LEAD-FREE Connection™

THE SOURCE FOR LEAD-FREE ASSEMBLY INFORMATION

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Contributors in this issue:

kester CONNECTING INNOVATION™

MacDermid Electronics Solutions

Specnor Tecnic Intl. Corp.

PROCESS SCIENCES INCORPORATED

RoHS Transition Should be *a Company-Wide Concern*

With just over six months before the ban on materials identified in RoHS begins, many companies are still lagging behind schedule in their RoHS conversion process. After meeting with several of these customers, one of the biggest deficiencies in industry today is that many companies are not dedicating the proper amount of resources to address the issues. Many companies have treated RoHS as an "engineering issue", meaning that process engineering group have often been assigned a broad task such as "bring the plant into RoHS Compliance."

As you may expect, when RoHS compliance is assigned to just one department within a company, delays should be expected and the project will not be successful.

The key to delivering company-wide RoHS compliance in a timely manner is a top-level management commitment and a fully empowered cross-functional team assigned to execute the project. RoHS compliance is not a simple manner and the hard work of many departments will be required to reach compliance on time. Achieving RoHS compliance quickly should be a goal on nearly every electronic assembler's horizon and achieving it ahead of schedule can only improve your position in the market.

Work Together & Beat the Clock

The following departments should have some involvement in the RoHS transition process: Design Engineering; Procurement; Process Engineering; Quality Assurance; Manufacturing; Human Resources (to assess re-training needs); Logistics / Inventory Management; Reliability and Test; and Field Service / Authorized Repair. Once RoHS compliance is achieved, the Sales and Marketing entities within an electronics assembler should be touting the capabilities of the company in the market place.

The RoHS transition will not be easy for anyone, but can be made easier with careful planning, management dedication and good execution. Kester is also ready to assist your RoHS conversion process with properly designed materials to improve yields coupled with engineering expertise to help optimize your process.

2005: A Year of Many Questions *and Answers*

There are about six months before the "Restriction on Hazardous Substances" (RoHS) takes effect. As this date approaches, assemblers don't have much time to make their products destined for European markets not only lead-free but also free of cadmium, mercury, chromium VI, polybrominated bipenyls (PBB) and polybrominated diphenyl ethers (PBDE).

Great strides have been made in the last two years with lead-free soldering process optimization. Alloys have been down-selected, flux systems re-designed, and equipment modified. Components are being made available in RoHS formats and board finishes for lead-free are now readily available.

A substantial portion of the assembly market is planning to transition in 2006 and they have obtained answers to their key questions. However, there is no doubt more questions will beg for answers well into 2006 and beyond.

Kester understands the transition is not an easy one and in the last three years has been offering its knowledge to the global industry. This has taken the form of seminars, in-house training, web-casts and value added services such as Kester University.

This article is a compilation of the many questions Kester Technical Support receives from customers around the world. Out of the hundreds of inquiries we receive each month we have summarized the most frequently posed questions.

ROHS DIRECTIVE QUESTIONS:

WHAT ARE THE LABELING REQUIREMENTS TO INDICATE ROHS PRODUCT COMPLIANCE?

The RoHS Directive doesn't require any specific label to be put on assemblies or box builds. Although some companies have designed their own labels and some are using it, by law it is not necessary. Any product entering the European market will be assumed to be RoHS compliant. The same applies to the lead-free logo; it too is not required.

Kester's Lead-Free Logo

Some manufacturers are using their logos to indicate the product is lead-free but this is usually for marketing purposes.

DO I NEED MATERIAL DECLARATIONS FOR MY FINISHED PRODUCT?

A Material Declaration showing compliancy for your product is not required by the EC law. However, if a product entering the European market is intercepted and found to be non-compliant to the RoHS after July 1, 2006, it will be important to demonstrate that a company has done all that is possible in insuring compliancy.

Material Declarations or data from each component used in the assembly will then be required. Keeping Material Declarations for each product's Bill of Materials is important and can show good due diligence has been exercised. A close relationship with suppliers is essential.

WHAT ARE THE MAIN ELEMENTS REQUIRED FROM A MATERIAL DECLARATION FORM FOR MY COMPONENTS, BOARDS, WIRING ETC?

The essential elements a Material Declaration must contain are as follows:

- Compliancy to European RoHS Directive banned substances
- Free of Polybrominated Biphenyls and Polybrominated Diphenyl ethers flame retardants, can be found in some plastic molding compounds and laminates
- Temperature maximum limits for a lead-free soldering process
- New Moisture Sensitivity rating for lead-free assembly

The key is to insure banned substances are not present, but also that the parts are lead-free process compatible. Lead-free soldering with SAC alloys will require hotter thermal profiles. To insure reliability, close attention must also be placed on the maximum safe temperature the part can see and the impact of moisture.

WHAT METHODS ARE AVAILABLE TO TEST FOR BANNED SUBSTANCES IN ELECTRONIC AND ELECTRICAL PRODUCTS AS REQUIRED BY THE ROHS DIRECTIVE?

The RoHS Directive requires that homogeneous parts included in electronic and electrical products sold in the European Community after July 1, 2006 contain less than 0.1% lead, 0.01% cadmium, 0.1% PBB and PBDE, 0.1% chromium VI and 0.1% mercury.

The testing of PBB and PBDE is not easy and can be very expensive; Chromium VI can also be expensive although analytical tests can be of a destructive nature requiring digestion in acids prior to analysis.

The proposed screening methods as per IEC 62321 dated September 2005, Procedures for the Determination of Regulated Substances in Electro-Technical Products is X-Ray Fluorescence (XRF) Spectrometry.

XRF is a non-destructive testing of banned substances and is an effective way to identify the presence of lead, mercury, and cadmium. It will also detect elemental bromine and chromium but will not be able to identify if it is in its molecular form as PBB or PBDE or the valent state of chromium. XRF will detect their presence.

XRF Spectrometer units with the accuracy needed cost in the range of $50,000 to $80,000 and therefore assemblers wishing to avoid liability are doing some spot testing of components, boards, wires, plastics and metal parts by sending them out to outside laboratories.

Kester applications laboratory has recently acquired a Fischer Technology XRF unit to assist customers in the screening of these parts. This is part of Kester's valued added services to our customers.

WHERE CAN I GET UP-TO-DATE WEB INFORMATION ON WEEE AND ROHS DIRECTIVES AND PROGRESS?

Getting up-to-date information is critical to your company's transition roadmap. A good place is the web and the following websites contains updates originating from the TAC (Technical Adaptive Committee) for the RoHS.

The website www. dti.gov.uk/sustainability contains copies of the WEEE and RoHS Directives but also the latest minutes of the TAC (Technical Adaptive Committee) meetings.

Another useful website in reference to the WEEE directive which includes the EU's perspective is www.europa.eu.int/comm/environment/waste/weee_index.htm.

WHAT ARE THE CHANGES IN REFERENCE TO LEAD-FREE ASSEMBLY IN THE JULY 2004 REVISION OF J-STD-020C?

The IPC/JEDEC J-STD-020C, issued July 2004, entitled Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices details the thermal profiles SMD components must meet to be classified as lead-free process capable.

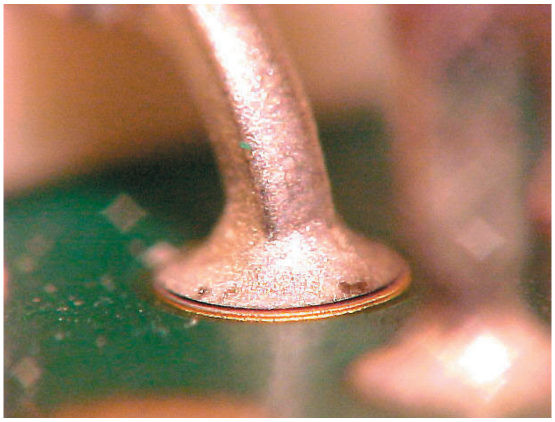
Higher thermal profiles with lead-free (235-255° C), may require component re-qualification to new moisture sensitivity limits. This needs to be understood by design, logistics, manufacturing and procurement personnel. Measures must be taken to avoid moisture issues such as popcorning, delamination and cracking issues during lead-free reflow.

SOME COMPATIBILITY QUESTIONS:

CAN I SOLDER LEADED COMPONENTS IN LEAD-FREE WAVE SOLDERING?

Leaded terminations cannot be soldered in a lead-free wave solder process. Lead-free solder bar will have a small amount of lead when received usually in the range of 0.01 to 0.08%. The RoHS Directive states a maximum of 0.1% lead; it does not take very much lead to surpass this limit. To avoid surpassing this limit, lead-bearing terminations should not be allowed. There is no effective way to reduce lead content except by dilution if lead were to go beyond 0.1%.

Also lead contamination can be a contributor to fillet lifting and fillet tearing. Although this is not considered a defect as per IPC-610D, further studies are required to determine the impact on high reliability assemblies. For consumer electronics, reliability would not be an issue since most are not exposed to thermal cycling or thermal shock during their use.


Fillet lifting in wave solder joint due to lead impurity

CAN I SOLDER RELIABLY LEADED TERMINATIONS WITH LEAD-FREE SOLDERS IN AN SMT PROCESS?

Component manufacturers often will use Sn90Pb10 or Sn85Pb15 for the tinning of component terminations. During soldering, a small amount of lead will be introduced into the lead-free joint and for small amounts of lead (< 2%), this doesn't impact the pull and shear force results when tested. Some assemblers have used a mixed bag of leaded and unleaded SMD's with no impact to product reliability. Most are in consumer electronics.

For the highest reliability a complete lead-free system is preferred. If leaded SMD components must be used, it is recommended to assess product reliability and therefore some testing may be required.

Also note that for RoHS compliance, lead must be kept below 0.1% in the joint also, lead in terminations may bring the final assembly outside of compliance.

QUESTIONS ABOUT RELIABILITY:

WHAT ARE THE RELIABILITY RISKS ASSOCIATED WITH THE HIGHER THERMAL PROFILE DEMANDED WHEN REFLOW SOLDERING WITH SAC305 SOLDER PASTES?

SAC305 solder melts in the range of 217-220°C and the thermal profile is therefore running hotter with peak temperatures of approximately 235-255°C depending on the assembly. Times above the liquidus temperature will range from 40-90 seconds in most applications. The peak temperatures for SAC305 thermal profiles are about 25 to 35 degrees hotter than the traditional leaded paste processes. Components, boards and flux systems can be stressed by this increased temperature and create reliability risks. Some of these risks are detailed below.

- Component molding compound damage
- Component internal damage
- Board delamination
- Component and board discoloration
- Dissolution of primary component metallization
- Increased thickness of intermetallic bond line
- Leaching and reduction of metallization
- Increased oxidation impacting subsequent soldering operations

To reduce the reliability risks, engineers must insure both components and boards are lead-free process capable. It is important to verify that the components are rated lead-free peak reflow temperatures up to 250 or 260°C. Additionally, moisture sensitivity ratings may be lower with lead-free processing; for further information on this, refer to the IPC-J-STD-020C. This document should be quite useful to procurement, where lead-free components can be referenced to the requirements set in this standard.

Using the lowest possible peak temperatures and time above liquidus temperature will reduce intermetallic formation and leaching of metallization. Sufficient heat will be required to solder all parts adequately and a careful balancing of the thermal profile will therefore be necessary.

ARE THERE RELIABILITY RISKS ASSOCIATED WITH SAC305 OR TIN-COPPER WAVE SOLDERING?

When SAC305 solder is used in wave soldering the temperature is normally set at 255-260°C and for Tin-Copper based solders the temperature normally is higher 260-270°C.

When soldering with Sn63Pb37 solder, the pot temperature is typically close to 260°C (500° F). If the contact times with molten solder in a SAC305 process is kept the same there is no detrimental effect.

However, many assemblers are finding that they need reduce conveyor speeds and increase contact times to achieve adequate hole-fill with lead-free solders. This can be further aggravated with thicker boards above 0.093” where contact times may need to be even longer to avoid poor hole-fill. This is a direct result of the differences in the alloys' physical properties; SAC305 and other lead-free alloys simply do not flow as quickly as Sn63Pb37.

Decreasing the conveyor speed (thereby increasing the contact time) can achieve adequate hole-fill. Extra contact time does not come without risks; damage to the solder mask, laminate and bottom-side SMD's may occur if the process is not carefully controlled.

With Tin-Copper based solders, contact times can be even longer due to reduced wetting speeds of these alloys; the risks of thermal damage may be higher.

WHAT IS THE IMPACT OF LEAD CONTAMINATION ON LEAD-FREE JOINTS ON PULL AND SHEAR TEST RESULTS?

For small amounts of lead in SAC alloys, no difference was noticed in pull or shear test data. Gintic Singapore Consortium report showed that up to 2% lead by weight in SAC joints had no discernable negative impact. However, lead-free terminations soldered with lead-free solders are still considered the most reliable.

In wave soldering, however, the presence of lead can result in some fillet lifting.

WHAT ARE THE FIRST STEPS TO TAKE TO INSURE A RELIABLE SMT, WAVE SOLDER PROCESS WITH LEAD-FREE SOLDERS?

The knowledge base for Lead-Free Assembly is still rapidly increasing. It is essential to select an alloy that has been carefully studied across the industry. Many SAC alloys would fit this category and a great deal of data now exists; however, this is not the case with some other alloys.

Understanding the physical and chemical properties of the lead-free solder alloy is important since many have reduced wetting behavior and higher surface tension. This will enable an engineer to optimize the soldering process to account for these differences and insure a solid solder joint.

Blistering of solder mask with excessive pot temperatures

QUESTIONS ABOUT THE LEAD-FREE WAVE SOLDER PROCESS:

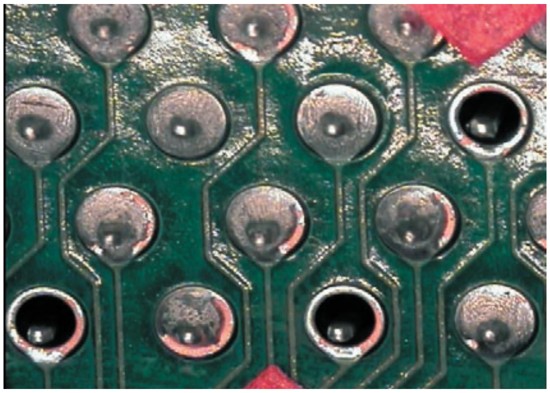
IN WAVE SOLDERING OF THICKER BOARDS WITH LARGE THERMAL MASSES AND HAVING SEEN A PREVIOUS HEATING CYCLING, HOW CAN I SOLDER THEM WITH NO-CLEAN FLUXES AND LEAD-FREE SOLDER?

Wave soldering of thicker boards (especially if they are copper OSP) with thicknesses in excess of 0.093” can be difficult especially in reference to hole-fill. Assemblers using water washable fluxes, which contain more chemically active materials, tend to fare better than those assemblers using no-clean fluxes with low solids content.

If no-clean fluxes are used and hole-fill is deficient, the following can be tried to increase solder penetration.

- ✦ Reduce conveyor speed
- ✦ Increase the contact time at the solder wave
- ✦ Increase solder temperature 5 to 10°C
- ✦ Turn off chip wave
- ✦ Apply more flux to the board
- ✦ Select a flux that is more heat-stable
- ✦ Turn off the air knife or reduce air pressure
- ✦ Use a no-clean flux with higher solids
- ✦ Use a flux with higher activity rating such as ROL1
- ✦ If using Tin-Copper alloys, switch to SAC305
- ✦ Use board finishes that are more easily solderable

In reference to board finish, fewer difficulties are experienced with hole-fill if the finishes are silver immersion, pure tin or lead-free HASL. Higher solids fluxes may produce assemblies with a higher amount of residue, but should preserve activator life during the preheating and soldering cycle. A higher solids flux should have improved heat stability and also better hole-fill than lower solids fluxes.

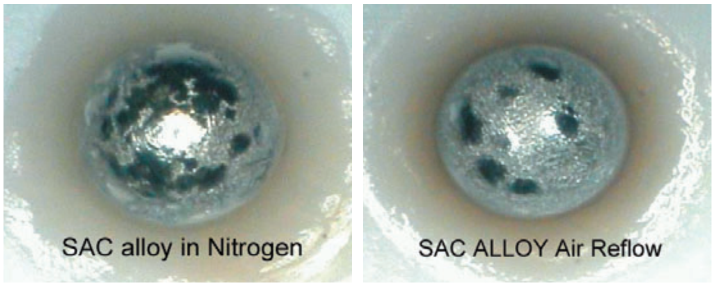


Lack of hole-fill due to poor wettability, 0.093" thick board

IS NITROGEN INERTING REQUIRED IN LEAD-FREE WAVE SOLDERING?

Nitrogen inerting may not be required in reflow soldering however in wave soldering it can help reduce dross to a minimum. Reports indicate an average reduction of 95% in dross formation. Since the cost of lead-free bar solder is higher than Sn63Pb37, the use of nitrogen in an operation where the solder wave is used 8 hours per day can be beneficial to the bottom line.

Nitrogen is only required at the solder pot to reduce oxide formation and should not be considered a necessity for good soldering results in nearly all applications.



Surface Finish Differences between lead-free in air and nitrogen.

Nitrogen inerting can also reduce defects such as non-wetting, insufficients but may increase bridging and icicling, particularly if the flux system is weak (no-clean L0 type) and/or overheated during preheat.

If nitrogen is not used, a flux designed for lead-free soldering can still insure excellent results if the other process parameters are optimized.

Questions about the Lead-free Reflow Process:

In the reflow SMT process, do I have to modify printing parameters or stencil design for lead-free?

If a lead-free solder paste is properly designed, it will likely contain a lower metal percentage by weight but printing parameters will not necessarily change. The change in metal content is a result of the density differences between leaded and lead-free solders; the volume-volume relationship of the paste and flux should remain roughly constant through the transition to lead-free pastes. The printing speeds of most lead-free pastes can reach 100 mm/second and above with good print definition. The solder paste's idle time and stencil life with lead-free are comparable to traditional Sn63Pb37 solder pastes.

Due to the lower spread of lead-free solders, exposed base metals may be seen around the perimeter of the solder joint. Although this is not a defect as per IPC-610, some customers may prefer complete pad coverage. If this is the case, it is recommended to open the apertures on the stencil to resolve this problem. However, care must be taken to avoid bridging, solderballs and solderbeads with higher pad coverage.

In the selection of a lead-free paste with excellent printing characteristics check the following:

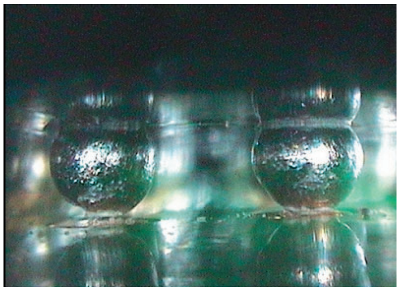
- Printing pressure requirements
- Printing speeds and print definition
- Idle time
- Stencil life
- Ability to spread on various finishes
- Tack life
- Powder diameter, Type III versus Type IV

For finer pitch applications there is a trend to use Type IV powder but this can lead to slightly higher paste costs and a reduced shelf life of the paste. Type IV powder also oxidizes more rapidly and can have a reduced stencil life.

Can lead-free BGAs be soldered reliably with leaded solder paste?

Lead-free BGAs contain SAC spheres for interconnection and many users of leaded pastes are concerned with the reliability of the solder joints.

Typical BGA joint with SAC



BGA Non-Wetting Defect

Some assemblers are soldering these with SAC solder paste and here material compatibility is a non-issue. However, in some cases, lead-free BGAs are required to be soldered with leaded solder pastes such as Sn63Pb37 and joint reliability can be questionable.

When soldering with Sn63Pb37 solder paste, there is a risk of increased voiding if the thermal profile used is a lead-free one to insure proper ball collapse. This generally means that the leaded soldering process needs to be taken up to temperatures typical of lead-free assembly in order to produce good solder joints.

Soldering lead-free BGAs can be reliable when soldered with leaded or lead-free pastes provided that good wetting can be achieved without excess voids.

Questions about hand-soldering with lead-free:

How can I develop a good lead-free hand-soldering process, which will ease the operation?

A recent study in the Lead-free Update by TechSearch International reported that hand-soldering was found to be more problematic to implement when compared to lead-free wave soldering and SMT.

The reason could be that hand-soldering is more operator dependent than reflow and wave soldering but also the surface tension in lead-free solders is slightly higher. Wetting or spread is also a little slower when compared to Sn63Pb37.

To reduce operator issues and to improve wetting, proper optimization of the soldering process is critical. To avoid issues, use a flux content of 2-3% by weight in the solder wire, use a solder tip temperature of 700-800° F. Also, Tin-Silver-Copper (SAC) solder will flow more readily than Tin-Copper (SnCu) solder.

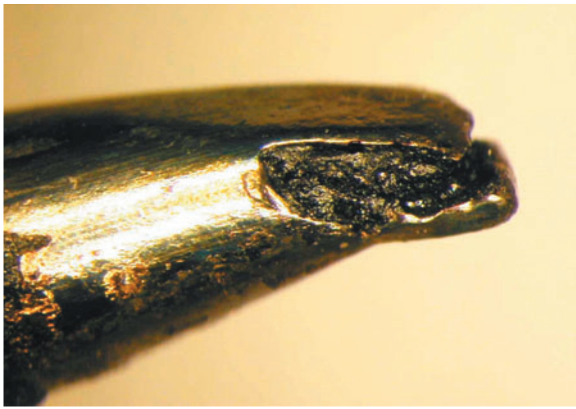
The main issues encountered with lead-free hand-soldering are cold solder joints, poor wetting, and de-wetting. These can be avoided with proper process set-up.

How can tip life be increased in lead-free hand-soldering processes?

High tin content solders such as SAC and Tin-Copper based alloys will leach metals more aggressively than traditional leaded alloys. This is the reason stainless steel wave soldering pots have a reduced life when used with lead-free alloys. The same process of iron being leached by tin to form Fe3Sn will occur with soldering tips.

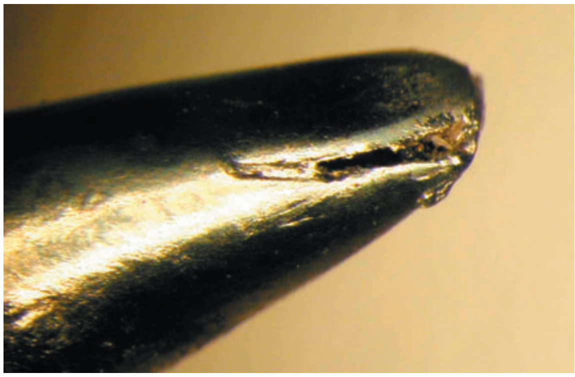
To prolong tip life, it is recommended to use the lowest soldering or contact temperature possible; usually 700° F works quite well with SAC solders. The other way to extend tip life is turning off the heat when the iron is not in use. Proper soldering techniques such as using the correct tip size and insuring the tip is well tinned at all times will reduce tip damage by operators not fully accustomed to the reduced wetting of lead-free solders.

Using more aggressive cored wire and liquid fluxes can also reduce tip life. Assemblers using water washable solder wires will experience a shorter tip life than those using no-clean fluxes.



Solder Iron Tip failures when using Lead-free.

Some soldering iron manufacturers are now coming out with thicker iron tips for lead-free soldering; this should increase tip life. However, remember that not all tips are created the same and some will last longer and cost less. There is still some work to be done at this level as to improve the life and performance of tips with lead-free.



Cored wire fluxes must be able to reduce oxides rapidly and give good wetting as to not extend the soldering contact times. The flux must remain unaffected by the higher soldering temperatures of up to 800°C. No-clean flux types must not char or discolor, while water washable types are required to be easily removed in traditional cleaning equipment and settings.

Peter Biocca is the lead-free Senior Market Development Engineer at Kester. Comments or questions pertaining to this article can be sent to pbiocca@kester.com.

Lead-Free Wave Soldering Factors

Getting good and some bad, through hole assembly results, the process window may be narrow and need to look at all factors to open up process window. Wave soldered through hole solder joint is over designed as it has larger surface area to wet than surface mount joint and if lead pull is done the component pin breaks before solder joint fails.

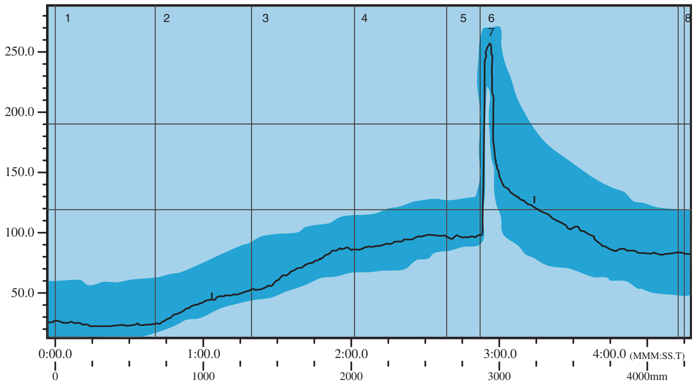
FACTORS THAT AFFECT THROUGH HOLE ASSEMBLY RESULTS:

EFFECT OF PRE-HEAT:

For lead-free wave soldering the pre-heat temperature is critical. It is important to do a thermal profile, as with lead-free higher temperatures, need to take the guess work, out as higher temperature can burn off all the active flux ingredients prior to hitting the wave or insufficient preheat can give poor hole. To complement the use of thermal profile, use of IR pyrometer to check top board temperature prior to soldering assembly more often for verification purposes.

The temperature of the board (component side) during preheating should rise as fast as possible to 45°C and just before soldering at a temperature of greater than 105°C. (Better results are seen at 110-120°C.) A lower preheat is also known to cause poor PTH fill. In one case study associated with preheat increase of 5-8°C rise in temperature to bring within range resulted in yield improvement greater than 40%.

The major difference between tin/lead and lead-free flow soldering is the higher melting point required by the lead-free alloy. Because lead-free alloys require higher preheat temperatures, thermal shocking of components as they enter the molten liquid wave should not exceed 100°C.



Example of Wave Solder Profile

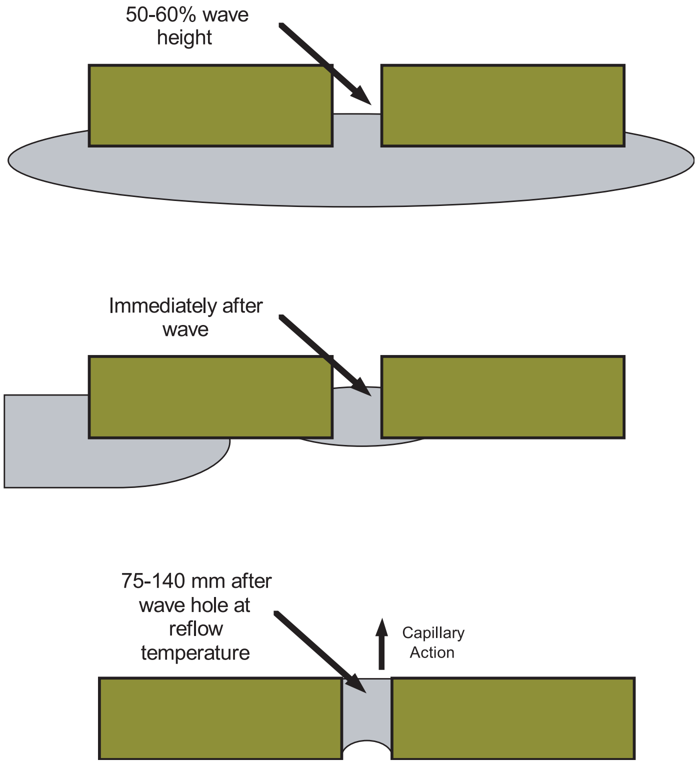
EFFECT OF FLUX:

Since the wetting characteristics of lead-free alloys are less than that typically exhibited by tin/lead alloys at lower process temperatures, the selection of a good flux is mandatory to assure good solderability. The flux selected must be able to withstand exposure to the higher process temperatures required for lead-free alloys. In general, fluxes used for lead-free through hole soldering must be able to withstand topside PCB preheat temperatures as high as 130°C and solder temperatures as high as 280°C for three seconds of contact time or longer.

Good flux will open up process, it means worry free consistent results. If the flux is marginal slight change will cause you to tweak the process. In a case study lead-free flux opened the process window from unacceptable to consistently acceptable all the time. It is not worth penny pinching when selecting flux, make sure to use flux that gives higher process window and yields. You can realize higher cost improvement yield improvement than saving on flux.

EFFECT OF WAVE HEIGHT:

This is very critical, to select correct wave height. Wave height should be such that Solder must reach the top of the hole prior to exiting the solder wave, which involves combination and capillary action. If the solder does not reach the top of the hole then insufficient amount of solder will remain the hole. In this case the solder that is in the hole will continue to rise due to capillary action after leaving the wave and leaving gap in the hole. In a case study Wave height adjustment yielded 5% improvement.



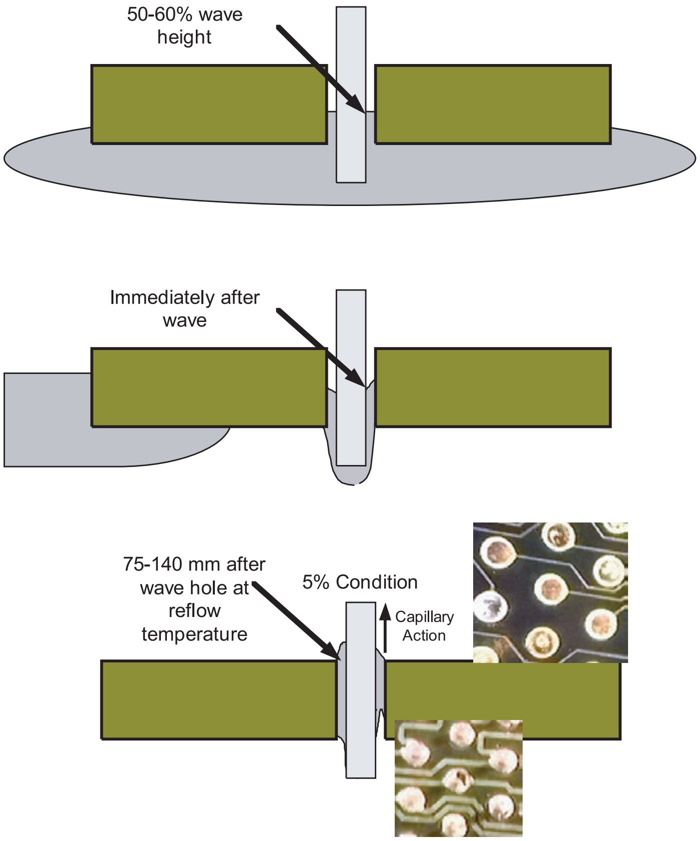
Example of unpopulated board Through Hole Soldering

EFFECT OF DWELL TIME:

For lead-free due to sluggish wetting of lead-free alloys compared to tin/lead, dwell time will be greater than tin/lead alloy wave usually at least half a second more. During the wave solder dwell you are taking board barrel temperature higher than the tin/lead alloy soldering. Boards with higher concentration of holes per unit area, with inner layer hole connections makes holes cooler, which results in slower heat up and cool down.

EFFECT OF WAVE TEMPERATURE:

Higher temperature will assist wetting faster as it will heat the substrate faster for soldering. Any thick boards (above 1.5 mm) and/or boards with an internal thermal plane (power/ground at layer 3,4,5) will rob heat from the PTH.



Example of populated board Through Hole Soldering

Simply raising wave pot temperature will be inadequate. A more intense preheat and wave-height adjustment is needed.

In conclusion lead-free Wave soldering is the potentially the most complex area for lead-free implementation and above are only few factors. Other factors to consider through hole to pin size ratio, alloy and impurities control etc. Key is optimizing to open up process window so that you have more latitude.

Bihari Patel is Applications Manager, OEM & Assembly Applications at MacDermid Inc. Comments or questions pertaining to this article can be sent to bpatel@macdermid.com

Cost Effective

Lead-Free Wave Soldering Conversion

As the deadline approaches for compliance with worldwide lead-free solder requirements, estimates show that some European and Asian companies are prepared while the majority of North American companies are still in the process of making the transition. The conversion to lead-free will not be a simple process – there are many variables to consider that will influence an electronics manufacturer's decision of how to implement this requirement in an efficient and cost effective manner.

Companies transitioning to lead-free recognize that certain elements of the wave soldering process such as flux, heat and solder will remain fixed in order to form high quality solder joints. Subsequently, critical variables inherent in the wave solder process, which include flux deposition, preheat and solder temperature, and solder dwell time need to be exactly controlled.

Because of increased tin content, lead-free alloys oxidize at a more rapid rate when the solder is in liquidous state as compared to tin-lead (SnPb) solder. Due to the higher tin content, tin oxide consisting of tin-oxygen (SnO) and (SnO2), forms at a faster rate combined with higher processing temperatures to result in more oxidation and dross buildup. In a standard SnPb wave pot, when impurities such as copper build up, intermetallics between the copper and tin form. By reducing the temperature of the solder pot and allowing the pot to sit idle for a few hours, the impurities rise to the top, and can be easily skimmed off the surface. This method works well for eutectic solder since the density of the copper-tin (CuSn) intermetallic is 8.28 and the density of the SnPb solder is 8.80 allowing the copper-tin intermetallic to float to the surface. With the implementation of lead-free solder alloys, the methodology will require change because of the lower density of lead-free alloys versus the CuSn intermetallic as shown in Table 1.

Solder Alloy	Melting Point	Solder Pot Temperature	Tin Content	Density
SnCu	227°C	270-280°C	99.3%	7.29
SnAg	221°C	265-275°C	96.5%	7.44
SnAgCu	217°C	260-270°C	96.5%	7.38
SnAgCuSb	217°C	260°C	90.5%	7.24
SnPb	183°C	250°C	63.0%	8.80

Table 1. Characteristics of Lead-Free Solder Alloys

Since most lead-free alloys are lower in density than SnPb solder, the CuSn intermetallics will sink and disperse throughout the solder pot. Also, lead-free alloys dissolve copper at a faster rate than SnPb solder which results in a higher rate of copper build-up and contamination of the solder pot. Over prolonged periods of operation, the lead-free alloys begin to exhibit sluggish behavior caused by the build-up of CuSn intermetallic that forms at the bottom of the solder pot. Generally, this problem doesn't exist with standard SnPb solders because the CuSn intermetallic floats and can be easily removed.

TEMPERATURE AND PROCESSES

The majority of lead-free solder alloys display decreased wetting characteristics and slower wetting times in comparison to SnPb solders. Additionally, flow characteristics of lead-free alloys are generally more viscous. Lead-free alloys have melting points between 30-40°C higher than SnPb solders requiring higher processing temperatures, which places greater demand on flux performance. The use of a higher activity flux should be considered, however, the volume of flux applied to a board and the uniformity of deposition is essential. Increased preheat is generally required because of the higher melting point of lead-free alloys. Solder pot temperature and solder contact time must be increased, but at the same time controlled to avoid thermal shocking, or excessive thermal differential upon entering the solder bath.

Often an existing wave solder machine may need upgrading with a newer spray fluxer to be suitable for processing VOC, water-based fluxes. An ultrasonic or nozzle type spray fluxer works best since the flux droplet size can be controlled and a continuous and uniform spray pattern can be applied across the entire board. This is essential since it is important to achieve the smallest possible droplet size with VOC-free fluxes to obtain good through-hole penetration.

More preheating is generally required because of the higher melting point of lead-free alloys. A longer preheating section is often needed to reach these higher temperatures and avoid thermal shocking when entering the chip wave. Preheating for lead-free wave soldering can require a heating length of up to 1.8 meters for conveyor speeds as high as 120 mm/minute and as long as 2.4 meters for conveyor speeds greater than 180 mm/minute. Achieving proper preheat temperatures on the topside of the PCB has the greatest single effect in reducing solder defects such as bridging and insufficient topside fillets. Optimum preheating of a PCB can best be achieved with a combination of infrared heating from the bottom and convection heating from the top.

An effective upgrade strategy is to replace an existing spray fluxer with an external spray fluxer. This not only improves the quality of flux application but frees up space inside the wave solder machine that can be used to extend the preheat capacity.

The operating temperature of the solder pot will generally increase depending on the lead-free solder alloy. For tin-silver-copper alloys (SnAgCu) with a melting point of 217°C, the solder pot temperature may be between 260-270°C. For high melting point alloys such as tin-copper (SnCu), the solder temperature may be as high as 270-280°C.

It is common practice to change the characteristics of the laminar solder nozzle since a longer contact time is generally required due to the lower wetting properties of lead-free alloys. Often the distance between the chip wave and laminar wave should be reduced to minimize any temperature drop between contact points. Increasing the length of the chip wave improves wetting while increasing the preheat output produces a similar effect. Reducing the fall height of the wave to decrease the distance of overflowing solder reduces the amount of dross generated with lead-free alloys.

PREVENTING LEAD-FREE CORROSION

Tests have shown that many lead-free alloys cause corrosion to the base metals used for solder pots, impellers and baffles due to the aggressive nature of tin at high temperatures as shown in Table 2. The surface of various base metals such as 304 stainless steel or cast iron will generally exhibit pitting and start to dissolve after prolonged contact with lead-free alloys. The use of a higher grade 316 stainless steel does retard this effect somewhat since 316 stainless steel exhibits a reduced rate of iron (Fe) dissolution because of a lower Fe content. Moreover, unprotected cast iron solder pots are prone to high rates of iron dissolution due to the high Fe content contained in cast iron.

Material	Advantages	Disadvantages	Longevity*
304 stainless steel	Inexpensive	No corrosion resistance	1 month
316 stainless steel	Inexpensive	No corrosion resistance	3-6 months
Cast iron	Inexpensive	No corrosion resistance	1-3 years
Surface coated stainless steel	Good resistance to corrosive effects of tin	Will degrade when coating is scratched	6-12 months
Surface coated cast iron	Good resistance to corrosive effects of tin	Will degrade when coating is scratched	3-5 years
Titanium	Excellent resistance to corrosive effects of tin	Can be expensive to fabricate	10 years

* - Longevity under sustained production conditions in direct contact with molten lead-free solder

Table 2. Summary of Base Metals

Various surface coatings can be applied to stainless steel or cast iron solder pot components such as Melonite, Teflon or others that will provide some degree of corrosion resistance. However, complications can arise from their use. Prior to application of base coatings, all base metal components need to be subjected to a passivation process that consists of dipping into a nitric acid, phosphoric acid or similar acid solution to clean the metal surface and form chromium oxide on the surface. This process complicates the ability to field retrofit components on existing wave solder machines. Nevertheless, applying surface coatings is a temporary measure because the application thickness is limited and the coatings are susceptible to scratching due to the removal of CuSn intermetallics that sink to the bottom of the solder pot. The removal of CuSn intermetallics can cause repeated scratching and breakdown of the surface coating with the resulting erosion damaging the solder pot components and contaminating the solder alloy.

An alternative to surface coatings is to use a base metal that is highly resistant to the aggressive nature of continuous tin scavenging. Titanium is the one material ideally suited for solder pump impellers, flow ducts and solder nozzles in contact with lead-free solder alloys since it is impervious to the effects of tin scavenging. Previously titanium had been considered expensive to fabricate. However, new developments in fabrication techniques have made titanium cost competitive with other base metals and have improved the integrity and quality when forming and welding complex shapes.

Because of the frequency with which surface coated solder pump impellers, flow ducts and solder nozzles wear out and must be replaced in lead-free soldering applications, the use of titanium has generated renewed interest. Retrofit kits are now available that replace the solder pump impeller, flow ducts and solder nozzles with parts made of titanium as shown in Figures 1, 2 and 3. The titanium-manufactured parts can withstand prolonged service in lead-free applications eliminating continuous replacement of surface coated parts.

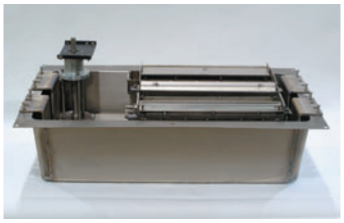


Figure 1. Titanium Lead-Free Retrofit Kit

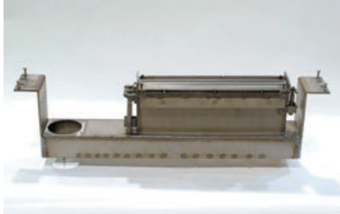


Figure 2. Titanium Chip Nozzle and Flow Duct

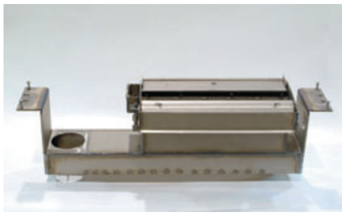


Figure 3. Titanium Laminar Nozzle and Flow Duct

Moreover, using a solder pot liner made of titanium which can be placed inside an existing cast iron or stainless steel solder pot to convert an on-site wave soldering machine for lead-free use lessens the complexity of lead-free conversion. One advantage for using the titanium solder pot liner, together with titanium solder pump impellers, flow ducts and solder nozzles is that they can be retrofitted to most major brands of wave soldering machines with minimal downtime as shown in Figures 4 and 5. They are currently in use and have met the lead-free requirements of major contract manufacturers and original equipment manufacturers throughout Europe, Asia and North America.

Figure 4. Titanium Solder Pot Liner

Figure 5. Installation of Solder Pot Liner

BUYING NEW OR TRANSFORMING OLD

Upgrading an existing wave soldering machine with a new spray fluxer, new preheat modules, and titanium retrofit kit and solder pot liner significantly reduces the cost of converting to lead-free wave soldering. This is especially true when applying an upgrade strategy to a pre-owned machine. Upgrading provides effective lead-free performance at a fraction of the cost of buying a new wave machine as shown in Table 3. Upgrading not only reduces capital outlay, but also reduces the lead-free conversion timeline since upgrades can be added in much less time then the delivery and installation of a new machine.

Machine Element	Recommendation	Typical Need	Upgrade Cost	Cost of New Machine
New spray fluxer	Varies with model	40%	$11 - 30,000	Included
Additional IR or convection preheat	Recommended for throughput	70%	$4 - 5,000	Included
Titanium solder pot liner, nozzles, flow ducts and impellers	Highly recommended for corrosion protection	100%	$15 - 25,000	Included
		Totals =	**$30 - 60,000**	**$105 - 150,000**

Table 3. Cost Comparison of Equipment Upgrade vs. Replacement

CONCLUSION

The use of a titanium retrofit kit offers a greater service life because of its' demonstrated resistance to the corrosive effects of lead-free solder alloys. The time required to simply install a titanium liner and retrofit kit inside an existing solder pot versus significant downtime to physically exchange a entire solder pot means tremendous cost savings for owners of wave machines. Consistent performance of titanium solder pumps, impellers, flow ducts or solder nozzles virtually eliminates the need for periodic replacement of these components. Given these favorable operational factors with the use of titanium, manufacturers can realize productivity gains, increased machine performance and, most importantly, lower operating costs critical in the face of fierce global competition.

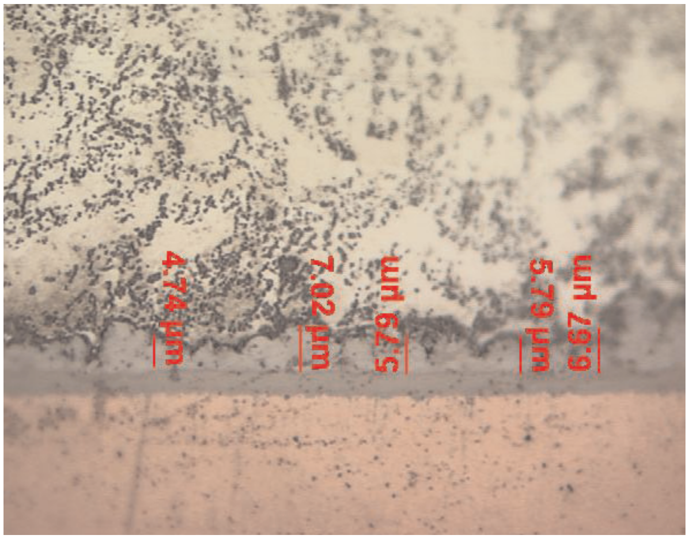
Tony Gyemant is Technical Director for Specnor Tecnic Intl. Corp. Comments or questions pertaining to this article can be sent to specnor@microtec.net

Lead-Free Impact
on Area Array Device Rework

The process for removal and replacement of surface mount Area Array devices (AAD's) has been in existence since the 1980's. During this time, the process for rework has been refined continuously to accommodate shrinking lead pitches, and increasing lead counts. Parts up to 2" x 2" containing over 2,700 connections can be reworked with yields greater than 99%. Conversely, flip chip and Quad Flat Leadless (QFN) parts down to 0.1" x 0.1" are routinely reworked with comparable yields. Process development has always centered around packages utilizing eutectic Tin/ Lead solder alloys. In the past two years some components are becoming available only in lead-free alloys. This change has already started to upset what had finally becoming a robust process for AAD rework. Following is a discussion of the impact lead-free solder will have on the various steps associated with AAD rework.

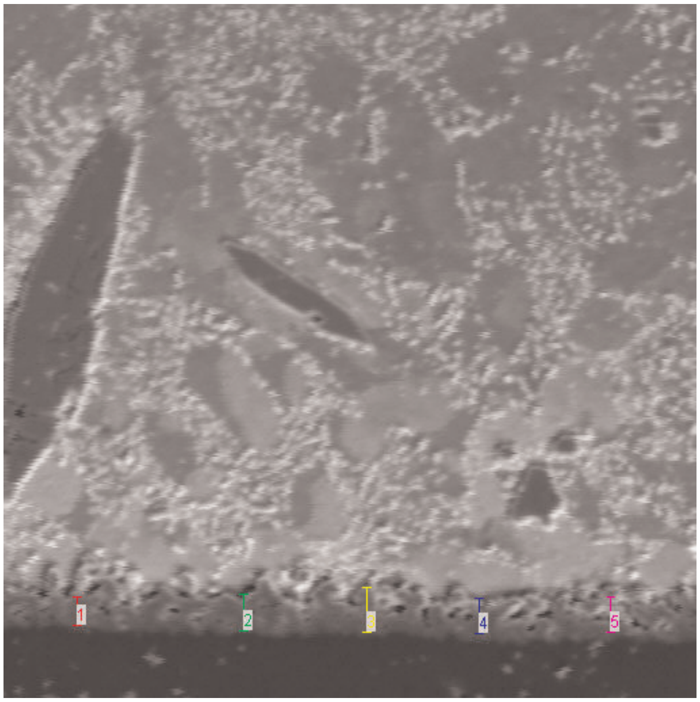
SITE DRESS

When removing an AAD from an assembly a portion of the solder from the part will remain on the assembly pad site. The method of removing excess solder from the pads is referred to as site-dress. The site dress process should leave either a flat pad, or slightly rounded pads with consistent volumes of solder. This process in not especially difficult, however any miscues could remove solder mask or pads and put the assembly in jeopardy of being scrapped. Three methods for removing excess solder are widely accepted.



1.Vacuum Removal - Several manufacturers have vacuum solder removal tools on the market. The preferred equipment blows hot gas from a collar around a nozzle that vacuums the solder. This process requires that the solder pads be at an elevated temperature to work properly as the heating ability of the tool is not sufficient to reflow the solder. Typically this equipment is set-up with the removal tool so that the site dress process is initiated immediately after component removal when the assembly is still hot. For Tin/ Silver/ Copper (SAC) alloy solders, this becomes more difficult as the assembly will loose 30°C to 50°C in a short amount of time. To implement this process for SAC alloys, the removal tool will likely need to go through another step to re-heat the solder pads and allow more time for vacuum removal. Using the vacuum removal tool when solder pads are not hot enough will result in pulled pads.

2. Solder Wick - Use of braided solder wick by a skilled operator can be efficient at removing excess solder and leaving a flat solder pad. Only skilled operators should be used for this process as the danger of pulling pads and removing solder mask is high. Using solder wick for SAC alloys should not create much of a challenge to an experienced operator.

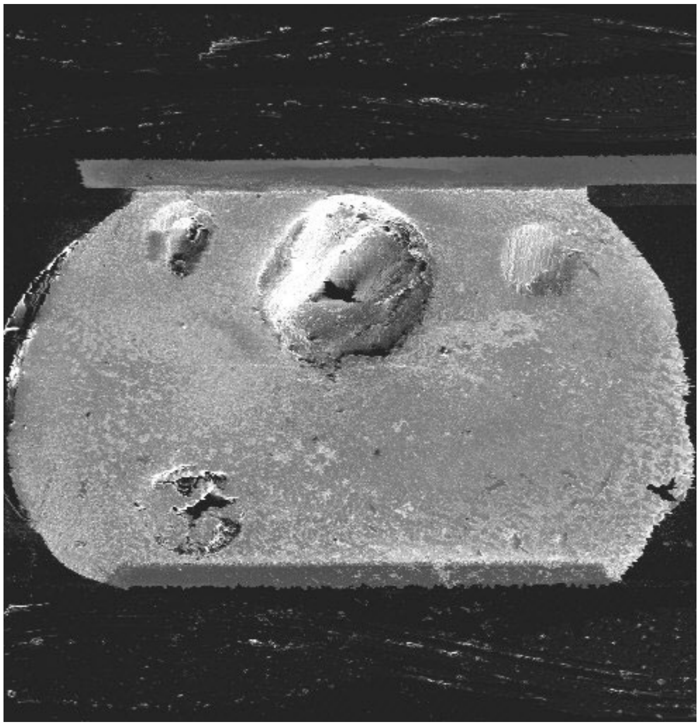


3. Concave Solder Tip - Solder tips are available for most soldering stations that utilize a concave depression to accept excess solder. This process is performed by lightly dragging the iron tip across the solder pads. Excess solder is collected in the tip, any solder pads that are void of solder will be redistributed with solder. In the hands of a skilled operator, this process is less prone to removing solder pads or mask as compared to the former two processes. The resulting pads will be left with a slight meniscus of solder. For replacement of a part this can present a problem with alignment as the component will slide off to one side of the pad. It is recommended that this process be used only when screen printing paste for reattachment of the AAD. Early investigations reveal little difficulty with incorporating this process for SAC alloy AAD's.

THERMAL PROFILING

Rework of AAD's requires an appropriate thermal profile for both the substrate and AAD package. With eutectic Tin/Lead alloy this translates into a peak component temperature of 200°C to 210°C and substrate temperatures (as measured on the top-side) of around 120°C. New lead-free components typically utilize SAC alloys that reflow at 217°C to 221°C. These parts require a rework profile to achieve component temperatures of 230°C to 240°C, and substrate temperatures approaching 150°C. To accommodate this change in profile requirements is not as simple as cranking up the heaters. There are numerous changes that will need to be implemented to achieve an acceptable rework process for lead-free AAD's.

The first step for lead-free reflow profiling is to accurately monitor temperatures at various locations at the AAD and on the assembly. With higher temperatures, the delta across the component and substrate will tend to increase necessitating the need to monitor more locations than with eutectic Sn/Pb AAD's. Crucial areas to be monitored include solder spheres under the part and a location on the circuit board in an area away from the rework site. Ideally you would want to monitor center solder connections as well as corner connections. Type K thermocouples can be slid under the part to make contact with corner solder balls. To monitor the center you will need to either drill in from the bottom of the assembly and install a thermocouple, or use a hypodermic needle style thermocouple that slides in from an edge. Another method of monitoring temperature is the use of infrared (IR) sensors. This non-contact method will only monitor the top of the component or substrate. Particular care should be taken to validate the accuracy by correlating results against type K thermocouples. It should also be noted that color and surface sheen can change readings dramatically due to different emissive properties. IR sensors will likely be most useful as a monitoring tool when processing large quantities of the same assembly.



When running a thermal profile there is almost always a delta in the temperature from the center solder joints to the corner as the part is heated. In general, metal topped and ceramic parts are hotter in the center and cooler on the corners. Plastic epoxy overmolded parts are usually cooler in the center. The goal of a localized reflow profile is to minimize the delta across the part. A large delta will result in warpage of the component that could lead to solder opens and bridges.

Forced convection reflow has been the standard for AAD rework for many years. Recent improvements in IR heating techniques have made this technology worth investigation. By monitoring temperatures at several locations in real-time, IR energy input can be varied to allow hot spots time to reach equilibrium with cooler areas. For applications where you will need to rework numerous different components and assemblies, IR is likely not the answer due to the difficulty in profiling safely. The danger with IR has to do with the rate of energy absorption of different materials and the ability of IR to heat very rapidly. If not monitored correctly you can burn an area of the circuit board or component in little time.

COLLATERAL DAMAGE

Damage to the circuit card or adjacent components during rework is not a new concern, but with an additional 30°C in the profile it is much more difficult to avoid when reworking SAC alloy components. Using forced convection to reach temperatures greater than 230°C on an AAD will result in temperatures in excess of 200°C around the rework site. Tantalum and electrolytic capacitors, as well as a host of through-hole parts will be damaged. For this reason the temptation of IR reflow begins to look attractive as the energy can be focused only on the part. Conductive heat transfer away from the part is minimal allowing adjacent areas of the board to stay well below 200°C.

REATTACHMENT

Placing AAD components back on the assembly can be done using two different fluxing methods.

1. Solder Paste - Screen printing either the pads on the assembly or the AAD is a process that offers the highest level of success with one major exception. Large components that have a tendency to warp will be more likely to bridge with the excess solder present when paste printing. The advantage for lead-free is that SAC alloys wet at a much slower rate, by having the paste in contact with both the component solder and substrate pads, the occurrence of open solder connections will be reduced. Finding insufficient reflow conditions with X-Ray will be easier because paste that has not fully reflowed will be more obvious.

2. Gel Flux - Application of a thin layer of gel flux to the substrate pads, or dipping component solder spheres in gel flux is a reliable method for fluxing to attach AAD's. This process does not require a micro stencil to complete rework and will aid prototype assemblers in both cost and lead-time. When working with eutectic tin/lead alloys the solder melts and as it wets the pads it centers the component on the pads. Tin/lead wets almost instantaneously so once the part is centered properly you can be assured a metallurgical bond. With SAC alloys the aid of surface tension to align will be reduced. Lengthened wetting times will also make it more likely that metallurgical bonds will not be formed enough to provide robust mechanical connections.

Work in defining an optimized rework process for SAC alloy AAD's is still in its infancy. It is a safe assumption that many years of refinements will unfold before lead-free AAD rework is as safe and reliable as it currently is with eutectic tin/lead solder. It is the opinion of this author that the transition to lead-free will slow the evolution of our electronics industry as we focus engineering expertise on reinventing products and processes. Do not underestimate the reinvention that will be required to rework lead-free AAD's.

Stephen Schoppe is President of Process Sciences, Inc. Questions or comments pertaining to this article can be sent to sms@process-sciences.com

LEAD-FREE Connection™

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Contributors in this issue:

kester
CONNECTING INNOVATION™

Global Headquarters:
Des Plaines, IL USA
Phone: 800.2.KESTER
or (+1) 847.297.1600
Internet: www.kester.com
Facilities: Canada ⋆ Mexico ⋆ Brazil ⋆ Germany ⋆ Singapore ⋆ Malaysia ⋆ Taiwan ⋆ Japan ⋆ China

MacDermid
Electronics Solutions

Global Headquarters:
Waterbury, CT USA
Phone: (+1) 203.575.5700
Internet: www.macdermid.com/electronics
Facilities: Singapore ⋆ Japan ⋆ Korea ⋆ China ⋆ Taiwan ⋆ Australia ⋆ New Zealand ⋆ Holland ⋆ England ⋆ Germany ⋆ France ⋆ Italy ⋆ Sweden ⋆ Spain ⋆ Canada ⋆ Mexico ⋆ Brazil ⋆ USA

Specnor Tecnic Intl. Corp.

Global Headquarters:
St-Hubert Quebec Canada
Phone: (+1) 450.462.8651
Internet: www.specnor.com

Process Sciences, Inc.

Global Headquarters:
Leander, TX USA
Phone: (+1) 512.259.7070
Internet: www.process-sciences.com

Copies available for download at www.kester.com

Any questions? Email us at:
lead-freeconnection@kester.com

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