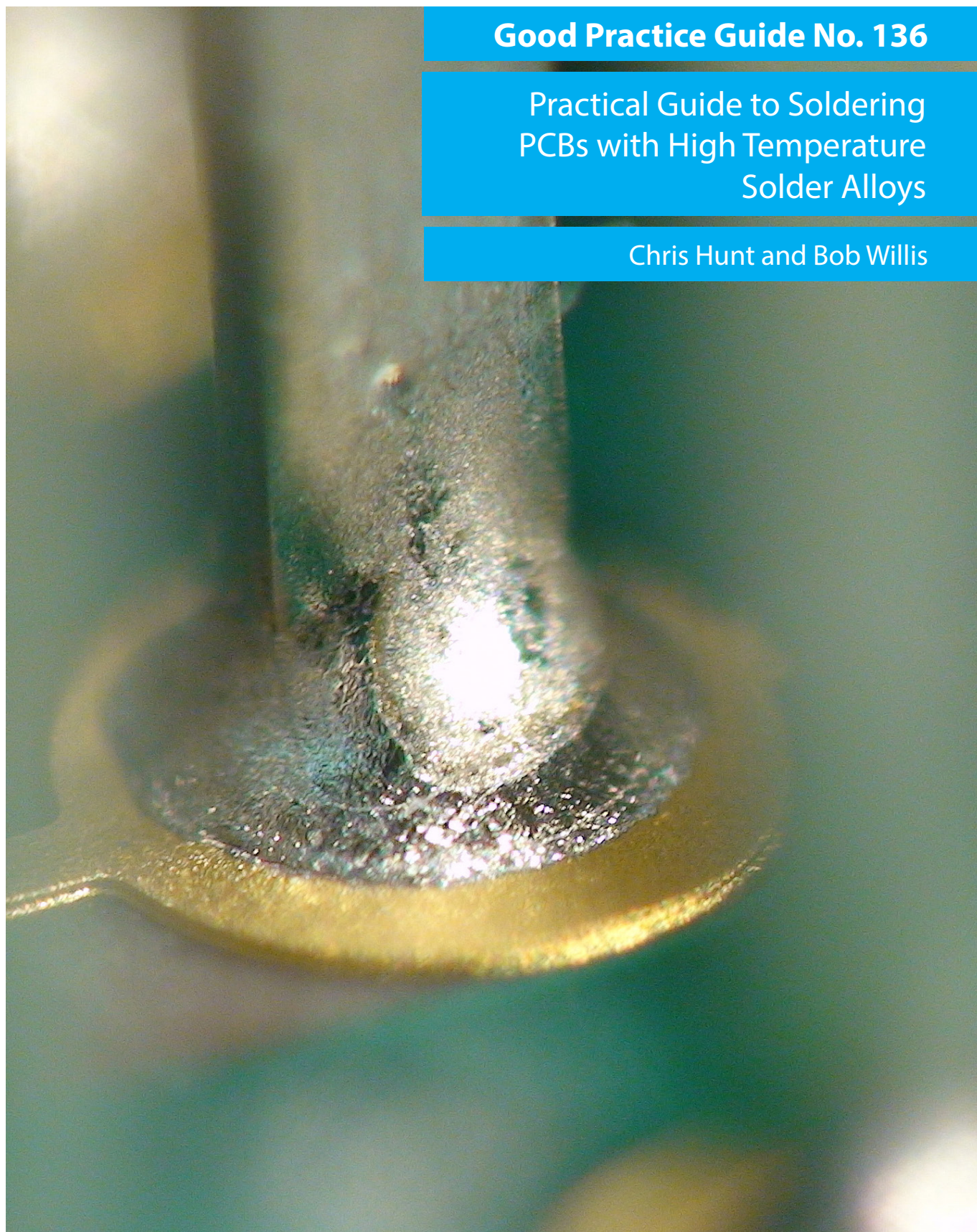


Good Practice Guide No. 136

Practical Guide to Soldering
PCBs with High Temperature
Solder Alloys

Chris Hunt and Bob Willis



Measurement Good Practice Guide No. 136

Practical Guide to Soldering PCBs with High Temperature Solder Alloys

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Materials Division

***Electronic Presentation Services**

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1 Introduction

Over the past few years there has been a lot of discussion on the need for higher temperature materials and expanding the use and knowledge of high temperature assembly techniques. When we start to talk about high temperature electronics it is not just the solder alloy but all of the materials that go to produce an electronic assembly. Substrates, components, connectors, cables and solder need to be examined; the needs of the assembly process also require careful consideration. Often due to the smaller volumes many companies who require high temperature capability have used manual soldering techniques particularly for through hole. Working at high temperature generally means operating between 150 °C-200 °C; however, there are many applications that have to work at much higher levels, up to 300 °C. Typically the industries affected by these hostile working conditions include, aerospace, automotive, petrochemical and military.

2 Investigation Outline

This short investigation was undertaken to obtain a basic understanding of the impact of through hole solder joints in high temperature applications after artificially ageing. The aim of this investigation was to get a better understanding of existing assembly methods and future soldering processes. Although the industry has been using high melting point lead/tin solders for many years there is limited information available. Generally there is limited reference to inspection criteria for soldering joints or the different process issues that may be experienced. The following report outlines the basic trials conducted and some of the important issues that must be considered during the design and assembly using different selective soldering techniques.

The following steps were undertaken during this investigation:

- Assemble through hole connectors
- Solder through hole joints using different solder alloys
- Undertake visual and X-ray inspection
- Microsection joints and measure the intermetallic thickness
- Expose samples to high temperature storage
- Microsection joints and measure the intermetallic thickness after ageing
- Visually inspect boards after ageing

In addition two other short exercises were conducted to make good use of the environmental test chamber time and to give an initial understanding of the impact of ageing on other materials which could be used during surface mount assembly. Six different conductive materials proposed for alternative die attachment were used to bond 1206 chip components to polyimide test substrates. The component joints were tested for shear strength before and after ageing for 1000hr at 200 °C. Sample bare boards were conformally coated to also look at the impact on two silicon and one Parylene coating after ageing at 200 °C.

3 Printed Circuit Boards

For high temperature operation up to 200 °C there is basically one option for traditional organic laminate. Polyimide laminate construction has been successfully used for many years for high temperature operation typically around 150-175 °C. The solder mask material and the solder finish also need to be considered for this high temperature post assembly environment. The most common surface finish selected for these applications is gold over nickel. In the case of the samples tested the solder mask was Sun Chemicals (Coats) XV501T

The laminate materials used during these trials are listed below.

A - MeteorWave

B - Nelco N7000 Polyimide

C - Ventec VT901 Polyimide

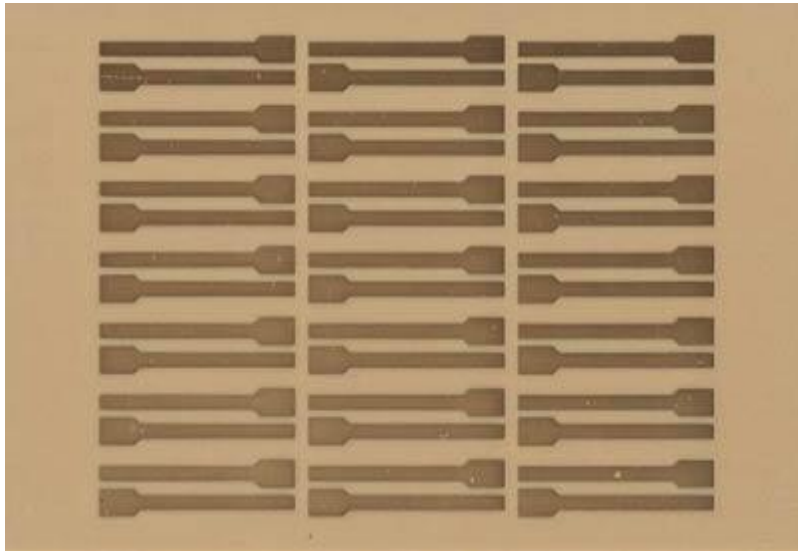
D - ISOLA P96 Polyimide

The test boards for assembly, thermal shock and peel testing were all produced by Merlin Circuits

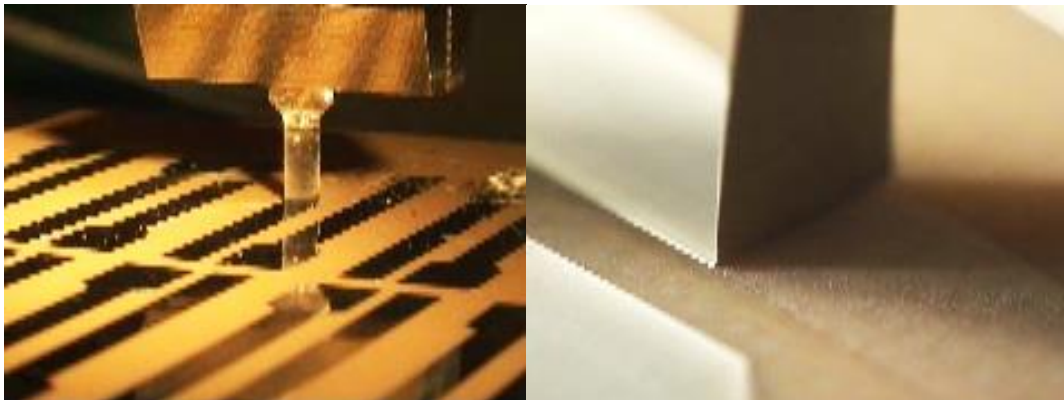
Assembly Test Board 1.6 mm 4 LAYER Preferred Polyimide Build

½ oz COPPER PLATED TO 1 oz		0.038 mm
0.1 mm DURAVER P96 SINGLE SIDED CORE		0.100 mm
1 x 1080 DURAVER P96 PRE-PREG		0.078 mm
1 x 1080 DURAVER P96 PRE-PREG		0.061 mm
1 oz COPPER		0.033 mm
1.00mm DURAVER P96 CORE		1.000 mm
1 oz COPPER		0.033 mm
1 x 1080 DURAVER P96 PRE-PREG		0.061 mm
1 x 1080 DURAVER P96 PRE-PREG		0.078 mm
0.1mm DURAVER P96 SINGLE SIDED CORE		0.100 mm
½ oz COPPER PLATED TO 1 oz		0.038 mm

During the project two bare board tests, thermal shock and copper foil adhesion, were conducted on a sample of the polyimide material (ISOLA P96 Polyimide). Testing was not conducted on all of the materials due to the size of the project and materials available. These were conducted on existing test patterns used at Merlin. The testing on adhesion was conducted on samples prior to exposure to 200 °C and after 500 and 1000 hr. Three surface finishes were included, lead-free solder level, gold over nickel and silver. Adhesion testing was conducted using a DAGE bond tester fitted with a peel test head and moving stage. The testing was conducted in line with IPC standards; however, the length of copper foil peeled during testing was 20 mm rather than 25 mm.



Polyimide peel test board consisted of 42 test strips



Peel test being conducted on a DAGE bond tester

Peel test results for the test boards at 0 hr

Nickel/Gold	5.46 N
Solder levelled	5.34 N
Silver	5.33 N

Peel test results for the test boards at 500 hr

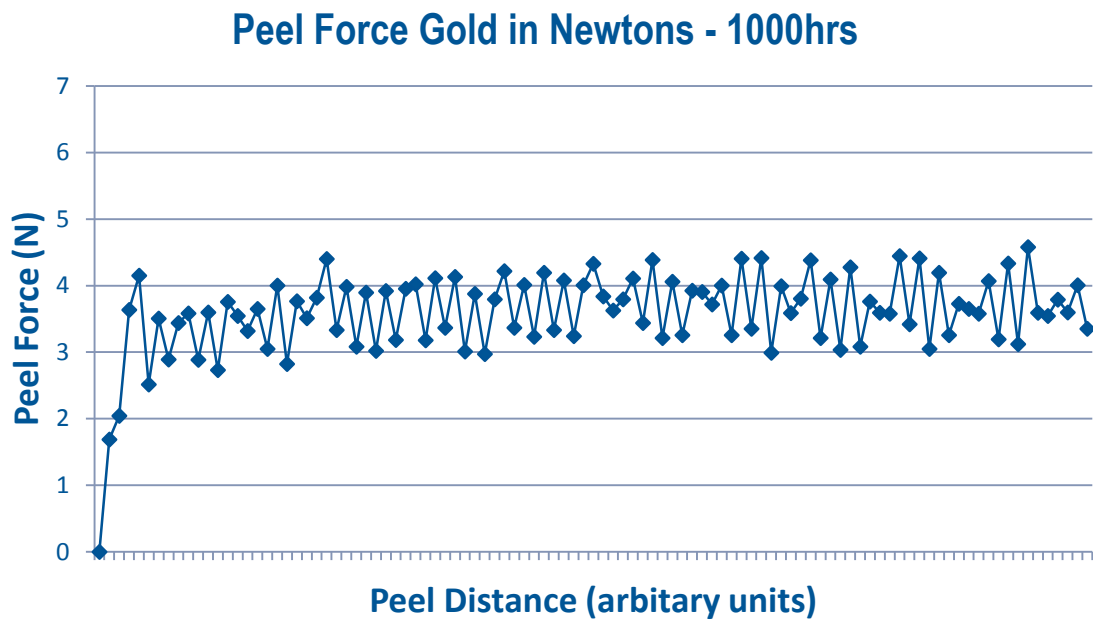
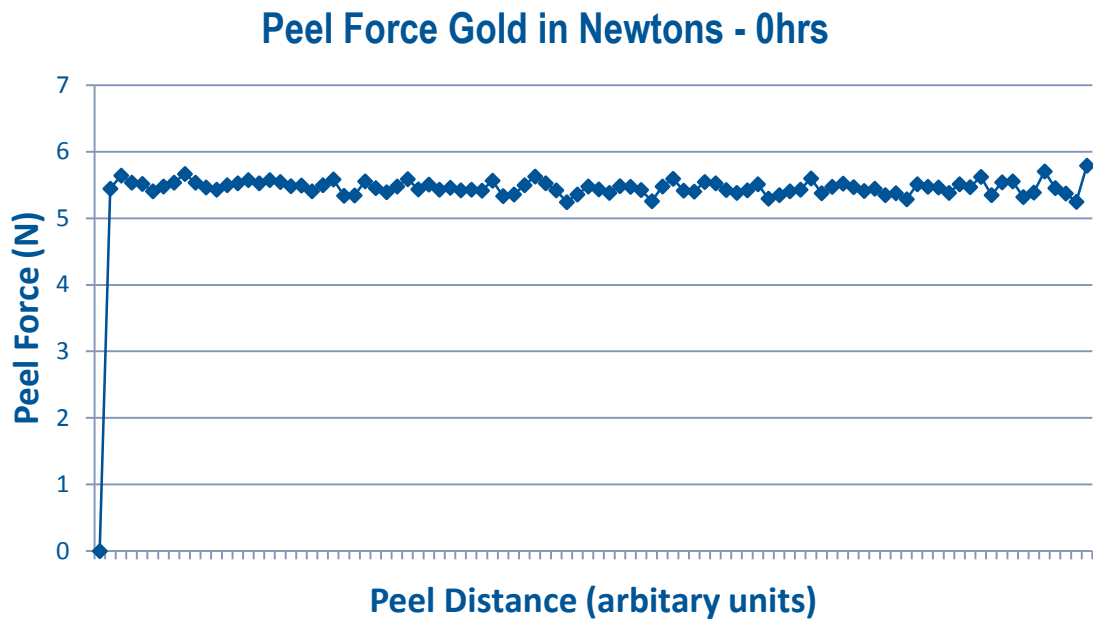
Nickel/Gold	4.12 N
Solder levelled	4.34 N
Silver	4.62 N

Peel test results for the test boards at 1000 hr

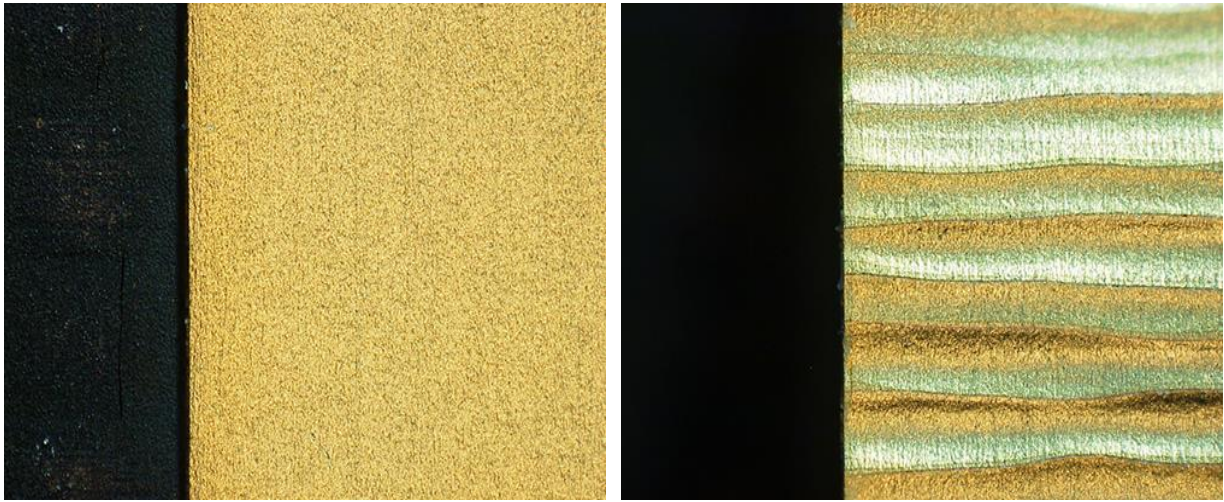
Nickel/Gold	3.64 N
Solder levelled	3.85 N
Silver	3.54 N

A recommendation to engineers conducting peel measurement is to prepare the samples for measurement prior to ageing. The simplest way is to start lifting the wide section of the track, then continue peeling tracks just beyond the point where the track necks down ready for clamping in the machine jaws. After ageing in a static oven it is more difficult to start the track peeling process on test boards. It would also be beneficial to modify the artwork to reduce the sharp transition between the track sizes to avoid breaking tracks during sample preparation.

The results of the peel test were satisfactory and in line with existing standards. One observation was the distinct cracking noise heard during peel testing on nickel/gold samples. As the foil is peeled from the surface of the laminate the cracking of the nickel can always be heard. After ageing the tone of the cracking sound changes and with it measurement fluctuation on the peak of the graph. The level of sound is noticeable due to the size of the track used on the test board and may not be detectable with existing track widths on production boards.

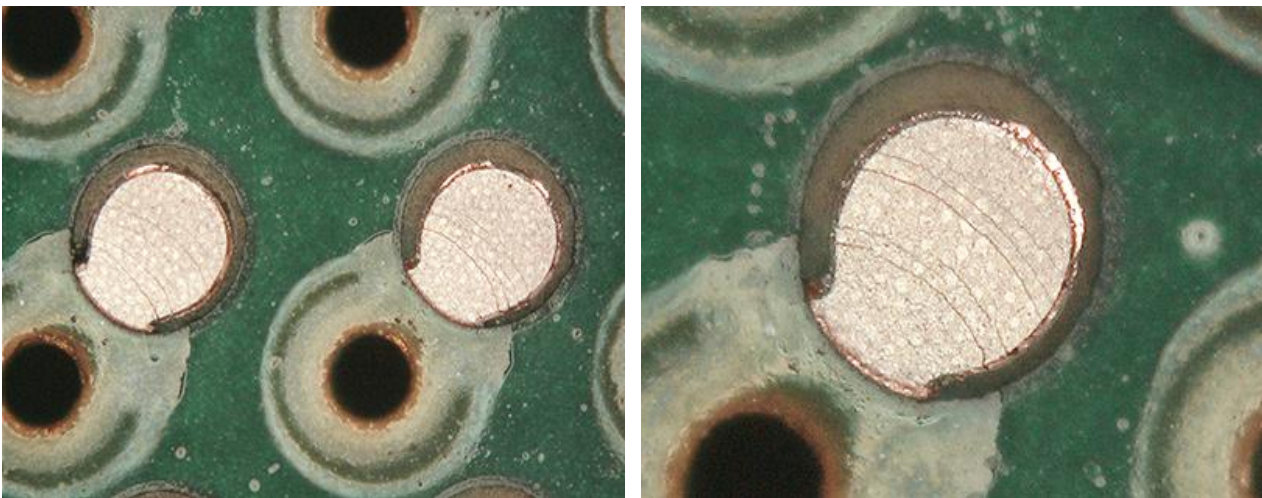


The graphs above show the peel strength measurements conducted on gold over nickel tracks before and after ageing. The peel force did reduce as expected and was seen on other finishes. The peak peel force variation or noise is obvious on the automated measurement system



The images above show the copper foil surface with nickel/gold before ageing (left) and after ageing then peeling (right) from the surface of the laminate

Cracking is not unusual and is quite common to see visually when conducting mechanical tests on area array solder joints on other projects, as with pads lifted from the surface of the board during dye and pry testing. It can also be seen on pads where high speed shear testing is conducted and the pad peels from the laminate surface as the ball joint separates.



Examples of BGA pads after dye and pry showing crack lines across the pads. The images are included here for reference and were not part of this project

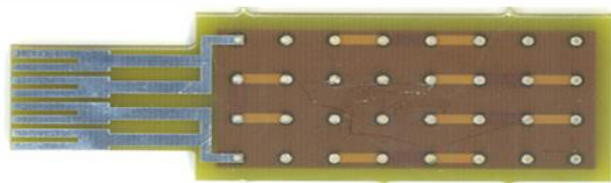
3.1 PCB Thermal Shock Testing on Substrate

Thermal shock test coupons were subjected to immersion in water at ambient temperature then lowered into a fluidised sand bath at 260 °C. This procedure is conducted six times for each of the samples. The resistance change is measured continuously during the test; increases in resistance may indicate that cracking is occurring in one or more of the plated through hole samples. This would normally occur around the knee of the plated through hole or, in the case of multilayer boards, at one of the inner layer interfaces. This is more likely to occur on multilayer boards or with material that has a large Z expansion rate during soldering or temperature cycling. Measurements did not exceed change in resistance allowed

during thermal cycling on any of the samples tested. Microsections of the samples did not show any cracking on the highest stress points on the knee of the holes.



Images above show Cemco equipment used for thermal shock. On the left is the water bath and fluidised sand bath, on the right is sample head and measurement system



A typical test board used for thermal shock resistance change is shown above

The samples used for the change in resistance test were confined to solder levelled boards as it was felt that these were most likely to show a change in resistance and possible cracking in the copper. The samples were solder levelled in a vertical solder levelling system with tin/copper/nickel. The microsection taken after the sand bath and change in resistance testing show the solder coating in the barrel of the plated through holes.

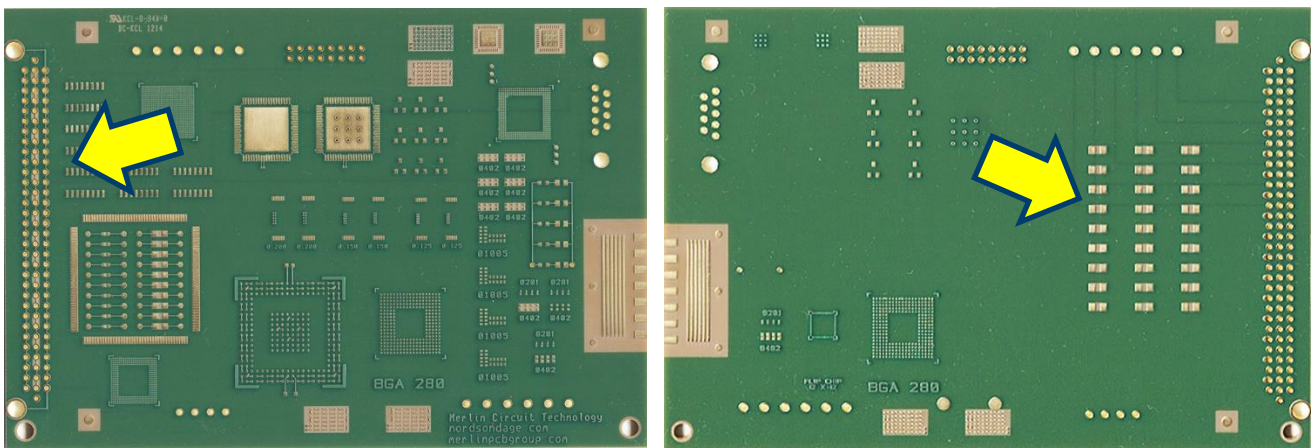


There was no evidence of cracking on the knee of plated through holes or at the through hole plating to inner layer junctions

4 Polyimide Test Board and Assembly

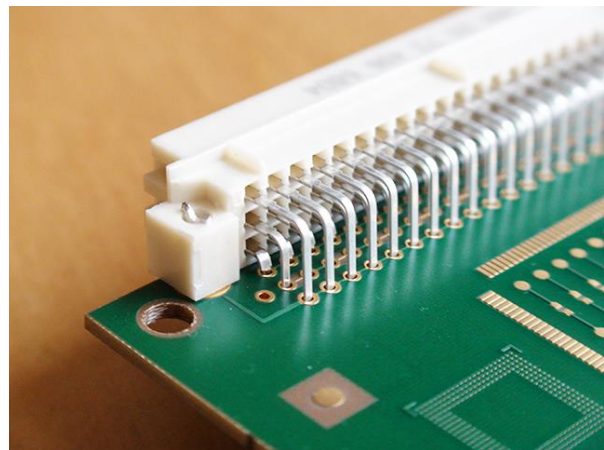
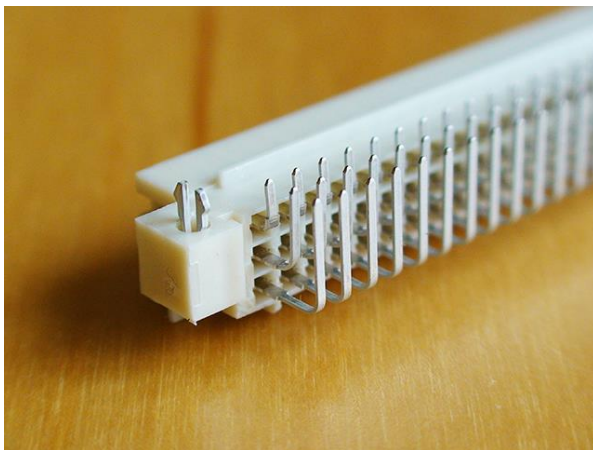
In many cases the assembly of products for the high temperature applications are either small or medium volume and can be successfully produced using manual soldering for through hole applications. Automated point soldering or selective soldering may also be used if the quantity of products required are higher or a company wants to automate the process. In this project we have used manual soldering, selective, robotic tip and laser soldering to produce sample joints with different alloys.

The solder wire flux cores in existing high temperature products were formulated many years ago and are not necessarily optimised to leave a low volume of residue on the surface of the board. The materials do work successfully but they would not be considered low residue. Existing suppliers offering High Melting Point (HMP) alloys and silver antimony (Sn95 Sb5) leave a lot of flux residues. Normally in this case the flux residues would be removed for conformally coating the boards, but in the case of the trials it is also important to clean the boards prior to high temperature storage testing. If not the residues become very difficult to remove and can make good adhesion of the epoxy difficult during preparation of microsections.

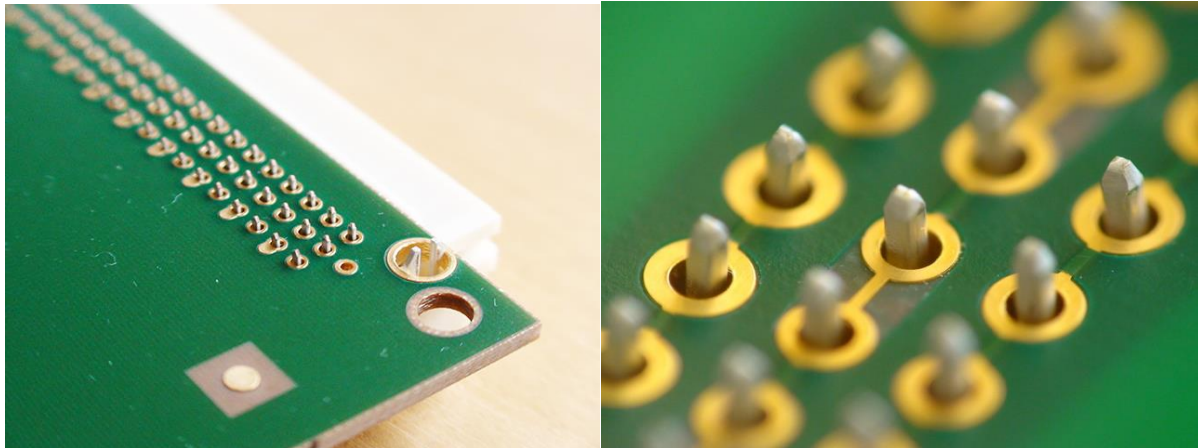


Samples were soldered using tin/copper, tin/silver/copper, HMP and Tin/Antimony solder wire

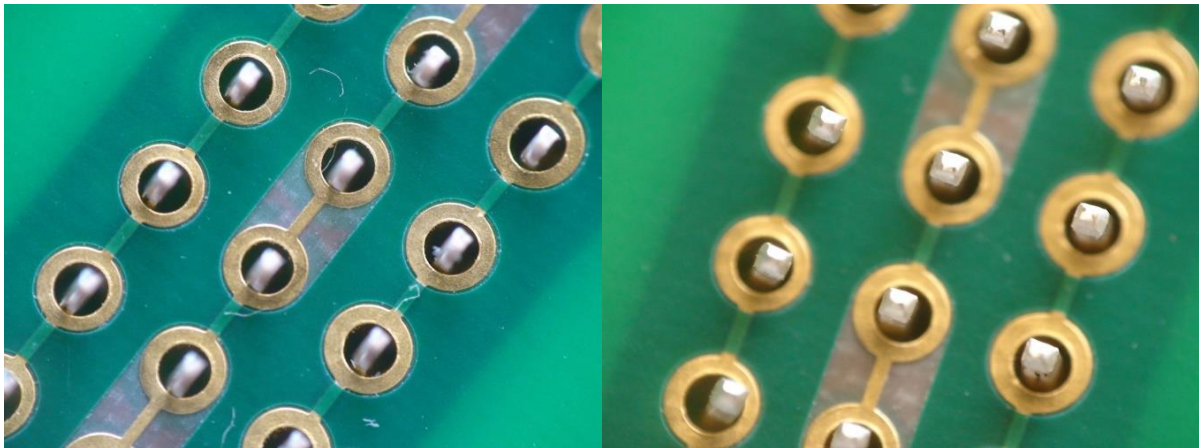
Printed circuit board design shown above was used for the soldering trials. The left image shows side one where the connector was positioned as indicated by the arrow. Side two was used for soldering of 1206 chip resistors as indicated by the arrow.



A three row high temperature connector was manually inserted into the board for soldering. The example connector does have a barb hold down feature to retain the connector to the board prior to soldering. This provides mechanical support prior to soldering and then is not required.



Example of the connector held in place prior to soldering with the metal stakes. This board design has also been used in the past for testing through hole intrusive reflow joints and mixed solder alloys in NPL projects. The author has also used this test board and connector for reflow soldering tin/copper/nickel and tin/silver/copper paste. Reports are listed and can be obtained via the NPL Defect Database <http://defectsdatabase.npl.co.uk>



In the above examples of similar connectors the pin cross section may be square or oblong, the largest dimension is taken across the opposite corners to define the finished hole size for manufacture. The benefits of having square or round pins is the reduced solder required for filling the plated hole, which is a benefit in selective soldering with cored wire or intrusive reflow with solder paste.

One of the important things with through hole soldering is the lead to hole ratio; in this case it is based on the pin size. The finished hole size required on the PCB after plating and surface finishes like nickel/gold would be the pin size plus 0.010" to make manual or automated through hole assembly easy. In this example where the pin is oblong the largest measurement for the pin is across the corners as indicated. The second example above shows the same connector but with square pins. When manually soldering, the difference in the hole fill can be adjusted by the operator feeding in more or less wire. Selective and wave soldering can tolerate some variation with little impact on the capillary fill of the hole. In the case of laser and robotic tip soldering the system computer needs to be programmed with the solder wire size and feed rate to achieve the desired through hole fill. If the connector pin or hole

size changes there will be too little or too much solder. Some systems, however, are able to automatically calculate the volume size requirement then adjust the solder feed.

4.1 Solder Alloys Used in the Production Trials

Tin/Copper/Nickel	Sn-0.7Cu	227 °C
Lead/Tin/Silver	Pb93-Sn5-Ag2	296-300 °C
Tin/Silver	Sn-3.5Ag	221 °C
Tin/Silver/Copper	Sn-3.8Ag-0.7Cu	217-221 °C
Lead/Tin	Pb980-10Sn	268-302 °C

It is worth mentioning that depending on which industry you work the meaning of High Melting Point (HMP) solder can vary. It is always important to check the alloy in question rather than just assume that HMP means lead/tin or lead/tin/silver.

4.2 Manual Hand Soldering

The soldering and desoldering process with higher melting point wires still follows standard good practice procedures but at some point manual soldering cannot achieve the ideal joint. The first step is to consider pre-heating the product for either initial soldering or rework. These practices have already been successfully used with standard lead-free alloys like SnCu, SAC and lead based HMP solders. However, the high lead based alloys do need more practice to get right.

Selected soldering iron suppliers offer the use of nitrogen which is introduced around the soldering tip. This has been beneficial when using low residue products but may not be so beneficial with high solids cored wire. Nitrogen is either produced locally to the soldering iron with small generator or provided from a company site facility. Suppliers have introduced nitrogen flowing around the heater before surrounding the soldering iron tip and joint. There is a benefit to the nitrogen being heated to avoid temperature fluctuation when introducing a cool stream of gas even at very low flow rates. Primarily the advantage is to reduce surface oxide formation on any surfaces particularly when the temperature is higher. In the majority of cases de-soldering of high temperature joints cannot be achieved successfully without preheat and also need contact tools to reflow the solder prior to package removal.

In automated soldering process where speed is important there is a benefit to preheating the joint area, also increasing the wetting characteristics of some surface finishes. Preheating can reduce solder wire spitting, another common problem where solder wire is fed direct to the tip or into the joint. Benefits have been seen with some soldering iron suppliers that have integrated their existing tools into robotic soldering cells. Set up and calibration can be achieved with special test boards and using thermal imaging cameras to compare temperature rise on the substrate with the degree in wetting.

Care needs to be taken with the soldering tips as inevitably they will have a shorter life due to the elevated temperature. In the past we have experienced the impact on soldering iron tips when the plating is damaged or poorly plated during manufacture. The core of the tip can be eroded by the tin if the plating on the tip is damaged. It is a difficult balance for tip producers to use the right balance of over plating and barrier coatings and not impact the heating capability and stability of temperature control at the soldering tip.

4.3 Selective Soldering

The selective soldering of sample boards was conducted in the traditional way using an ACE KISS-102 Selective Soldering machine with a 12 mm nozzle. A wide soldering nozzle helped to maintain the heat of the two high temperature alloys as the solder progressively wicked up the barrel of the plated through holes. This may also be the best approach if thicker boards or denser connections are made on inner layers. The flux was applied with a drop jet nozzle for accurate, localised application.

It is important to use the minimum amount of flux to achieve the required hole fill. It is still possible to conformally coat boards in a no clean process. In many industries this has been standard practice for many years although cleaning is definitely increasing in popularity to give a high level of confidence in the reliability and a simplified material selection process. Soldering was conducted by bringing the 12 mm nozzle up to the board and running the wave down the length of the connector. The soldering performance exceeded IPC 610 with very little flux residue left on the surface of the joints or solder mask. There was evidence of solder balling between pins adhering to the solder mask surface. This is not uncommon and the solder mask and flux combination could be reviewed in pre-production trials. It is very common in manufacture not to specify the solder mask material type used or conduct trials on compatibility between materials, which is poor engineering practice.

Sample boards were soldered using HMP Sn10Pb90 and Tin/Antimony Sn95Sb05 solder and an AIM liquid flux NC277. The dwell time for the joints was approximately 1-2 second with a nozzle speed of 229 mm/min. The solder temperature for HMP was 360 °C and 340 °C for Tin/Antimony.

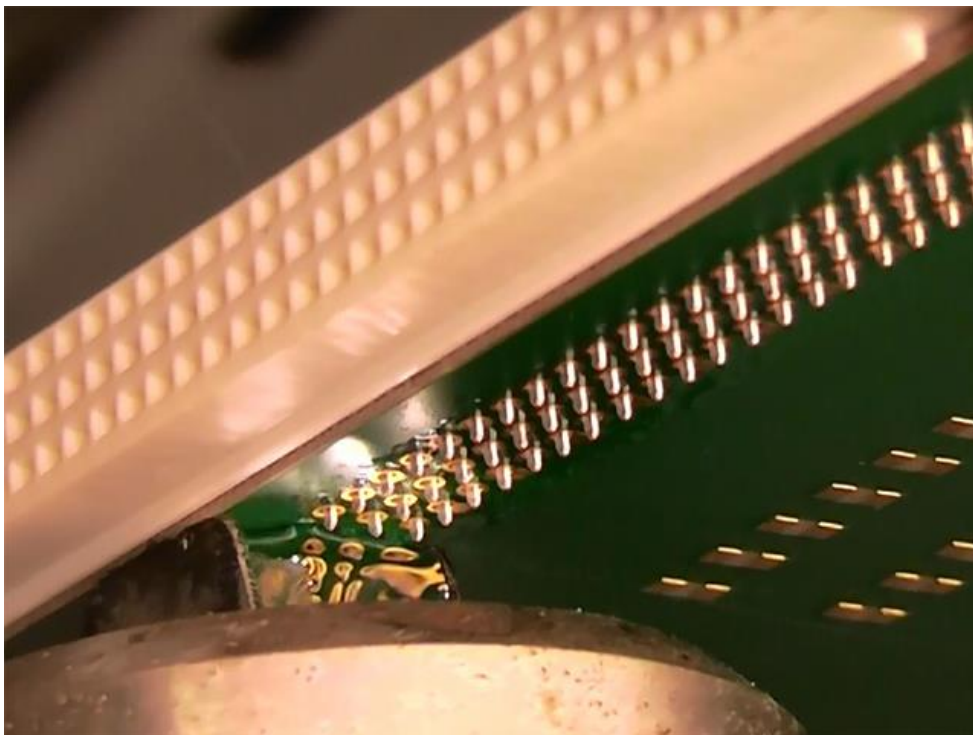


Image above shows a test board and connector being soldered with the wide nozzle

4.4 Selective Robotic Iron Soldering

The robotic iron soldering system is basically a fully automated soldering iron with computer controlled parameters, programmed manually or by importing PCB design files. The systems are either three or four axes robots with either proprietary soldering heads and wire feeder systems or units that have been integrated with commercially available heads. This can also be the case for laser systems. Robotic soldering has started to become more popular in recent years with high reliability and automotive manufacturers trying to reduce the use of manual soldering. It has also been used in high volume production where a small number of joints need to be produced on each assembly making it more viable than selective wave or jet soldering. It is clear that the sample board and connector used in this trial is more suited to a selective wave soldering process, but the speed of soldering was not necessarily part of this assessment.

As with any other printed board assembly a product should be designed for manufacture rather than adapted to suit a process. One of the key features is accurately and repeatedly locating the product for the soldering operation, even if some form of vision alignment is provided. Fixturing of the product for the soldering operation is very important for repeatability. If the product is a single board assembly then tooling or a fixture nest will be required for multiple boards if tip or laser soldering processes are to be used. If the boards are still in a multi-panel then standard tooling can be used but the panel must be supported to prevent sagging and inconsistent height. Some equipment has automatic height sensing to deal with sagging or warpage of boards.

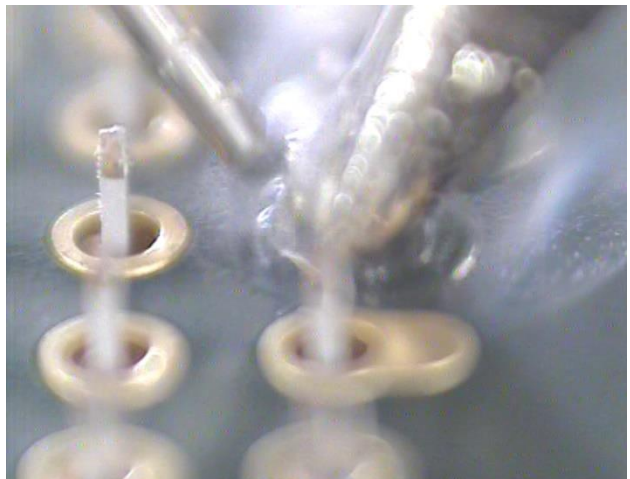
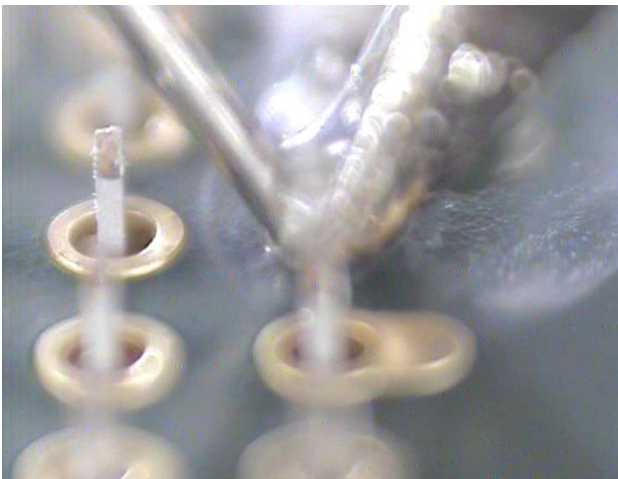
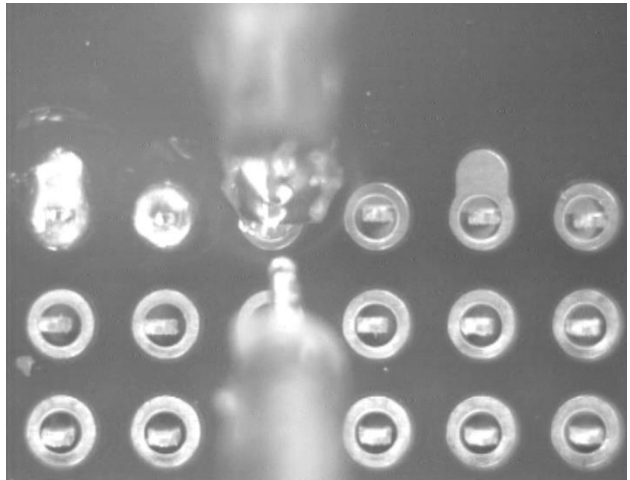
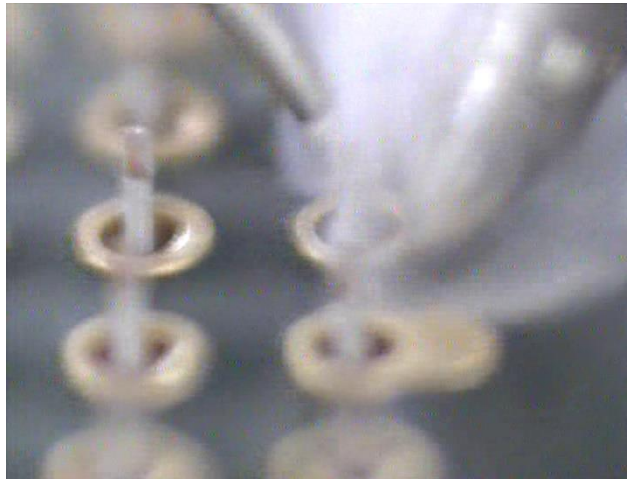
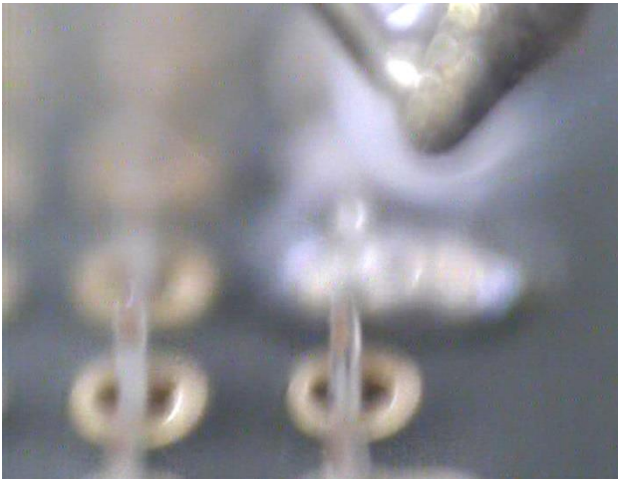
An example of the soldering set point parameters used in one trial are illustrated below and were determined by the equipment supplier to achieve satisfactory filling of the plated through holes with his equipment. The machine parameters are provided as an example only. It is very important to define the process parameters used for soldering and determine their repeatability during trials. Through hole fill is the key parameter in terms of inspection and in process quality control but inspection of the board, copper plating, laminate, pad and solder mask are also important.

4.5 Tip soldering

Soldering iron tip 2 mm
Solder iron temperature 385 °C
Pre solder feed 0.4s
Pre heating 0.8s
Solder feed 0.4s
Solder wire feed speed 75%
Solder wire pull back 0.1 mm

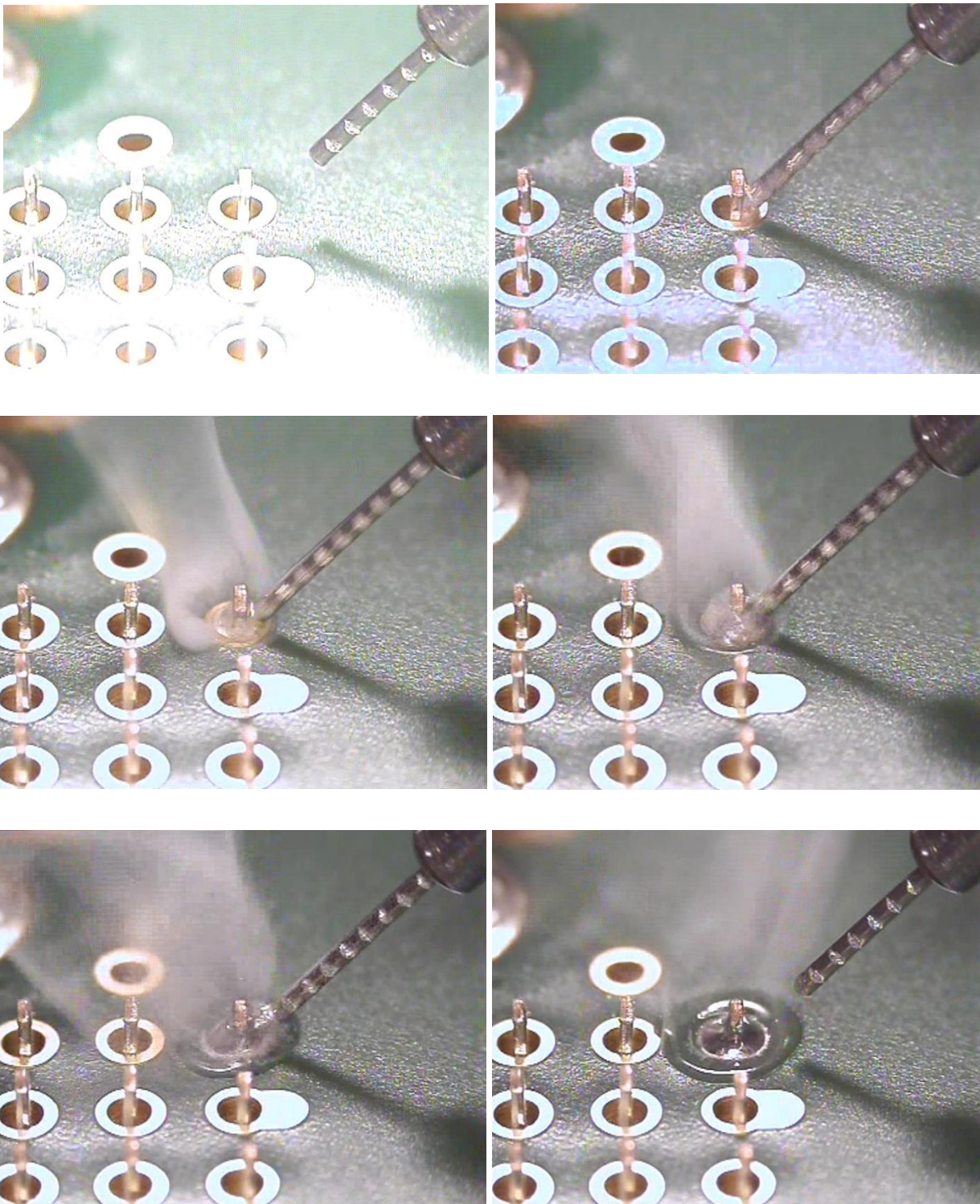
4.6 Laser Soldering

60 watt single emitter 940 nm wavelength
Minimum light diameter 0.5 – 0.8 mm
Preheat 0.0s with 0 watt
Solder feed 0.6s with 25 watt
Hold time 0.2s with 25 watt
Solder wire pullback 0.1s
Solder wire speed 100%



The images above show the steps in a robotic iron soldering process. These may vary slightly based on different machine types but fundamentally are the same steps to achieve satisfactory soldering. Step 1 Tin the tip, 2 Move tip to joint area, 3+4 pre-heat joint area, 5 feed wire to joint, 6 retract wire then iron tip and move on to the next joint

4.7 Selective Laser Soldering



The images above show the steps in a robotic laser soldering process. These may vary slightly based on different machine types but fundamentally are the same steps to achieve satisfactory soldering. Step 1 pre-heat pad and lead, 2 pre-heat and feed wire, 3-4 reflow and continue wire feed, 5-6 retract wire and move to next joint

Some machine suppliers are able to automatically calculate the amount of solder wire required to fill the hole and provide positive solder fillet during programming of their software. This is based on a simple calculation based on hole size, board thickness and pin size and the wire diameter. Some suppliers are able to do this automatically using vision systems which are also used for programming the equipment.

4.8 Cored Solder Wire

Cored solder wire is used in manual, laser and robotic tip soldering and needs to be considered for its compatibility with these processes. As we are talking about high temperature solder alloys there may be a limit to the range of products provided by suppliers including the size of wire and flux options. Some suppliers may not produce wires and rely on others to produce the products for them and, in this situation, the sales volume may be small and not profitable for the limited high temperature market.

4.9 Flux residues

When you solder individual solder joints with cored wire you will have residues left after the soldering operation. Depending on the number of solder joints in any one location the amount of residues will be more apparent; a good example of this is a connector. Depending on the pad size, hole size, hole to lead ratio and thickness of the board the amount of residue will increase or decrease. This is simply related to the amount of solder wire fed to create the joint.

If the board is to be cleaned after soldering, the volume of flux left on the surface of the board is less of an issue but the residues must be soluble in the cleaner to be used. The residues may be more or less difficult to remove based on the soldering process. Laser may be easier than iron; using nitrogen as opposed to air may also have an impact. As most products destined for the high temperature market will be conformally coated cleaning may be a given.

As seen during the introduction of lead-free cored wires, there were generally two directions that suppliers followed. A residue that was still relatively soft after soldering or one which was brittle and easily cracked. This allowed test pin to make contact with the solder joints through the flux residues; however, both did still provide problems for the user. Where boards are conformally coated it is possible for the residues to expand and contract during thermal cycling which then leads to the coating separating or lifting. In turn allowing moisture to accumulate in those areas may cause corrosion or dendrites to form in the presence of an applied voltage. This may then not be a failure specific to activators from the flux but caused by lifting of the coating.

4.10 Flux Volatiles/Vapours

Each solder wire will have different characteristics depending on the supplier's flux formulation and the volume of the flux included in the wire. During soldering the flux flows out from the wire aiding the soldering process. As previously stated there is a lot of flux left on the surface of the board and joints; however, it is the impact of the vapour potentially condensing on the optical systems used in the soldering systems that can impact the process. Unfortunately this is often not noticed in small production runs or equipment trials.

Where optical temperature measuring systems are used on the equipment they must be kept clean, otherwise the system's measuring capability will be affected and result in poor soldering results. Optical systems are also used for alignment, inspection and PCB warpage measurement. Air knives may be fitted to blow vapour and flux residues away from the optics during soldering; however, the system should be cleaned during normal maintenance.

4.11 Solder Wire Spitting

One of the potential problems with cored wire is spitting from the flux which in turn can lead to solder balls on the surface of the board after soldering. Partly this a problem created by the end user as they try to optimise but in reality speed up the soldering process. By watching the soldering process closely or using video you can see these problems happening in real time.

Although during the wire selection process an engineer can trial different products and different core sizes, other options have been used by different suppliers. During soldering the flux can explode from the wire as or before the solder reflows. One option is to indent the wire decreasing the wall thickness. The theory is the pressure is released in a more controlled way. The indents in some cases are formed by the wire indexing wheel that is used to feed the solder through the nozzle for the soldering operation. Perhaps by making the shape of the feeder a specific design it allows two functions from a single operation.

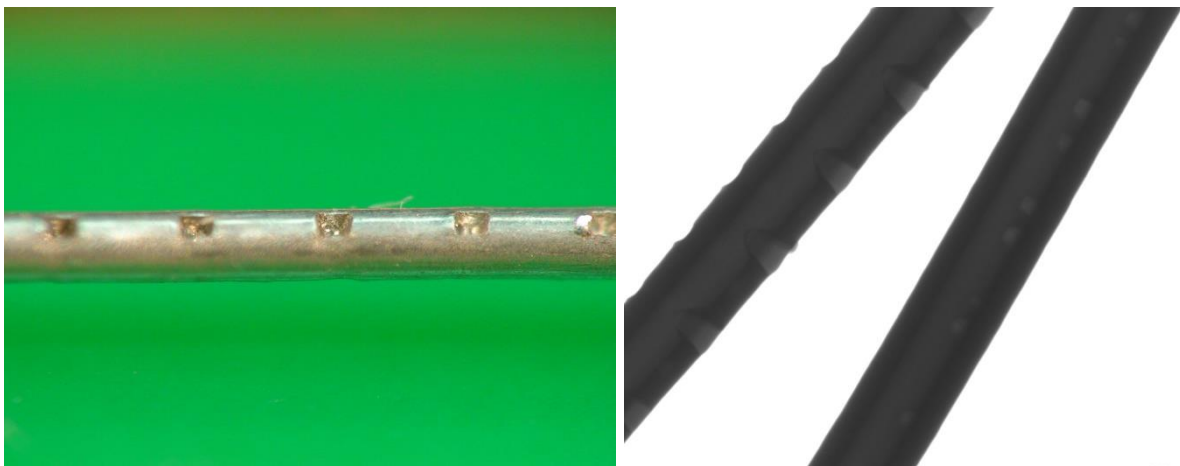


**Image on the left shows the cored solder wire with surface indentations after feeding.
Using X-ray the depth of the indents can also be seen on the right**

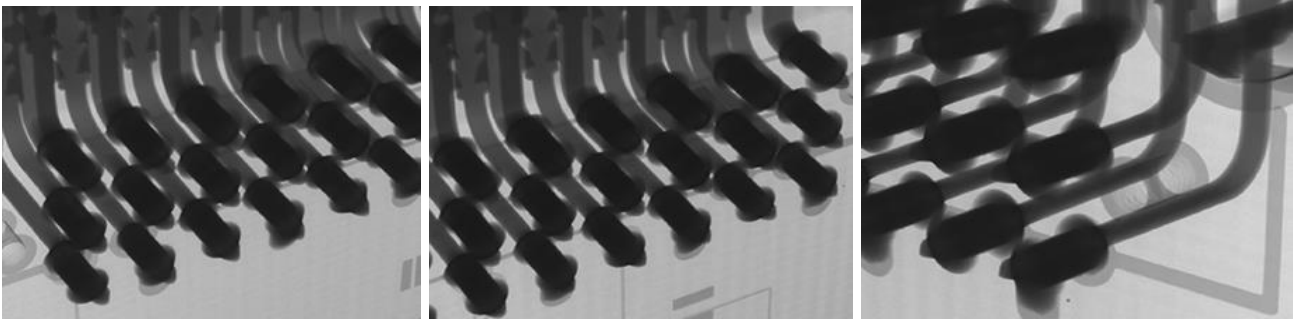
Very simple testing of different wires with and without indents or v-scoring has showed solder and flux being ejected from the solder surface. The tests involved feeding the cored wire onto a heated white ceramic tile. When the solder wire touches the surface reflow would take place; in most cases plain wire did result in spitting and scored or indented did not. Assessment can be made by simply checking the white tile surface for solder residues, this technique has been used successfully as an assessment tool and recorded on video.

5 Solder Joint Inspection

5.1 Visual and X-ray Inspection

Each of the sample boards produced was inspected visually after assembly for successful soldering and through hole fill. Based on the industries where high temperature products are used the minimum requirement would be IPC 610 level 3. However, in reality most inspection departments in these businesses would be looking to exceed IPC criteria and achieve 100% through hole solder fill with positive fillets on both sides of the board.

Optical inspection was conducted with traditional microscopes and digital cameras with macro lenses. X-ray inspection of board samples was conducted using a DAGE X-ray system. There were a few exceptions but in the main all solder joints exceeded the IPC requirements and, with process optimisation, further improvements could be achieved.



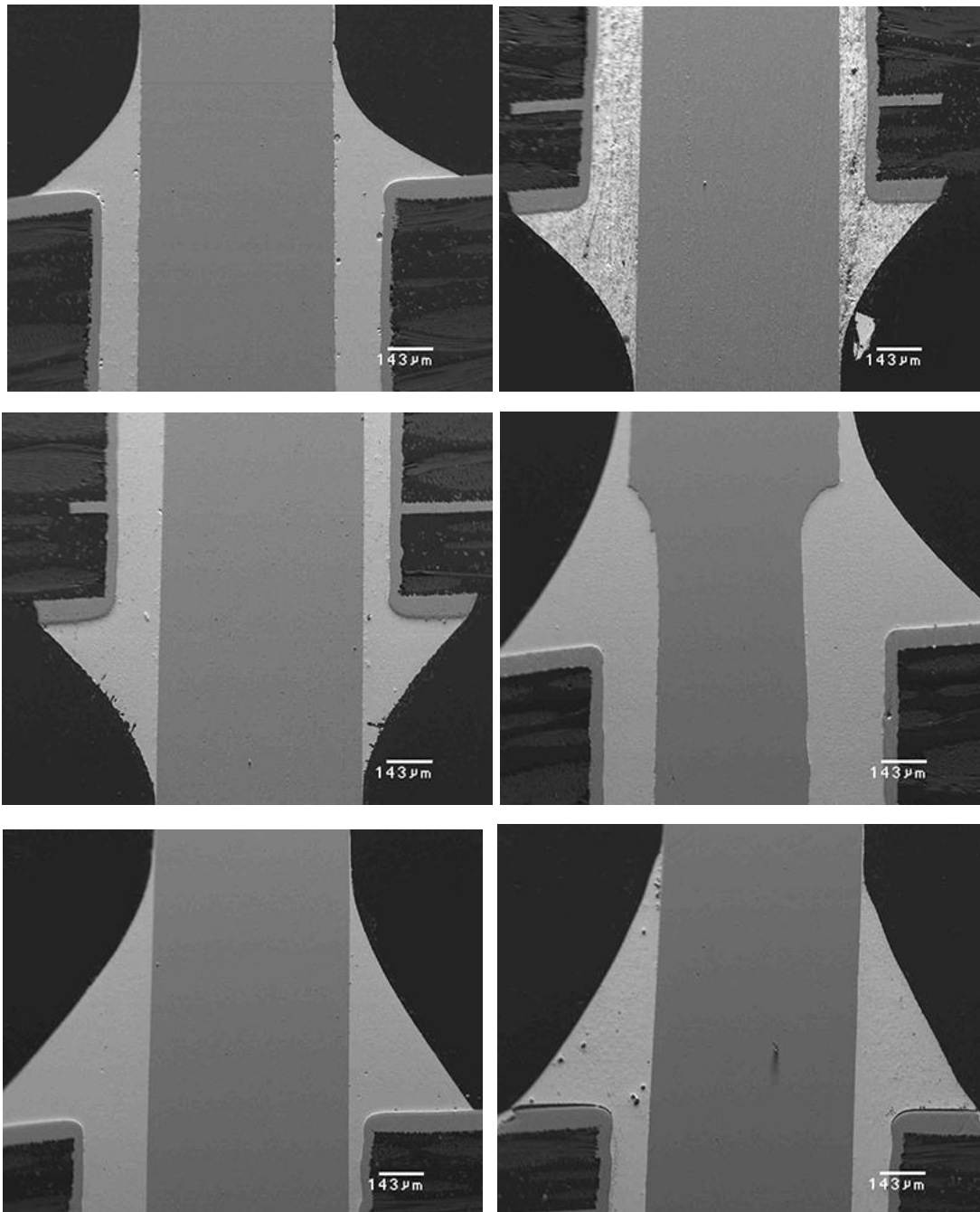
X-ray images above are all typical of the laser and robotic soldering performance achieved on the sample boards. Further optimisation of the process parameters could also achieve a reduction in the process time for each soldering operation



Optical images are typical of solder joints produced with high lead and tin/silver alloys

5.2 Microsectioning of Joints

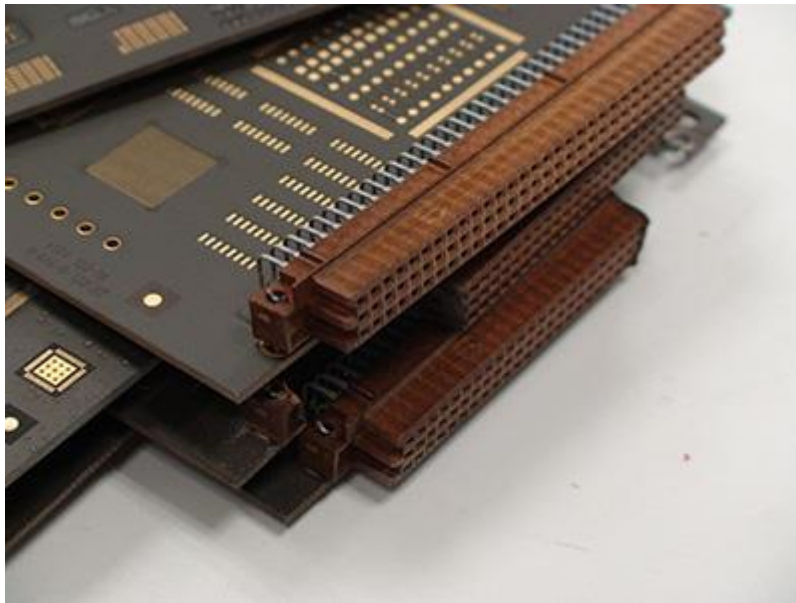
Sample joints were cut from the printed board for microsectioning. The samples soldered with cored wire were cleaned prior to potting, due to the amount of flux remaining on the surface of the joints. In the past excess flux residues have reduced the support to the solder during the grinding and polishing stages and is good practice. The samples selectively soldered were not cleaned prior to potting due to limited flux residues remaining on the surface of the board. Measurements of the intermetallic thickness were undertaken on each of the samples and indicated on the microsection SEM images. The majority of the samples prior to ageing provided intermetallic thickness of $\leq 1 \mu\text{m}$. One sample showed measurements of between 1-2 μm . This sample was produced with laser on tin/copper alloy but is not considered to be significant.



The six microsection images shown above were taken at 0 hrs.
Sections were also taken after the boards had been stored at 200 °C for 1000 Hours.

The average results of the measurements are recorded below after 1000 hrs, they ranged from 5 μm to 16 μm .

Sample 1	Tin/Antimony Hand Soldered		5 μm
Sample 2	Tin/Antimony Selective Soldered		10.5 μm
Sample 3	HMP Selective Soldered		16 μm
Sample 4	SAC Laser Soldered		8.5 μm
Sample 5	SAC Robotic Iron Soldered		8.1 μm
Sample 6	Tin/Copper/nickel	Laser Soldered	9.2 μm
Sample 7	Tin/Copper/nickel	Robotic Iron Soldered	8.4 μm



Example of boards above after storage at 200 °C for 1000 hrs. As expected there was discolouration on all boards and connector bodies. The connectors used in the trials were not specifically designed for high temperature storage at 200 °C

Sample boards from the trials are also being subjected to thermal cycling between -55 and 125 °C with visual examination of the boards and solder joints. As there was no electrical monitoring of the connections only visual examination will be conducted on completion of 1000 cycles. Experience shows that it is very rare to have failure in through hole plated and soldered connections. The results of these ongoing trials will be discussed in a future report.

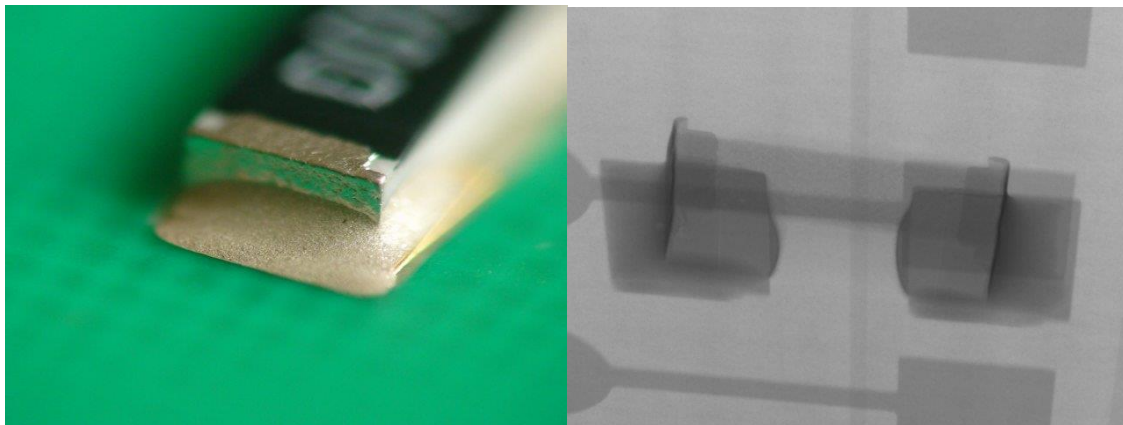
6 Alternative High Temperature Assembly Materials

The following images were taken during the assembly, soldering/curing and inspection of 1206 chip components using different materials designed for high temperature applications. The materials were stencil printed on to the pads using a 0.004"/100 µm laser cut foil before manual placement of the components. The surface finish on the pads was gold over nickel, the dimensions of the footprint design were taken from another NPL study and not optimised for these materials. The resistors had a tin coating over nickel which is the most common surface finish in the industry for passive parts. There are other references to work on high temperature materials in the NPL report MAT 64 "High Temperature Solder Replacement to Meet RoHS" Reports are listed and can be obtained via the NPL Defect Database <http://defectsdatabase.npl.co.uk>

This short exercise was undertaken alongside the existing project looking at through hole soldering. The process and the assembly results could be optimised with a larger sample size. After assembly the sample boards were exposed to 1000 hrs at 200 °C. Prior to ageing samples were shear tested and the results are provided below

6.1 Material 1

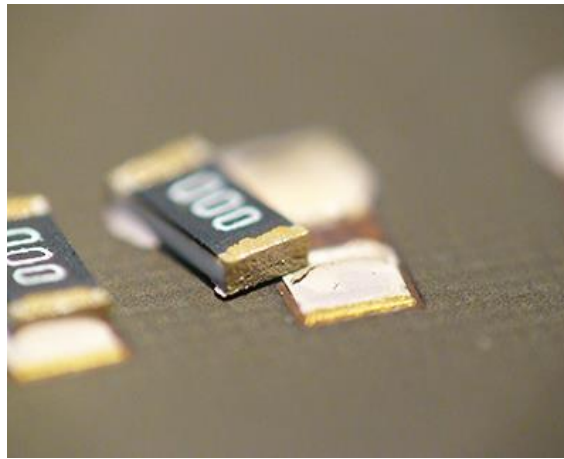
The material is a die attach adhesive for high volume applications cured at approximately 150 °C for 10 seconds. The adhesive contains electrically conductive silver flakes.



The optical image above shows the component join after assembly and an X-ray image

Average shear test result after soldering = 69.8

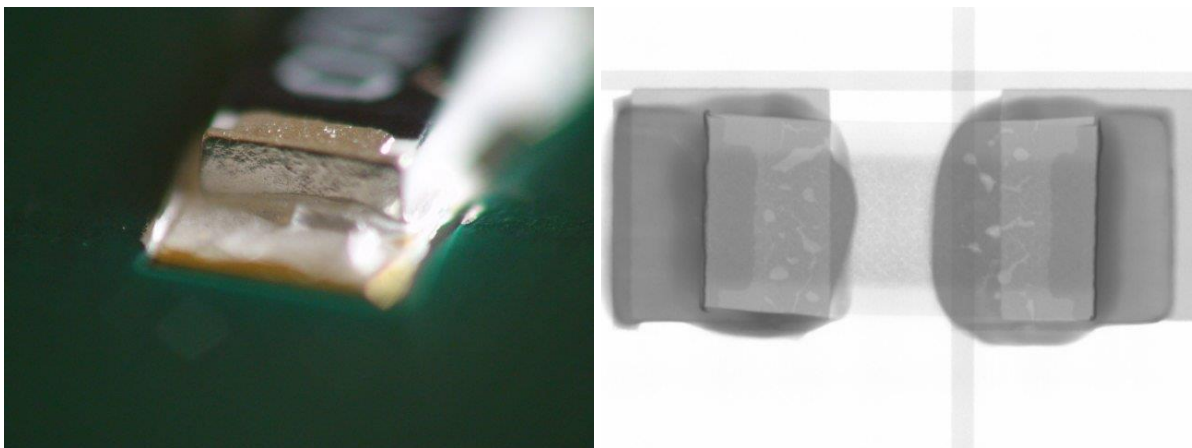
Average shear result after 1000 hrs@200 °C = O (All samples sheared off board with no force recorded)



Example of the resistor separating in the material interface

6.2 Material 2

The material was a sintering silver paste die attach adhesive for high thermal and electrical conductivity. The material can be used without pressure, preheated to 250 °C for 10 mins then held at 250 °C for 60 mins. Where pressure is used the process would be modified. In the case of these samples no pressure was used.



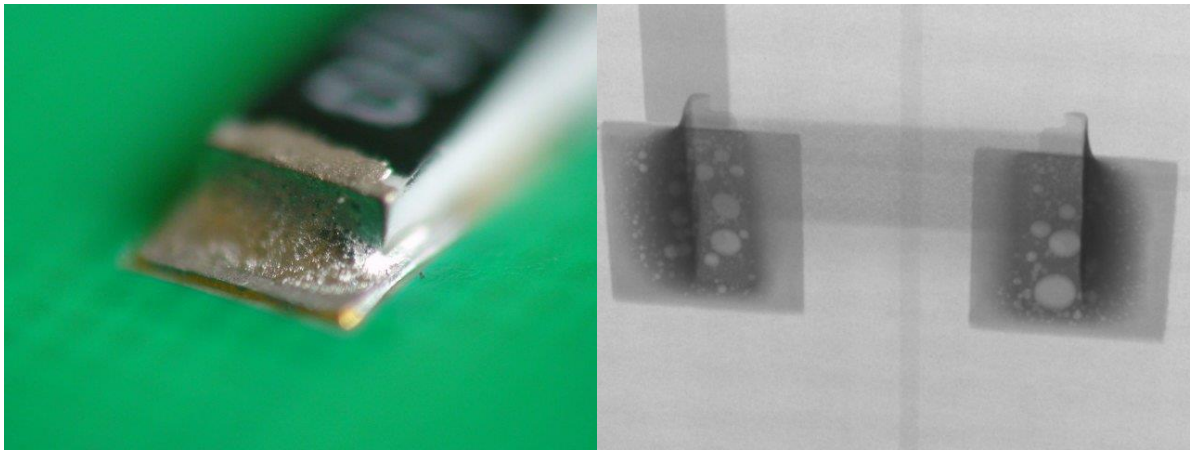
The optical image above shows the component joint after assembly and an X-ray image

Average shear test result after soldering = 0 (Due to none cure of samples)

Average shear result after 1000 hrs@200 °C = 0

6.3 Material 3

This material was a lead-free paste for high reliability applications which has a melting range of 208 – 217 and a reflow temperature of 235 °C. The solder alloy of 90Sn with a combination of silver, copper, bismuth, antimony and nickel helps to produce an alloy that is very good at withstanding thermal shock or vibrational stress found in automotive or high stress environments but due to its relatively melt point is not designed for high temperature reliance; this material was added to show the effect of high temperature on a high reliability process.

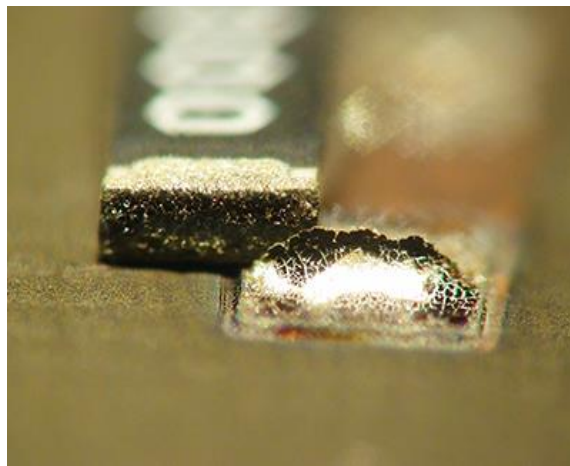


The optical image above shows the component joint after assembly and an X-ray image

Average shear test result after soldering = 87

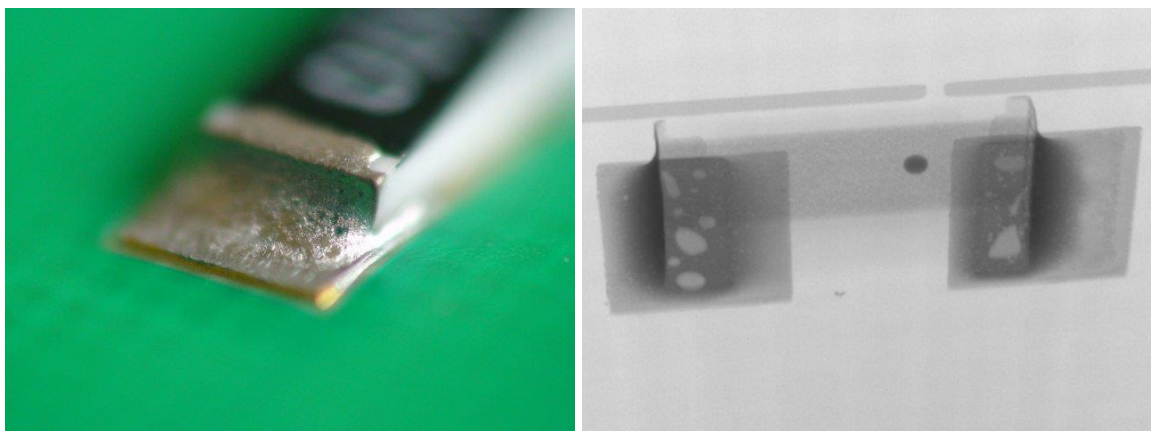
Average shear result after 1000 hrs@200 °C = O (All samples sheared off board with no force recorded)

Example of the resistor separating at the termination interface



6.4 Material 4

The material was a SAC387 dispensing paste with a melting temperature of 217 °C and a reflow temperature of 235 °C. It is halogen free and is provided as a type 5 paste product. It is designed for high speed dispense applications but is also used for reworking fine pitch or small devices.



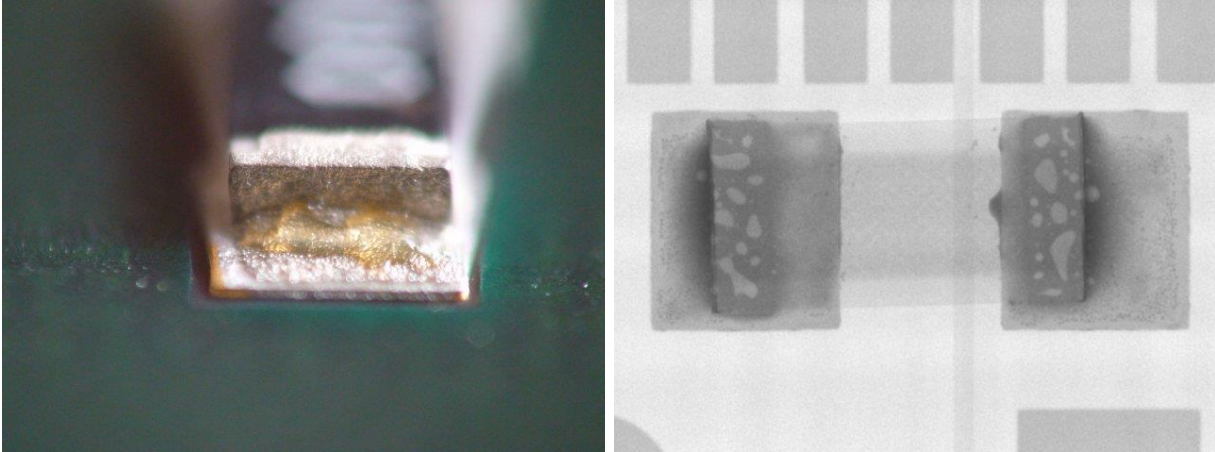
The optical image above shows the component joint after assembly and an X-ray image

Average shear test result after soldering = 78.6

Average shear result after 1000 hrs@200 °C = 47.1

6.5 Material 5

A dispensing grade epoxy solder paste designed for die attachment. The solder alloy is SnSb92 with a melting point of around 245 °C reflow temperature of approximately 275 °C. As an epoxy based system the process window is relatively small; the epoxy material is also used to strengthen the joint at higher temperatures to prevent failure in harsh conditions.



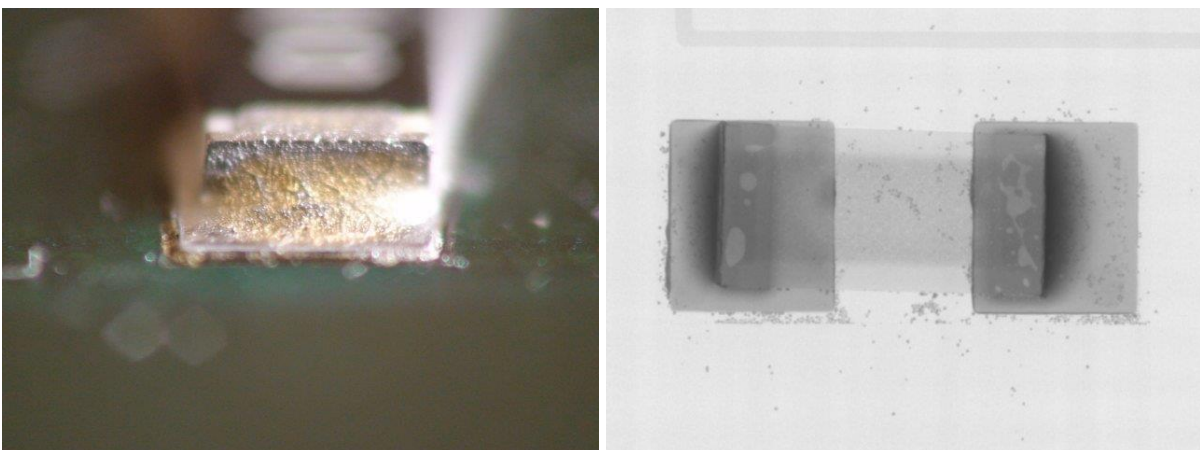
The optical image above shows the component joint after assembly and an X-ray image

Average shear test result after soldering = 73.8

Average shear result after 1000 hrs@200 °C = 34.45

6.6 Material 6

This was a dispensing grade solder paste for die attachment on copper lead frames. The solder alloy is – HMP a high lead alloy and has a melt temperature of 296 – 301 °C and needs a reflow temperature of >330 °C



The optical image above shows the component joint after assembly and an X-ray image

Average shear test result after soldering = 54.4

Average shear result after 1000 hrs@200 °C = 40.61

Microsections were produced for each of the sample materials in co-operation with suppliers. Sections were also produced for pads that had been used for shear testing to examine the interfaces of the joints remaining on the pad surfaces with the following conclusions:

All samples show significant joint degradation after 1000 hrs at 200 °C, due to intermetallic layer growth.

The nickel plating on the 1206 resistor terminations has formed abnormally thick intermetallic layers by reaction with the tin coating and the high tin solder alloys after reflow and 1000 hrs at 200 °C.

The nickel plating on the PCB pads has formed abnormally thick intermetallic layers by reaction with tin in the solders

As a result of volume changes associated with formation of the thick intermetallic layers, discontinuities at the intermetallic to solder or adhesive interface have degraded the bond between PCB pad and component termination.

There was evidence of incomplete reflow on the samples made using the higher melting point solders Sn92Sb8 and Pb93.5Sn5Ag1.5

Further analysis on the samples has been conducted by the suppliers and is available for discussion

7 Additional Process Observations

The following are some additional comments on the solder joints, flux residues or the general soldering quality found on the samples examined and supported by images. Some of these examples may be considered cosmetic issues by some companies, but are worth including for future reference. There is limited information on the use of high temperature materials or issues specifically relating to selective laser or contact soldering so inclusion of general observations will be a useful reference now and in the future. The NPL Defect Database is an online resource for defects, causes and cures and we would welcome material to include on high temperature issues. These and other process issues will be added to the database for future reference. You can login to the NPL Database free at <http://defectsdatabase.npl.co.uk>

7.1 Board Burning and Mask Damage



Although products designed for high temperature applications with organic substrates can stand up to high soldering temperatures they can still be damaged. This can occur if the soldering times or temperatures are too high or, in the case of soldering irons, the tip comes into contact with the surface of the board or pad for too long a period of time.

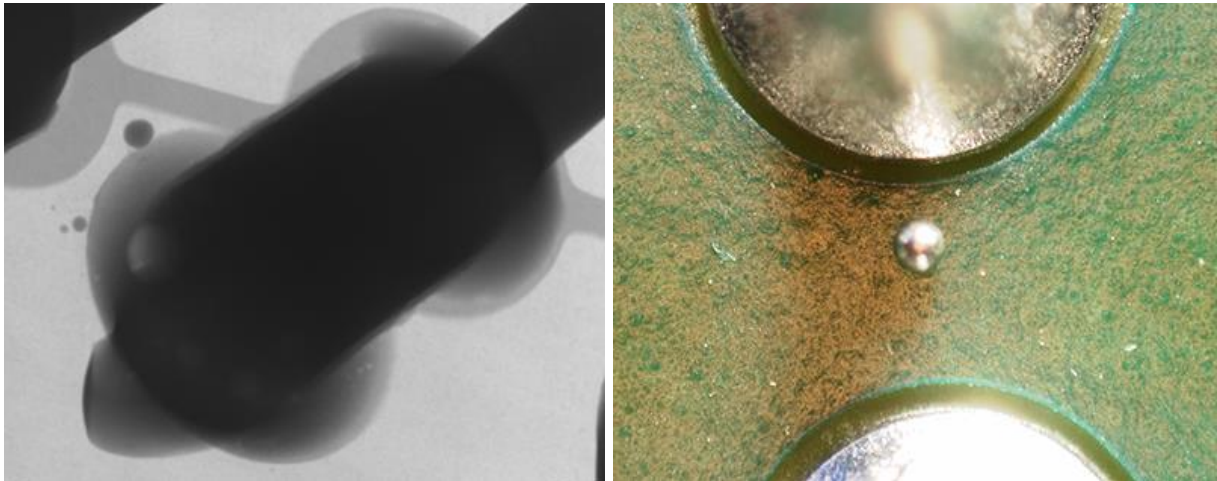
During automated soldering the program that defines the tip's contact position and force must be well refined. If, due to change in position of the board, change of tip, poor product tooling or system drift, the soldering iron tip will cause damage to the board. It is also possible for damage if the z position of the tool tip is poorly controlled with no pressure sensing. The image above shows damage to the surface of the solder mask caused by the tool. It is, however, possible to change the shape of the pad so it has a teardrop shape or a tail opening in the solder mask where the tip can land and make contact. This makes good thermal contact between the solder on the tip and the pad increasing the speed of soldering without damage to the board surface.

7.2 Flux Residues after Soldering



In most cases soldering with high temperature wire will generate much higher amounts of flux residues on the surface of the board. This is certainly the case on all of the materials used and from practical experience in the field. The cored wire used for this application could be re-developed to reduce the residues for a no clean process. However the residues and the flux balls that are often seen to spit during the soldering operation may not be considered an issue in some industries. The residues from different vendors' products were either soft or hard and brittle and very easily displaced but not as soluble in cleaning solutions. The key thing is to select the correct combination of flux and cleaner; cleaning suppliers have normally conducted many trials on different materials and have great databases of results against time and fluid concentrations.

7.3 Solder Balls



Solder balls, due to spitting, is a reality in both laser and robotic iron soldering based on the pressure placed on engineers to speed up the process. X-ray image shown on the left illustrates solder balls.

In the first case a side by side evaluation needs to be conducted to compare the materials, making sure the wire size and flux core are of the same volume. By testing different wires with the same feed rate and temperatures, wetting performance and degree of spitting can be compared on specifically designed test boards. After initial testing the best wires can be tested with wire scoring or indentation to increase the speed of operation without solder balling. Reducing spitting by creating exhaust paths for the volatile material in the cored wire as the solder moves from a solid to a liquid can be very beneficial.

Solder balls are also seen on selective soldering process, right hand image above shows a ball between two connector pins, with high temperature materials. This may be more apparent than with conventional lead-free soldering as the temperatures used are higher. Care needs to be taken with the product design, solder mask selection/specification and the flux material being used to reduce balling even if it is acceptable in some standards.

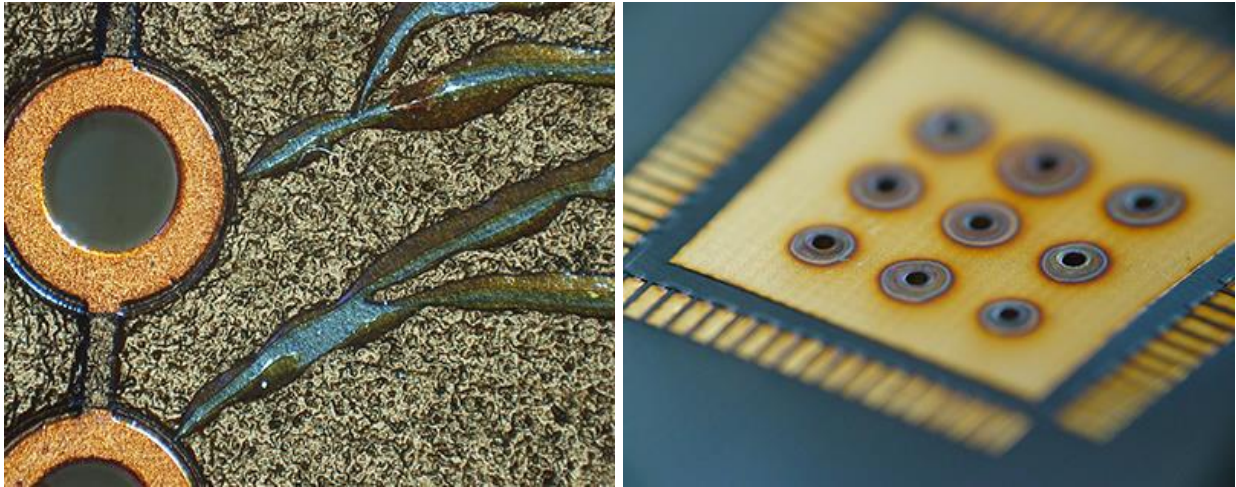
7.4 Flux Bubbles



These were most commonly seen on laser soldering and probably related to speed of temperature rise and cooling during the soldering operation. If the flux is to be removed by cleaning and, provided the material is still soluble in the chosen cleaning system, there should not be a problem. If the boards were to be conformally coated as part of a no clean process it may be difficult to differentiate the flux bubbles with voids or bubbles from the coating process.

The bubbles are an indication of the process parameters used and the flux vehicle which could be developed further for this type of automated process. Inevitably where there is an increasing market for wire for this type of operation there may be more innovation. As the bubbles are in the flux residues it is probably not an issue; however, it is a task for engineering to develop the process with material suppliers to optimise the process.

7.5 Coating Peel or Cracking

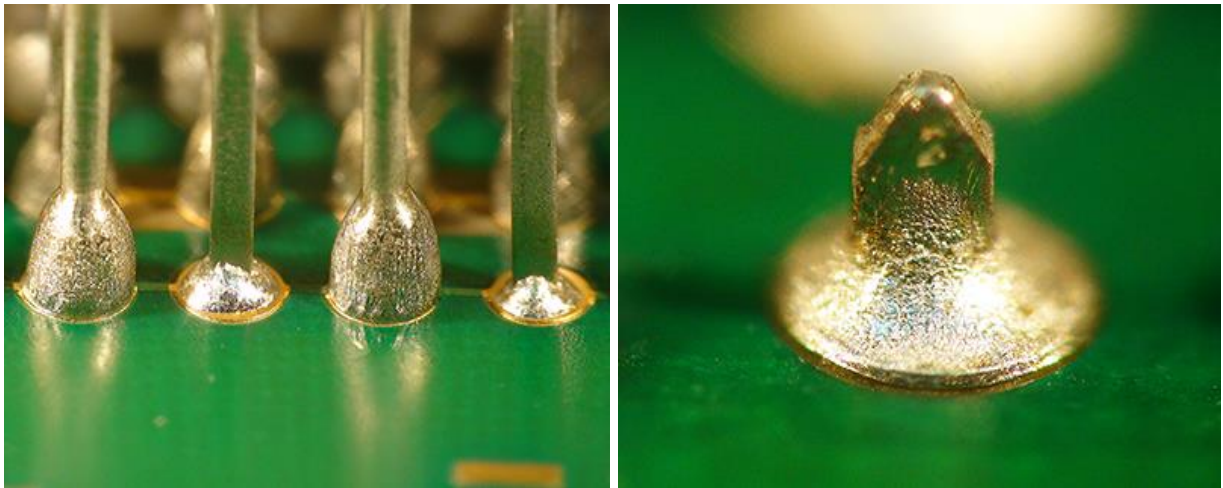


There are just two conformal coating materials widely used in the industry which can work or are potentially rated to work up to 200 °C, that is silicon and Parylene. Parylene C is not rated to this peak continuous operating temperature but some sample boards were included in these trials. Parylene D would be the coating specified for the temperature range tested. Six bare boards were coated with materials and then stored at 200 °C for 1000 hrs.

Both silicon coatings protected the surface of the board and gold coating with no evidence of laminate or gold discolouration. Many of the gold boards subjected to high temperature storage and not coated did show evidence of discolouration. It's not clear at this stage the reason for the discoloration as it was mostly associated with solder mask interfaces. The Parylene boards did show some cracking and then flaking on a small section of the board but in many areas the coating did provide protection. Both the silicon coatings provided complete protection with no evidence of coating failure.

7.6 Inconsistent Solder Volume

During the assembly trials there were examples of solder volume variation from pin to pin which would need to be examined further. As the plated through hole size and thermal demand on the test board were fairly consistent this is probably related to solder feed variation on one system.

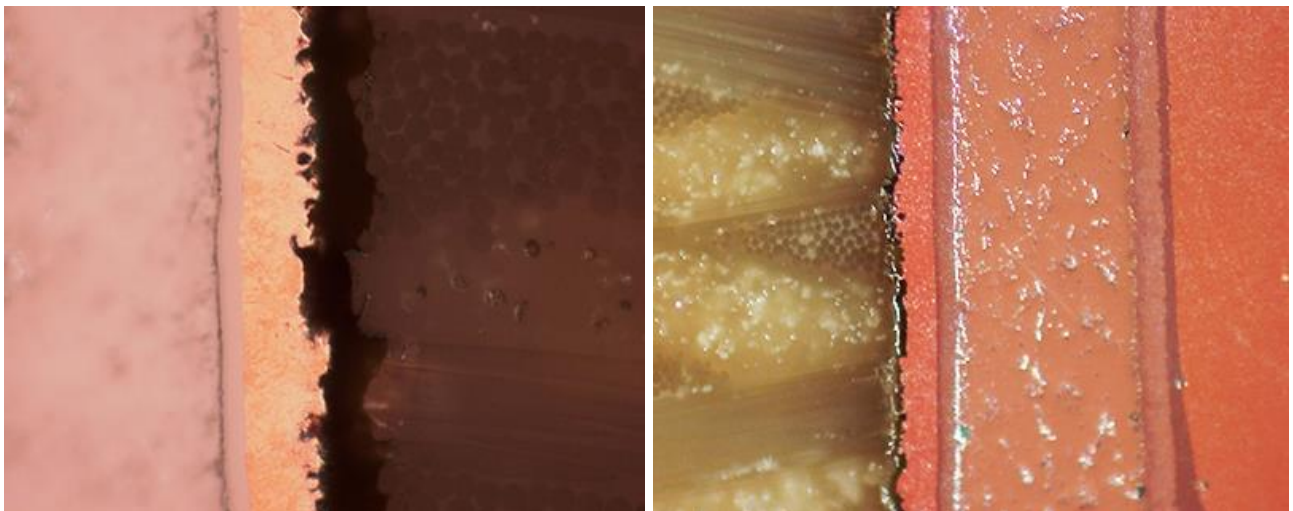


Examples of poor control of solder volume during through hole soldering

7.7 Copper Hole Wall Pull Away

During soldering if excessive heat or duration at elevated temperature is experienced the copper barrel can pull away from the surface of the drilled fiberglass in a plated through hole. This can occur where the adhesion of the copper to the drilled hole is poor during manufacture, but in the cases shown below it was related to the soldering parameters used.

Some separation of the copper barrel can occur during temperature cycling of through hole joints but it is uncommon to see this cause an electrical failure. Selected areas of copper separation in the barrel can also lead to a reduction in through hole pullout strength, but again not necessarily lead to failures. In the case of the two samples below further optimisation of the soldering parameters should eliminate the copper separation.



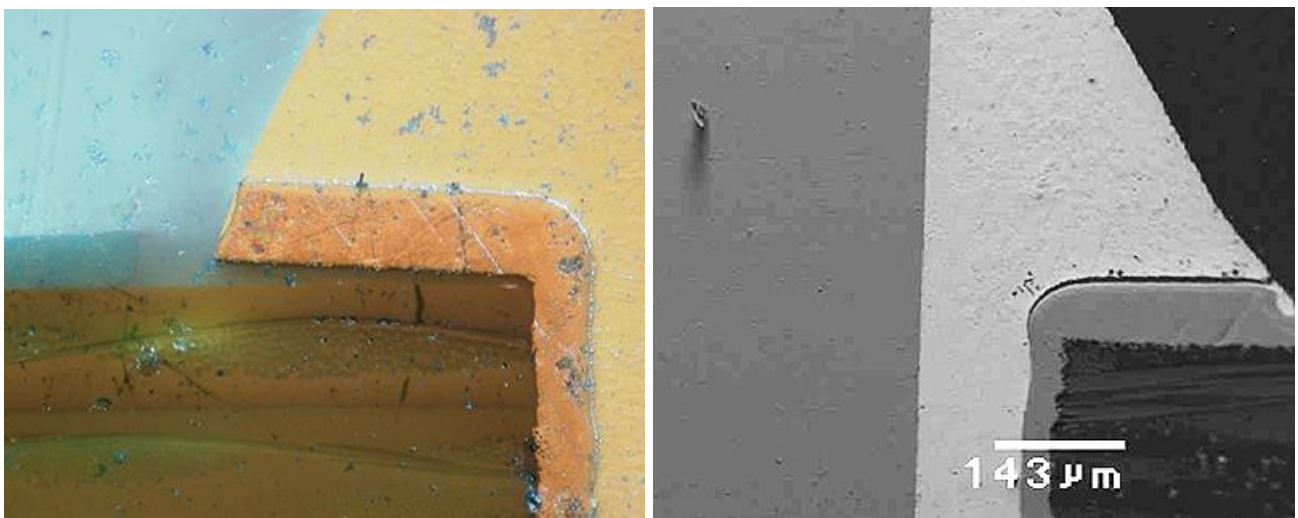
7.8 Solder Fillet Lifting or Pad Lift

Solder fillet/pad lifting was first experienced in lead-free soldering and has been found in selective, wave and intrusive reflow. It has not to date been seen to cause a reliability problem and is not always associated with all through hole joints on a single board.

7.9 Solder Fillet Lifting or Pad Lift

Solder fillet/pad lifting was first experienced in lead-free soldering and has been found in selective, wave and intrusive reflow. It has not, to date, been seen to cause a reliability problem and is not always associated with all through hole joints on a single board.

A solder joint can be perfectly formed but either the edge of the pad is lifted from the surface of the laminate or the solder fillet tip lifts from the edge of the soldered pad. Both points are highlighted in IPC 610F “**Acceptability of Electronic Assemblies**” for lead-free materials only. It is considered acceptable for class 1, 2 and 3 products. The microsection images above show pad lifting from the surface of the laminate on the left, this type of issue was experienced in the past with tin/lead when soldering thick multilayer boards where the expansion and contraction of the board after soldering left the copper pad lifted from the substrate.



The same phenomena has been seen on some samples from these projects. The image on the right shows the solder fillet lifting from the surface of the copper pad. This can be seen on tin/copper and SAC alloys which would be acceptable to IPC. However, where it happens on HMP solder which is lead based it would not be acceptable, suggesting the need to change the statements in the IPC 610 which just relate to lead-free exceptions.

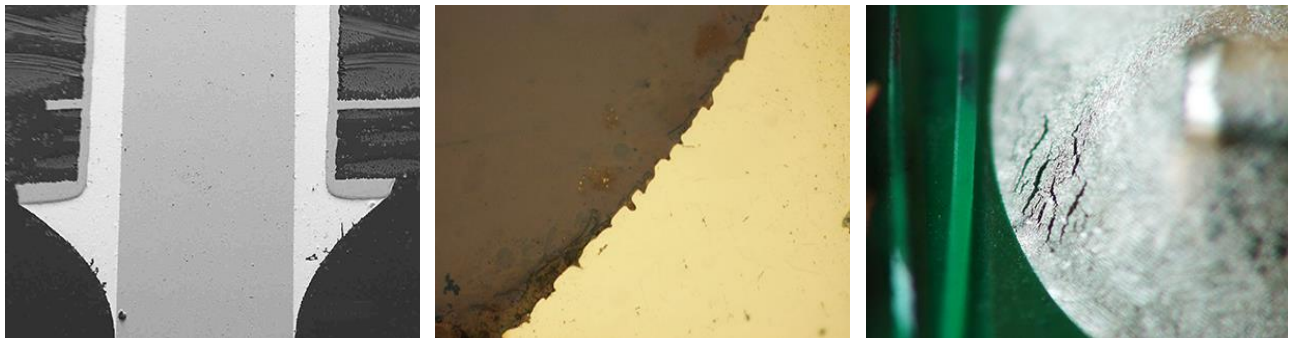
7.10 Poor Thermal Balance

During soldering it is important to get the right heat input to an assembly, particularly with laser soldering. Balancing the heat to the board, pin and solder wire is necessary to achieve successful hole fill. Robotic soldering with laser or solder tip needs to be programmed into a computer whereas an operator watches and responds to the soldering conditions. Some systems have optical sensors and do learn and adjust the soldering parameters based on performance; however, most are dumb. In the case below satisfactory soldering has been achieved to the plated through hole but the pin was not raised to correct temperature prior to feeding the solder into the joint.

The mass of the pin and possibly the body of the component has caused slow heat transfer and then stopped the solder wetting to the pin. The impact of temperature drop in the solder has also resulted in the solder not flowing on to the opposite side of the board.



7.11 Solder Fillet Tearing



Again this is a process phenomenon we have seen with Tin/Silver/Copper SAC alloys during the introduction of lead-free. It is not normally seen on tin/copper, but more commonly seen on higher silver SAC. During these trials the tearing was seen on the surface of robotic laser and iron soldered joints but did not appear to increase in size after static ageing or during temperature cycling. Tearing is highlighted in IPC 610F “**Acceptability of Electronic Assemblies**” for lead-free materials only. It is considered acceptable for class 1, 2 and 3.

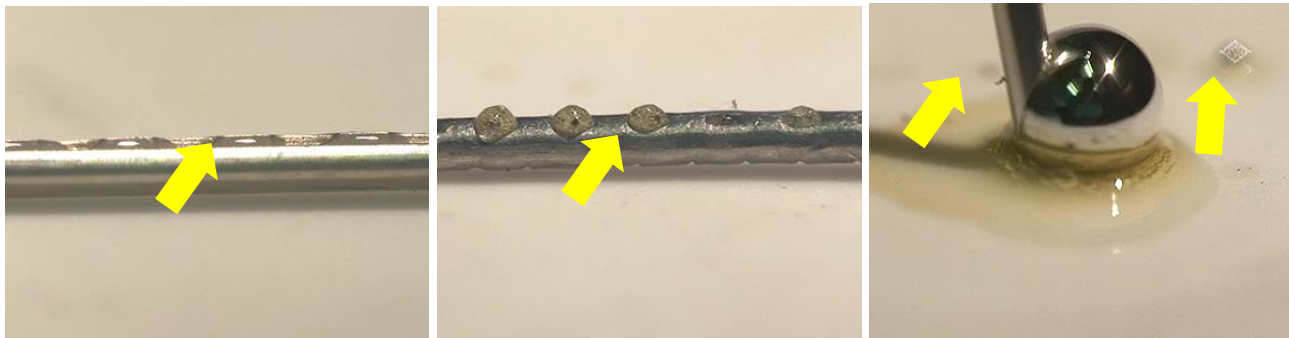
The two microsection images above show the tearing of the solder between the grain boundaries on the surface of the joints. The optical image on the right shows the surface of one joint with the tearing visible in the solder surface.

7.12 Flux Spitting/Vapours and Condensation

Flux spitting is really just the same problem as solder balling. Trying to solder at a speed that is too fast for the material or process settings being used. If a company was to develop newer cored wire engineers would still try to push the process window, hence the best way is to look at the materials and the process.

Testing and observing the soldering characteristics of the wire during heating and reflow is very useful to compare products. JapanUNIX has used high speed video to show the difference in wires and the degree of solder balling. Video on their website show the benefits of wire preparation prior to reflow.

During this project we have also been able to control the flux volatile escape from the wire and, with it, spitting of solder balls



**Images above left and centre show the point that flux escapes from the wire during heating.
On the right solder balls formed on a white ceramic tile when the wire was not prepared**

8 High Temperature Electronics Manufacturing Workshop – Current and Future Technology

NPL Electronics Interconnection Group will be running a workshop on High Temperature Assembly and Soldering at Teddington on Wednesday 4th February 2015. In addition, workshops will also be running at other manufacturing conferences and exhibitions. The team can also offer the workshop in-house for companies if required, contact kate.clayton@npl.co.uk

Workshop outline:

When we start to talk about high temperature electronics it is not the solder it is all the parts that make up an electronic assembly. Substrates, components, connectors, cables, solder and all of the assembly process needs to be examined in detail. Working at high temperature means between 150-200 °C, however, there are many applications that have to work at much higher levels, up to 300°C. Typically the industries affected by these hostile working conditions include, aerospace, automotive, petrochemical and military.

A **FREE** copy of the High Temperature Electronics Defect Guide will be provided to each delegate. The defect charts can be printed on site for future reference or training. A guide to major reference sources and publication on high temperature manufacture will be discussed and suppliers providing different assembly resources

Topics may include:

- Oil, Gas, Space, Automotive and Military Applications
- Reference books, specification and standards
- Product temperature range
- Component compatibility
- PCB substrate choices and specifications
- Soldering alloy choices
- Assembly and soldering options
- Reliability Assessment and testing
- Final coating or potting options
- Failure modes

Workshop delegates will receive a copy of the speaker's slide presentations plus a **FREE** copy of the latest High Temperature Technology report produced by NPL and its user guide to practical soldering for polyimide substrates.

9 Acknowledgements

We gratefully acknowledge the support of the Materials Measurement Programme sponsored by the National Measurement System unit of the UK's Department for Innovation Universities and Skills.

The Electronics Interconnection Group at NPL would also like to thank the following suppliers for their time and support during this project. Also thanks for providing facilities or equipment to allow sample boards to be assembled and soldered.

ACE Production Technologies

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Spokane Valley
WA 99216, USA
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Harting Connectors

51 Caswell Rd
Northampton
NN4 7PW, UK
Tel : 01604 827500

Merlin Circuits

Merlin Circuit Technology Ltd
Hawarden Industrial Park
Manor Lane, Deeside
Flintshire, North Wales
CH5 3QZ, UK
Tel: 01244 520510

Laminate suppliers to Merlin Circuits for the project included:

ISOLA Group
Lamar - Nelco
Ventec Europe
Park Electrochemical Corp

Henkel Ltd. Headquarters

Technologies House, Wood Lane End
Hemel Hempstead
Hertfordshire
HP2 4RQ, UK
Tel: 01442-278000

Japan UNIX

2-21-25, Akasaka,
Minato city
Tokyo, Japan
Tel: 81-335880551

mta Automation ag

Bernstrasse 5
CH-3238 Gals

Switzerland

Tel: 41 32 338 82 82

Apollo Seiko LTD

3969 Lemon Creek Road

Bridgman, MI 49106

USA

Tel: 269-465-3400

Apollo Seiko

Kaisertech Group

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Manor Way, Eastleigh,

Hampshire, SO50 9YA, UK

Tel: 02380 650065

DKL Metals Ltd

Avontoun Works

Linlithgow

EH49 6QD, UK

Tel: 01506 847710

HumiSeal Europe

505 Eskdale Road

Winnersh, Berkshire

RG41 5TU, UK

Tel: 01189 442333

ParaTech Coating UK Ltd

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NN5 7RX, UK

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