMENT

The continuity results reveal a clear indication of the performance of the solder alloy when combined with different pcb finishes. The solder alloy performance does not rank in the same order for the resistors and BGA data. The resistor data reveal that SnPb performed the best, but surprisingly the addition of 2% Ag to this alloy reduced the performance significantly. The SnAgCu performance was approximately 20% poorer than SnPb, but this is not potentially an issue since hardly any of the 0805-type resistors showed any failure for any alloy. In the case of the PBGAs the SnAgCu performed the best, and again the SnPbAg alloy the worst. The performance of the SnAgCu solder was significantly better than that of the SnPb solder, and for this component a very pleasing result. For the PBGAs the pcb finish was not influential on failure rates. However, for the chip components an effect of the pcb finish was observed, with the AuNi finish best with the SnAgCu and SnPbAg solders, but the Cu/OSP finish superior with the SnPb solder.

The PBGA solder attachments are ranked in two sets. The first set of results (Figures 29-31) focused on at the most critical part of the components' attachment and expresses the reliability of one solder ball failing in the first cycle of a square "ring". It is obvious that a silicon chip moulded in the plastic body markedly influences the mechanical behaviour of a component and this is the reason why rings that are adjacent to the die perimeter have failed first. This is why some PBGAs only have part filled arrays. There was no significant impact of the PCB finish on the solder joint performance.

The second set of PBGA results examined the component reliability as a product (Equation 2) of all contributing balls formed in square rings. It was assumed that the ball reliability in any ring is constant. The component reliability is expressed as a probability of failure in the 1st cycle (Figure 32) or a probability of functioning without a failure over 500 cycles (Figure 33). There was no significant difference between the reliability of PBGA484 components soldered onto the two different pcb finishes (AuNi and Cu + OSP).

4.4 COMPARISON OF SHEAR & CONTINUITY

In order to compare the ability of shear testing to rank solder joint reliability, a possible correlation between the shear and the continuity results was investigated.

In Figure 34 the correlation coefficient between the results from the shear and continuity test is plotted. The correlation coefficient was calculated from the failure rate and ultimate shear force for the same number of cycles. A linear fit was made through the shear data and another through the continuity data after the same number of thermal cycles for each solder and pcb finish combination. These two fits were then correlated. The negative values of the coefficients are due to the ultimate shear force declining with cycle number. In Figure 34 there is no indication that pcb finish influences the validity of the relationship between the two methods.

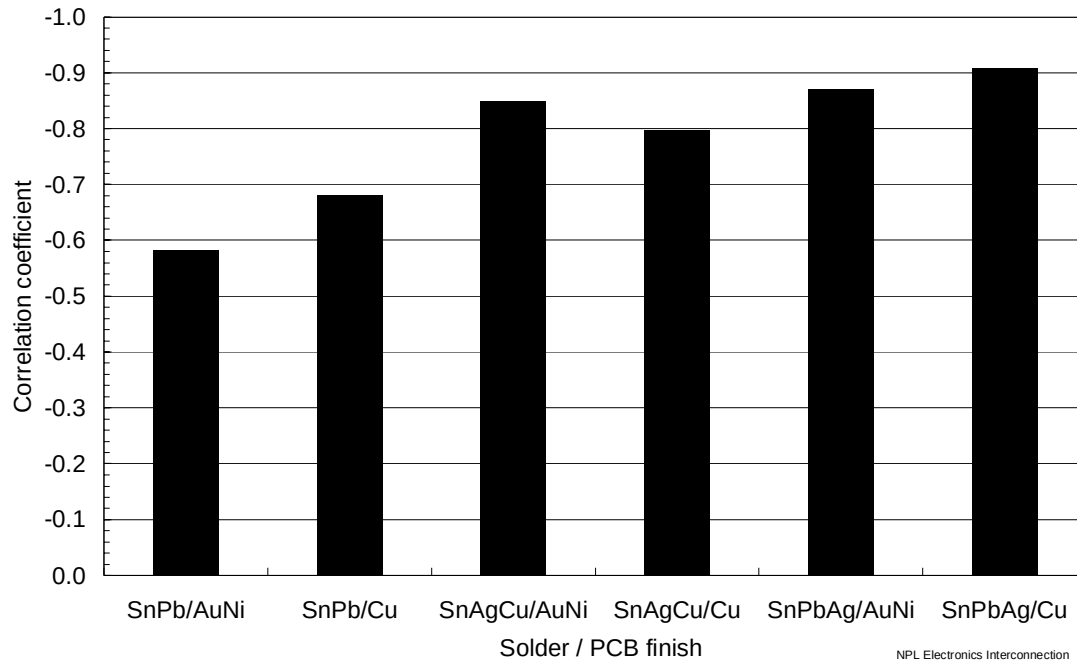


Figure 34. Correlation coefficients for shear and continuity tests for 2512-type resistors

The high correlation for the results using SnAgCu and SnPbAg solders is very encouraging, in particular for the potential use of the shear test to measure reliability. Although the results for the SnPb solder are not as good, they are significant enough for the technique to be useful.

Table 8 Correlation coefficients for shear and continuity tests for 2512-type resistors

Solder/PCB finish	Correlation coef. for R2512
SnPb/AuNi	-0.583
SnPb/Cu	-0.681
SnAgCu/AuNi	-0.849
SnAgCu/Cu	-0.798
SnPbAg/AuNi	-0.870
SnPbAg/Cu	-0.909

5 CONCLUSION

This study has investigated the reliability of SM components, ceramic chip resistors and BGAs, and with three solder alloys: eutectic tin-lead, eutectic tin-lead with 2% Ag, and finally the leading candidate for the lead-free alternative, the ternary SnAgCu eutectic. Two reliability indices have been used, the force required to shear a component, and the electrical continuity. They have been complemented with microstructural investigations.

- This investigation has shown that that a correlation exists between the results of shear testing and conventional continuity testing using DC techniques. This is alloy dependent, but for SnAgCu and SnPbAg solders the correlation is better than 90%; for SnPb solder the

correlation is 60%. Further work is recommended to explore the precise nature and the wider applicability of this important finding.

Further conclusions can be drawn from the performances of the different alloys. The resistance to solder joint fatigue for PBGA and 2512-type resistors was alloy dependent.

- For the PBGA components the lead-free SnAgCu eutectic alloy out-performed the lead-containing solders. However, for the ceramic 2512-type resistors the SnPb alloy had the superior performance.
- The results confirm previous findings that for BGAs the solder balls lying under the periphery of the silicon die are most likely to fail. The work also confirms that the ceramic resistors can fail at an early stage in accelerated testing, and hence constitute an excellent component for assessing solder joint reliability.
- In these trials the SnPbAg alloy consistently exhibited a performance that was poorer than that of the other solders. This is a somewhat surprising result and warrants further exploration.
- The NiAu pcb finish conferred superior pre-cycling joint strength when compared with the Cu(OSP) finish. However, after thermal cycling there was no difference between the results for the two pcb finishes. The PBGA results were also insensitive to the pcb finish.

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