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Assessment of Reterminated RoHS Components for SnPb Applications

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Abstract

The banning of Pb in electronic component termination finishes has flushed through the supply chain making it impossible in some cases for hi-reliability users to purchase Pb containing interconnects. It has also led to increasing problems with tin whiskers. Many end-users are now reterminating components with SnPb solder. This paper will discuss the results of a recent joint industry project undertaken at NPL to evaluate the retermination process on a range of electronic package styles. Details will be given of package styles covered, evaluation techniques employed, inter-comparison of reliability data, results and areas of concern.

Introduction

The introduction of European legislation that bans the use of lead in electronics (reference 1), has led industry to embrace new finishes on components that are lead-free. The electronics industry prefers to use fusible tin alloy coatings, since they have superior solderability, and consequently are more tolerant of deficiencies in the assembly process. However, none of the possible replacement alloys for SnPb plated finishes are a clear favourite compared to pure tin. They all have significant disadvantages from a plating perspective, while offering no advantages in the soldering process. Hence, pure tin is now dominating lead-free component supply. The Achilles heel of pure tin is the phenomena of spontaneous single crystal Sn growths, known as whiskers, which can occur under certain conditions. Whiskers can grow up to several millimetres in length and short out to adjacent contacts.

The banning of lead in electronic component termination finishes has flushed through the supply chain making it impossible in some cases to purchase lead containing interconnects. This issue is exercising military and avionics manufacturers who are not qualified to use lead-free parts and must re-terminate these parts to have tin-lead finishes. For many high reliability users, this is a real problem. They cannot obtain SnPb component coatings for many components but require a whisker-free assembly. Well documented failures due to tin whiskers range from communication satellites losses, missile and military radar failures, nuclear power station reactor shutdowns, through heart pacemakers and medical monitors, to poor reliability in consumer applications. NASA has an excellent web-site with many details on the occurrence of Sn whiskers (reference 2).

The solution, to which many end-users are turning, is to replace the Sn finish of components with a SnPb substitute by dipping into molten solder. This evaluation of the retermination process covered a comprehensive assessment of a range of components after retermination, assessing solder coverage and composition, solderability package to lead frame integrity, ball shear and moulded package integrity.

The project was conducted to two phases. Phase 1 was an intercomparison between a range of reterminated and as-received components. Phase 2 was a thermal cycle reliability comparison between the two types of components.

Phase 1 Methodology

A range of twenty five industry representative components were selected for processing at two different suppliers specialising in reterminating. All components were from RoHS compliant sources. Two thirds of the components were surface mount, ranging from chip resistors to QFP and BGAs, up to 256 I/Os. The remaining third were through-hole components, up to 14 I/Os. The package styles covered are given in Table 1 below.

Table 1: List of components assessed in the project

Identifier	Description	Package
Ret01	Resistor Network	SOIC14
Ret02	Power Mosfet	SOIC8
Ret03	CMOS 16-bit bus transceiver	TSSOP48
Ret04	Schottky diode	SOT-23-6
Ret05	CMOS Triple Buffer	SOT-23-8
Ret06	Tantalum capacitor	TAJ-D
Ret07	Surface mount LED	LED
Ret07	Surface mount LED	LED
Ret08	Voltage regulator	S-PAK7
Ret09	Dual Switching diode	TSLP-2-1
Ret10	Thick film chip resistor	R1206
Ret11	Thick film chip resistor	R2512
Ret12	Small signal diode	Axial
Ret13	Small signal diode	SOD80
Ret14	Dummy LQFP100 0.5mm pitch	LQFP100
Ret15	CABGA64-0.8mm pitch, 0.46mm ball dia	CABGA64
Ret23	Inductor	Axial
Ret24	Rectifier	Axial
Ret25	Capacitor	Axial
Ret27	Current Operational Amplifier	Radial
Ret30	PBGA256-1.0mm pitch, 0.5mm ball dia	PBGA256
Ret31	Daisy chained dummy SOIC14	SOIC14
Ret32	Polypropylene capacitor	Axial
Ret33	Regulator and Comparator	PDIP14
Ret35	Slide switch	TH Switch

After retermination the components were inspected for the following criteria;

(i) Termination composition using X-ray florescence (XRF).
(ii) Termination quality and coverage using optical microscopy.
(iii) Solder coating thickness, intermetallic compound thickness and package to lead frame integrity using metallurgical micro-sectioning, optical microscopy and scanning electron microscopy
(iv) Moulded packaging integrity using scanning acoustic microscopy
(v) Solderability with Gen 3 Mustmate III globule and bath testing system
(vi) BGA ball shear measurements

Phase 1 Results and Discussion

Termination composition

Following retermination all components were tested to determine the coating thickness and their elemental compositions using Fischer XAN-DPP X-ray florescence system. All showed acceptable levels of Pb with the lowest average being 25.9% and 27.4% for each of the two retermination process supliers. The component type in both cases was an LQFP100 (0.5mm pitch).

Termination quality and coverage

All reterminated components were inspected under microscope (magnification x10–60) to check solder coverage and other surface conditions. Relatively few problems were experienced with the surface mount components. The only issue of note was some bent terminations on LQFP100 components. These were restricted to the supplier which used manual handling during the retermination of these devices. Examples of these components after assembly and the resulting open and misaligned joints are given in Figure 1.

Some through-hole components exhibited issues with poor coverage and package body damage. Poor coverage occurred for two reasons. Firstly, some terminations exposed outside the package body were not solderable, due to the method of component manufacture. These were not solder coated during original manufacture and therefore it was not possible to reterminate these areas with SnPb solder. Examples of this can be seen in Figure 2. Other problems were experienced with components where the terminations extended into cavities within the component body. To prevent damage to the package body or solder wetting the body if metallic, the package bodies of such components were held above the solder pot during retermination. This resulted in incomplete conversion of the solder coating on the termination as the SnPb solder did not wet high enough along the termination (Figure 3).

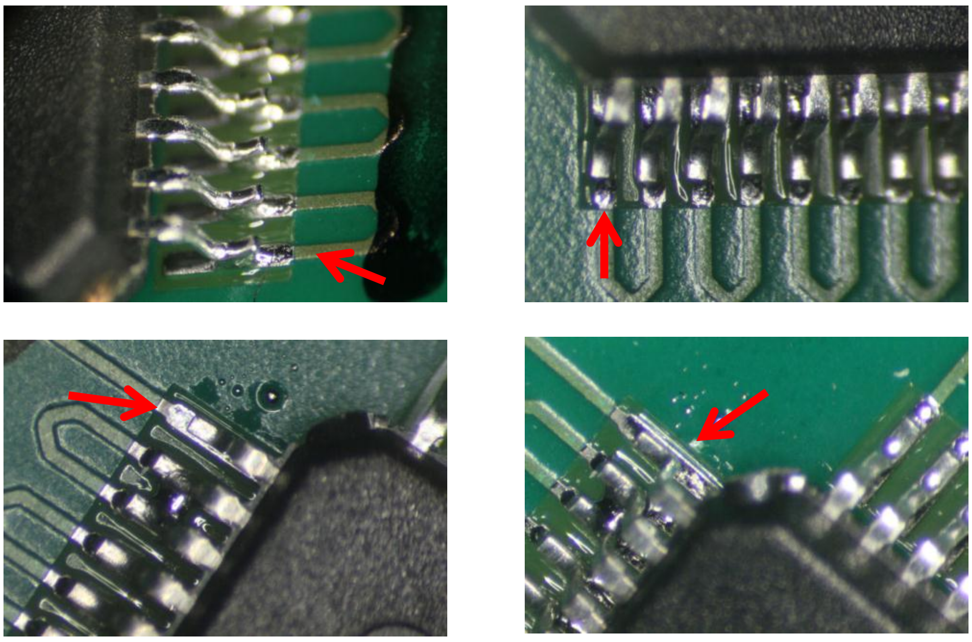

Figure 1: Examples of open joints and bent terminations on QFP components after manual handling during retermination

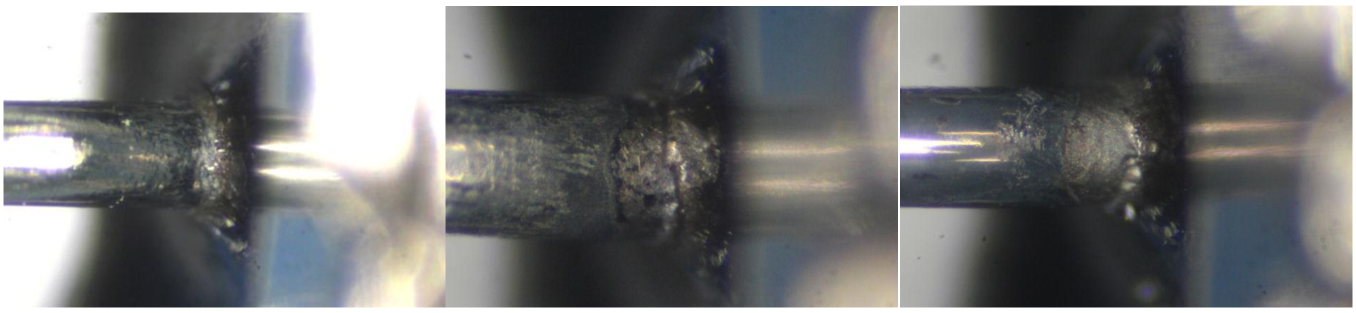

Figure 2: Showing upper termination areas on original (left) and reterminated examples (centre and right) exhibiting non-wetting due to original manufacturing issues

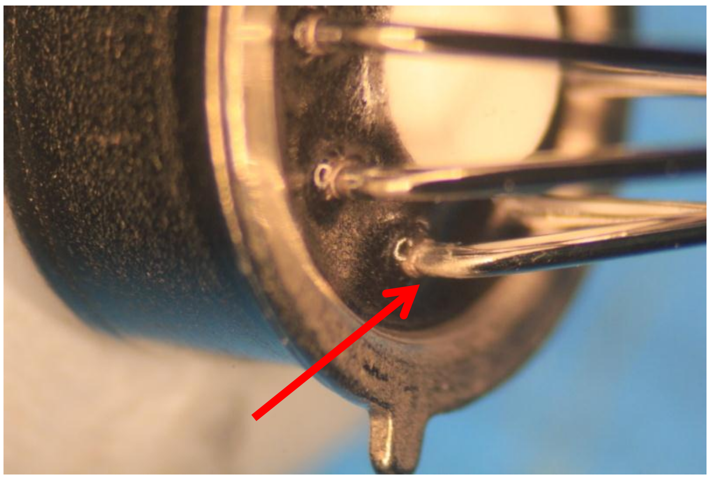

Figure 3: Showing unconverted region at top of termination inside metal can component recess

Several examples of damage to TH component bodies were also seen, with the possibility of exposing unconverted areas of the component termination (Figure 4 and Figure 5). It should be noted that in normal assembly, these areas of the components would not see molten solder temperatures being on the opposite side of the PCB to the soldering operation. However, during retermination, in an effort to achieve full conversion of the termination, package bodies may be subjected to temperatures well in excess of those to be expected in normal soldering.

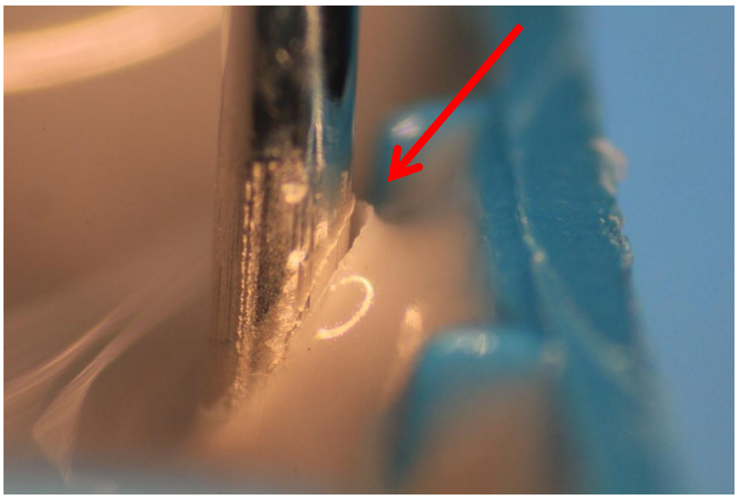

Figure 4: Separation of the component body encapsulant from the termination after conversion to SnPb

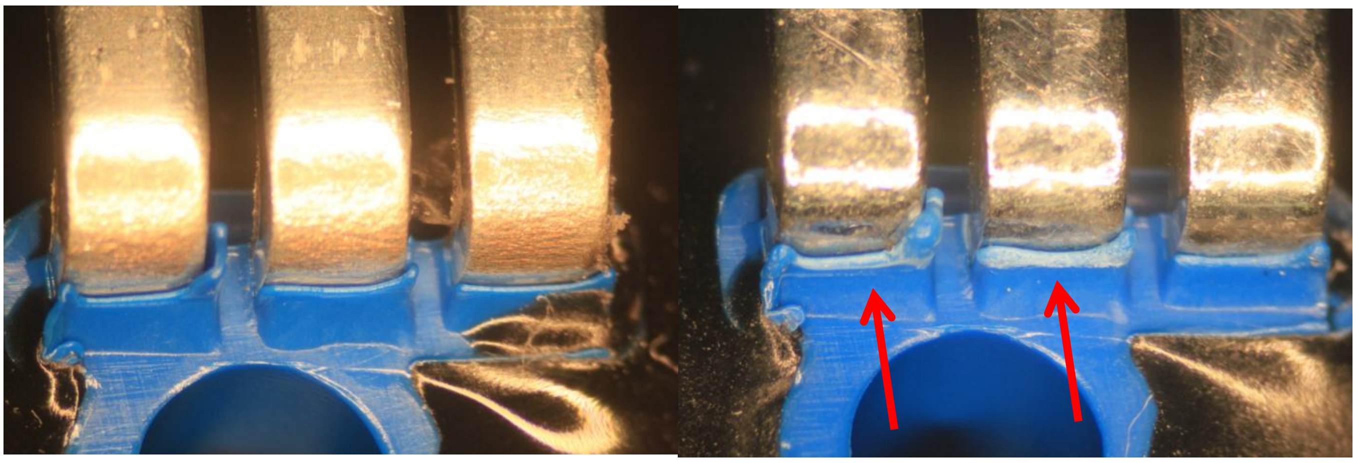

Figure 5: Body encapsulation before (left) and after (right) conversion to SnPb

Solder coating thickness, intermetallic compound thickness and package to lead frame integrity

Examination of micro-sections of both the original and reterminated samples showed greater variation in solder thickness of the reterminated samples. The molten SnPb formed menisci in lead bends of components causing significantly increased solder thickness as can be seen in Figure 6 and Figure 7. This could lead to placement problems in production particularly for fine pitch components. Additionally, thinner solder was noted around the edges of terminations compared to the original terminations. After long term storage, these areas may present poor solderability during assembly. No significant intermetallic thickening was noted as a result of the conversion process.

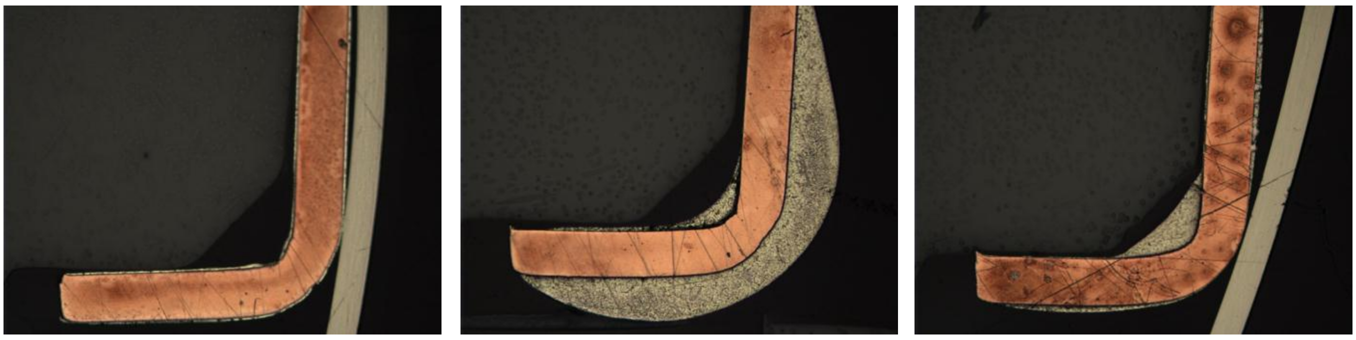

Figure 6: Optical micrographs of a SM LED terminations before (left) and after (centre and right) showing increased solder volume at termination bends

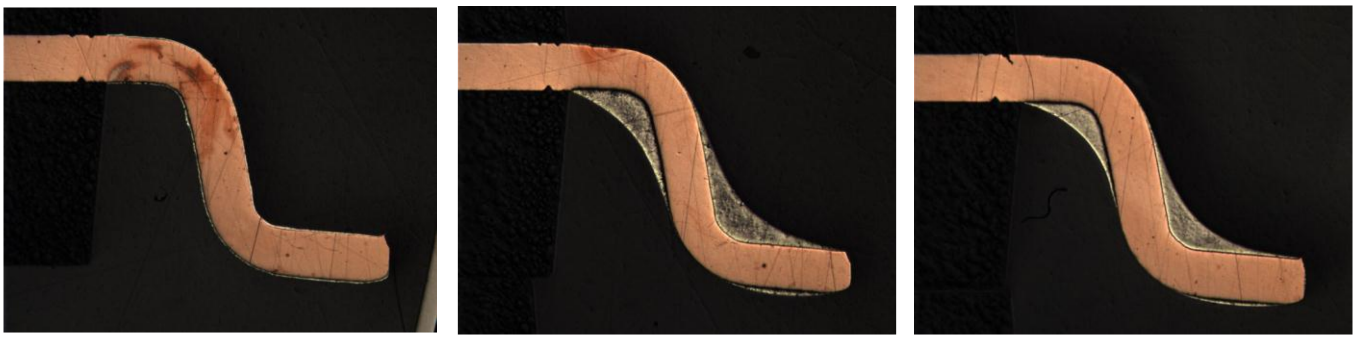

Figure 7: Optical micrographs of a SPAK gull-wing terminations before (left) and after (centre and right) showing increased solder volume at termination bends

Solder ingression along internal gull-wings of reterminated plastic bodied components was also noted in optical and SEM micrographs, an example is shown in Figure 8. This was confirmed to be SnPb using EDX analysis. No solder was present in the original components although the separation between the component body and lead-frame was present. It is perhaps, testament to the efficacy of the conversion process that SnPb has penetrated into the component body along the lead frame.

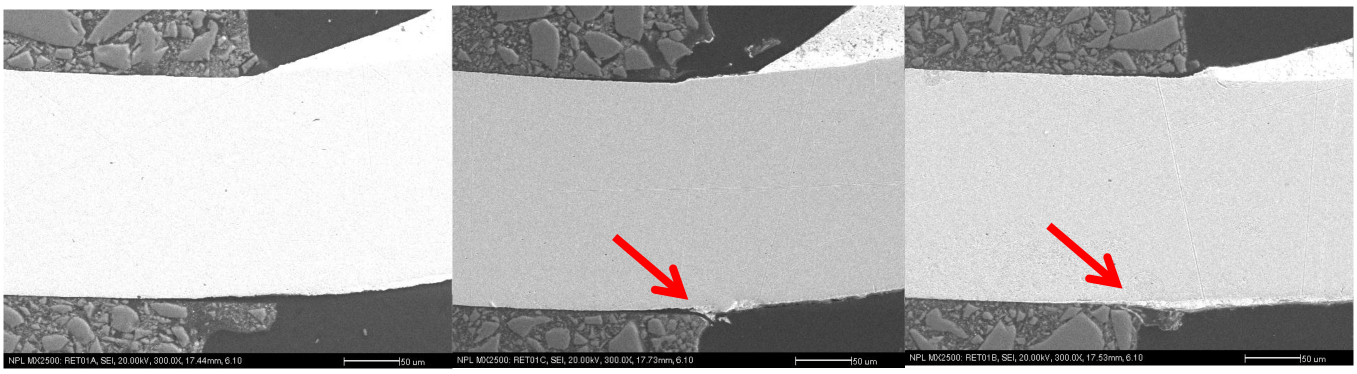

Figure 8: SEM micrographs of a LQFP100 gull-wing terminations before (left) and after (centre and right) showing solder ingression along lead frame

Moulded packaging integrity

Scanning acoustic microscopy was undertaken on all moulded plastic bodied devices in the study. SAM did not locate any differences between components before and after the retermination process.

Solderability

Quantitative solderability testing was undertaken on all components in the study and all components passed in the original and reterminated conditions. Example solderability test results are shown in Figure 9 and Figure 10. The solderability of the reterminated components was as good as or better than original components.

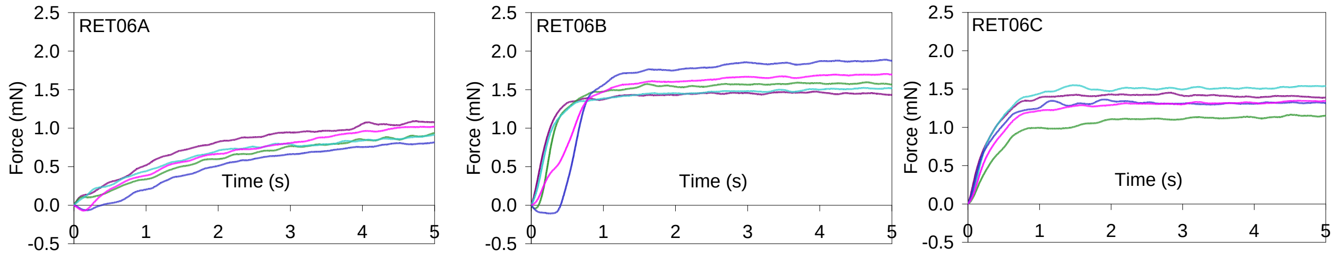

Figure 9 : Example solderability test results for a tantalum capacitor before (left) and after (centre and right) the retermination process.

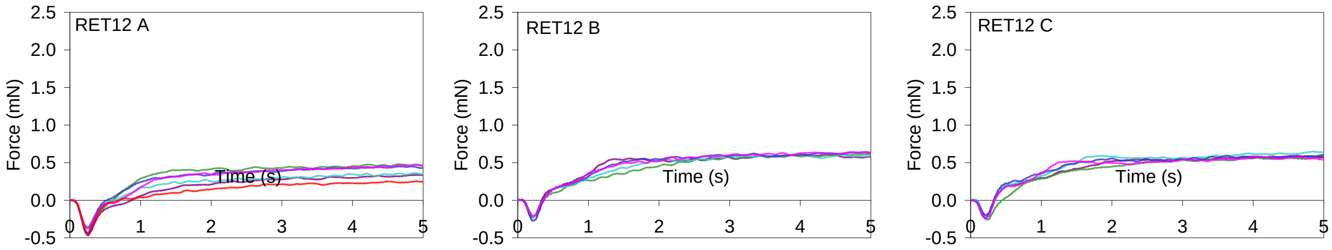

Figure 10: Example solderability test results for an axial diode before (left) and after (centre and right) the retermination process.

BGA ball shear measurements

Shear testing of the balls on the ball grid array component (PBGA256) are shown in Figure 11. The force required to shear the reterminated balls from the components was slightly lower than for the original components but this may be due to change in alloy from SAC to SnPb.

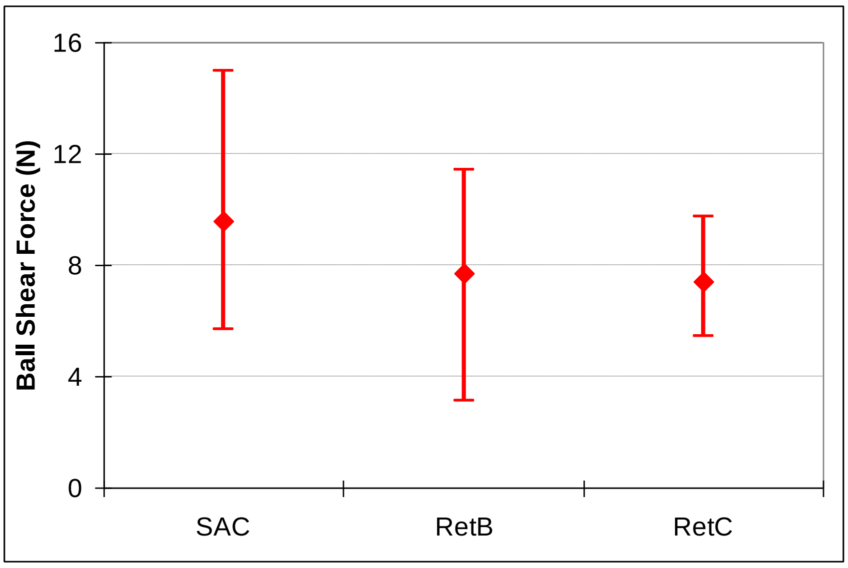

Figure 11: Comparison of shear test forces for the original SAC balls and reterminated SnPb balls (RetB & RetC)

Phase 2 Methodology

Test Vehicle Design, Assembly and Inspection

The test vehicle was specially designed to incorporate a range of common surface mount component styles currently in everyday use within the electronics assembly industry. The components incorporated were both as-received, RoHS compliant and refinished by the two specialist suppliers. A list of components and their termination finishes is given in Table 2.

Table 2: Component list

Component	As-received	Reterminator A	Reterminator B
PBGA256	**SnPb & SAC**	**SnPb**	**SnPb**
R2512	**Sn**	**SnPb**	**SnPb**
R1206	**Sn**	**SnPb**	**SnPb**
SOIC14	**Sn**	**SnPb**	**SnPb**
PQFP100	**Sn**	**SnPb**	**SnPb**

All components were interconnected to edge fingers for insertion into an edge connector. As components were internally daisy-chained or were low resistance, this enabled electrical resistance of the components to be constantly monitored to determine electrical failures. Each BGA has four separate, concentric interconnected rings as shown in Figure 12.

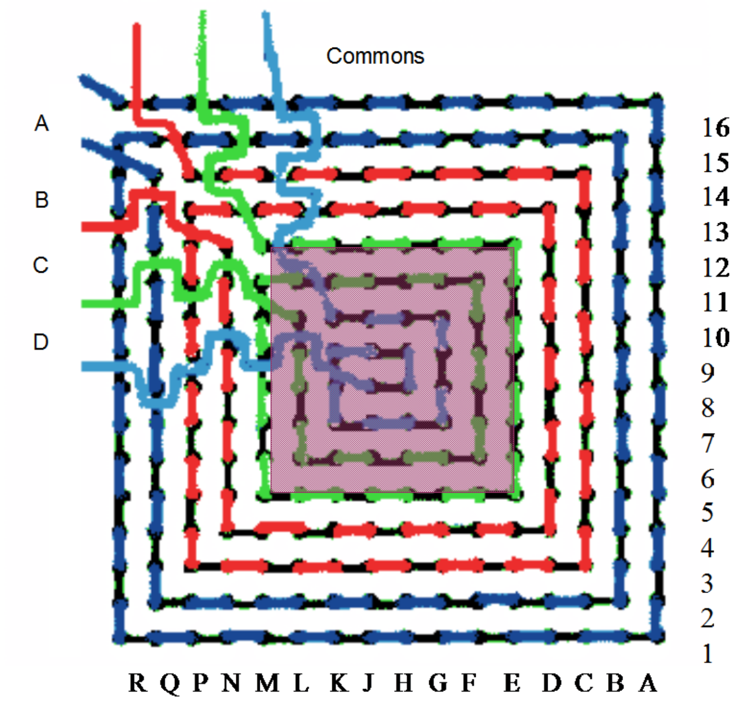

Figure 12. Diagram of daisy-chaining within BGAs showing four concentric interconnected rings (A, B, C and D)

The test board design incorporated 3 routed sections for easy breakout. This can be seen on the left-hand side of the board in Figure 13. These sections were utilised for shear testing.

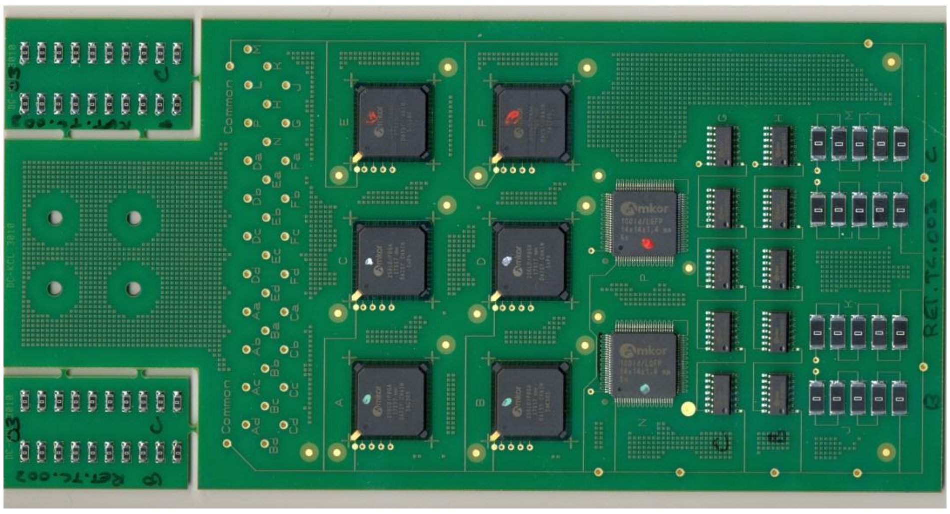

Figure 13. Test vehicle

A total of 15 assemblies in 10 batch variants were manufactured using reflow soldering of SnPb solder paste

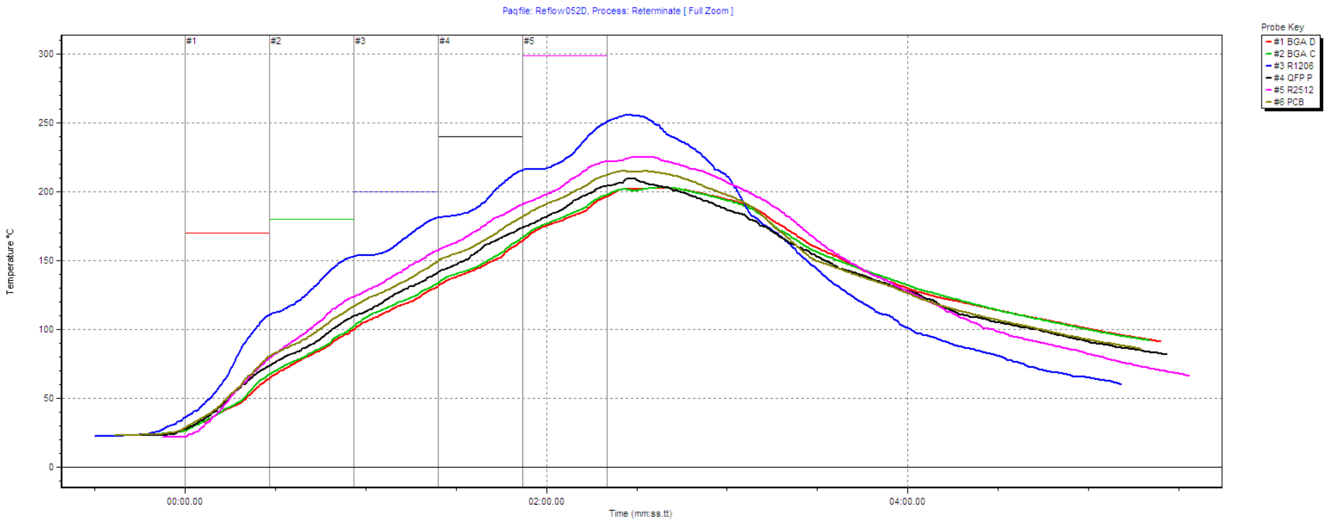

Figure 14. Thermal profile for reflow.

After soldering, all assemblies were 100% visually inspected by a single operator using a 10X to 30X stereo microscope. The assemblies were inspected to IPC A610 Rev C class 3. No rework was undertaken. Any defective solder joints were logged and removed from subsequent test results.

Test Vehicle Conditioning

Each assembly was subjected to 3000 thermal cycles, -55 to 125°C, 5 min dwells, ramps ~ 10°C/min. Constant electrical monitoring of the test vehicles was undertaken through the thermal cycling. Periodic shear testing of R1206 was undertaken at 0, 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2750 and 3000 cycles.

Shear Testing

The chip resistors are well suited to shear testing, having a flat edge to which a chisel tool can be easily positioned. Shear testing of resistors is shown in Figure 15.

The 1206 components were tested on the board in order to determine the ultimate shear strength for the SM joints (the maximum force prior to fracture). All testing of thermally cycled samples was undertaken at room temperature.

The shear test samples were on a routed section of the assembly, which could be easily removed to allow mounting in the shear test equipment. The stand-off height of the chisel tool above the PCB surface was 80μm. During each test, the shear tool was moved forward at a defined speed of 200μm/s against the test component, and the force was monitored until the solder joint broke. The shear tester is a Dage Series 4000, with a DS 100Kg testing head. Twelve 0603 and 1206 chip resistors were tested for each condition (24 on each PCB).

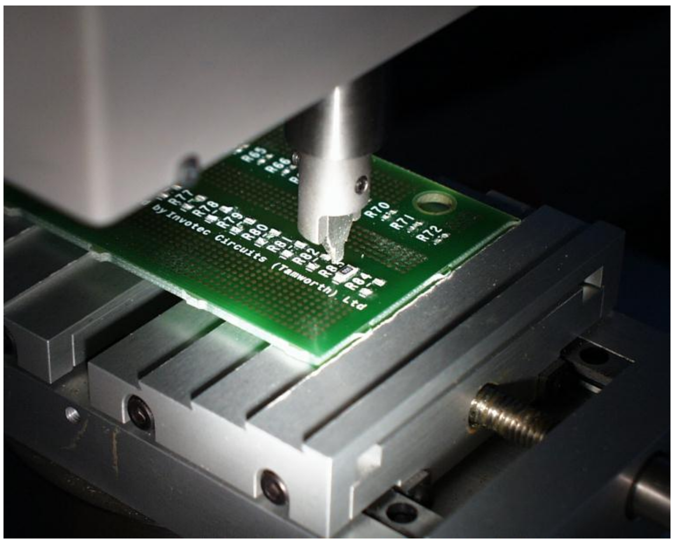

Figure 15: Shear test jig and push-off tool

Phase 2 Results and Discussion

Figure 16 shows the degradation of the shear strength of 1206 resistors as a function of thermal cycle conditioning. The degradation is similar for the three sample sets (A- as-received, B- first reterminator, C- second reterminator). The as-received exhibit slightly more rapid degradation in shear strength and this is related to the increased solder joint volumes associated with the reterminated components, resulting in a greater stand-off.

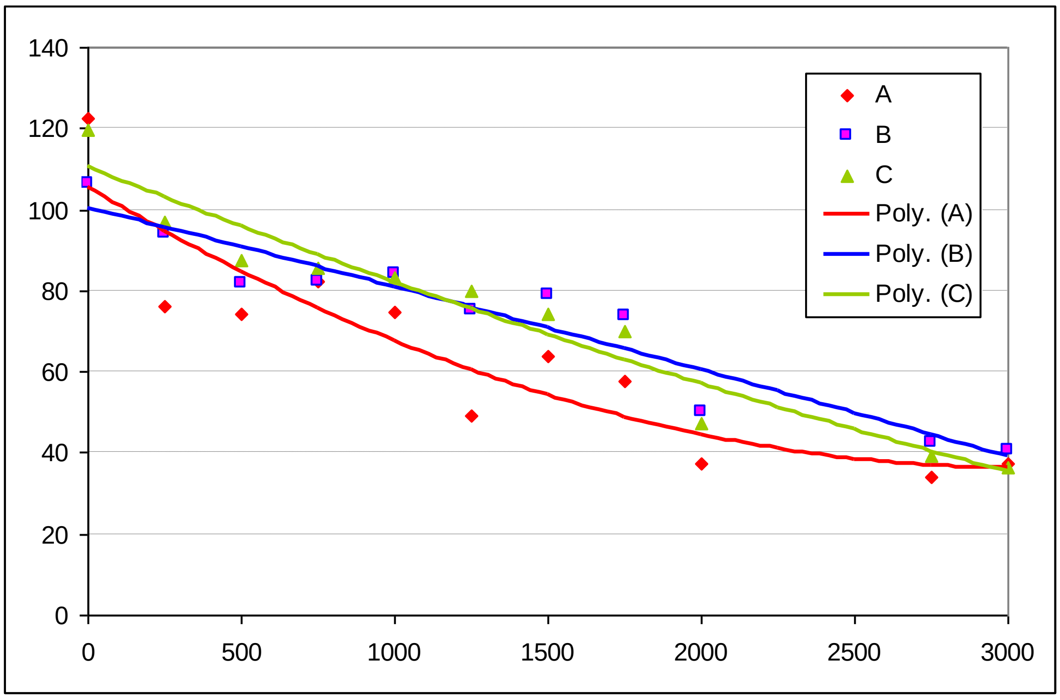

Figure 16: Degradation of the shear strength of 1206 resistors as a function of thermal cycle conditioning (A- as-received, B- first reterminator, C- second reterminator)

Figure 17 shows similar data for the constant monitoring of electrical performance of the 2512 resistors during the 3000+ cycles of thermal cycle conditioning. Electrical failures occurred earlier for the As-received Sn components (RETA). Few failures were experienced for either of the reterminated component sets (RETB & RETC). Again the higher failure rate of the Sn finished components is related to the increased solder joint volumes associated with the reterminated components, resulting in a greater stand-off.

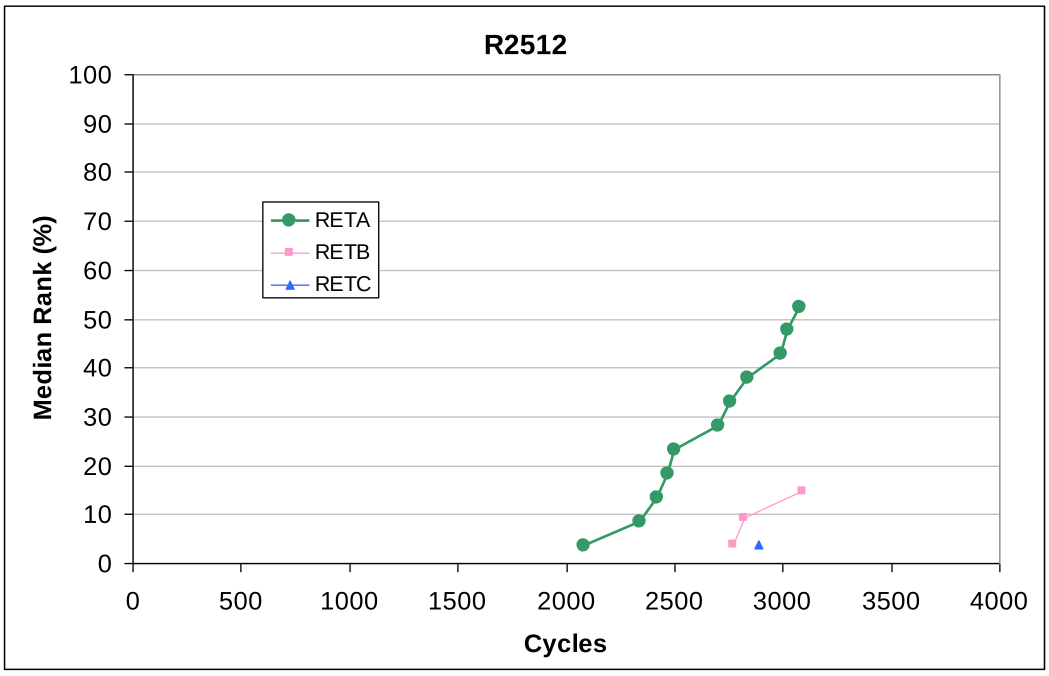

Figure 17: Electrical performance of the 2512 resistors during thermal cycle conditioning

Figure 18 shows the failure rate of the C-rings of the PBGA components as a function of thermal cycles. All three SnPb data sets (RET30B – first reterminator, RET30C – second reterminator, RET30SnPb – SnPb control) show very similar failure rates. The RET30C results indicate a slightly improved failure rate. This can be explained the standoff heights given in Table 3, where the height for RET30C can be seen to be greater than for the other components. This is due to a larger ball being used in this retermination operation. The performance of the SAC control BGAs is superior to the SnPb terminated examples because of the better fatigue performance of the SAC alloy at the strain rates generated during this type of thermal cycling.

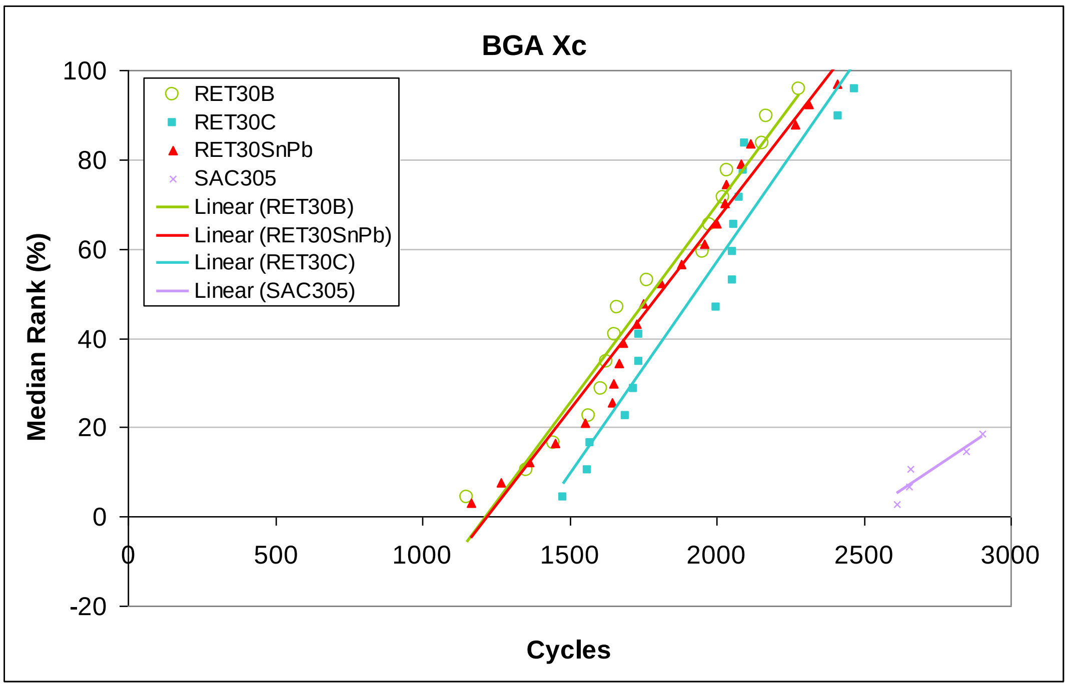

Figure 18: failure rate of the C-rings of the PBGA components as a function of thermal cycle conditioning (A- as-received, B- first reterminator, C- second reterminator)

Table 3: PBGA Standoff Measurements

Component	Standoff
PBGA SnPb control	**0.29mm**
PBGA RET30B	**0.30mm**
PBGA RET30C	**0.38mm**
PBGA SAC control	**0.30mm**

Phase 1 and Phase 2 Conclusions

A range of RoHS compliant components have been examined after retermination by two different retermination process suppliers. Few differences were noted between the suppliers, except that some damage to terminations of fine pitch gull wing leads was noted on the supplier who utilised manual handling during the retermination process. XRF measurements showed all components were RoHS non-compliant after retermination with at least 25% Pb present in all terminations. Solderability was acceptable for all reterminated components, being as good as or better than the measurements for the original components. In some examples, reterminated components showed increased solder thickness at the bend of terminations. This may lead to problems during component placement, particularly for fine pitch components. Additionally, thinner solder was noted around the edges of terminations compared to the original examples. After long term storage, these areas may present poor solderability during assembly. Solder ingression along internal gull-wings of reterminated plastic bodied components was also noted. No solder was seen in the original components although the separation between the component body and lead-frame was present. No significant intermetallic thickening was noted as a result of the conversion process. Some through-hole components exhibited issues with poor coverage and package body damage. Poor coverage occurred when terminations exposed outside the package body were not solderable, due to the method of component manufacture or where the terminations extended into cavities within the component body. Several examples of damage to TH component bodies were also seen in areas of components would not see molten solder temperatures in the soldering operation. Scanning acoustic microscopy did not locate any differences between original and reterminated components. Ball shear measurements on ball grid array components were acceptable. Thermal cycle solder joint reliability was improved for reterminated components compared to Sn originals. This was related to the increased solder joint volumes associated with the reterminated components, resulting in a greater stand-off.

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References

1. DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment; http://www.rohs.gov.uk/Docs/Links/RoHS%20directive.pdf
2. http://nepp.nasa.gov/whisker/