Why Lead-free?

Unit 7 ▪ Forest Row Business Park ▪ Station Road ▪ Forest Row ▪ East Sussex ▪ RH18 5DW
Tel: +44 (0) 1342 822844 Fax: +44 (0) 1342 824155 email: info@almit.co.uk www.almit.com
Almit GmbH Tel: +49 (0) 7142 773327 Almit AB Tel: +46 3134 00270

The Move to Lead-Free Solders

Introduction

A very important issue which will ultimately concern manufacturing operations throughout the World is the pending conversion to Lead-free solders.

At present, there is no legislation on the matter. However, there are a number of EU documents on waste from electrical and electronic equipment (WEEE) that have been adopted, and may become law by 2004. Where European vehicle electronics are concerned, by 2003. The ROHS directive intends to eliminate Lead in electrical and electronic equipment by December 2004.

The main thrust of Lead-free legislation originated in the USA. Latterly, it has moved onto Japan, and now into Europe. Most progress by way of research, development and manufacture has stemmed from Japan, with the result that certain types of Lead-free products are now directly available from *Almit*.

It would appear, however, that proposals at this stage exclude Aerospace/Military applications, whilst separate legislation is expected for motor vehicle applications.

The proposed legislation also purports that the export and import of designated materials, (i.e. products containing Lead), will not be allowed into the EU nor will export be permitted.

Certain sectors of the OEM UK electronic production market are already up and running with Lead-free solders. The motor and mobile telecommunications industries, test trials were positive and as a result have succesfully introduced products containing Lead-free solders onto the market.

Why is it necessary to go Lead-Free?

Manufacturing and QA management have rightly posed the question as to why it is necessary to go Lead-Free, since there is little evidence of lead solder being harmful to users. The answer really boils down to the fact that when lead is in direct contact with the skin, little or no absorption takes place, it is only harmful when ingested through the eyes, nose or mouth via dust, fumes or from soiled hands.

The use of preventatives, such as goggles, gloves and other hygiene measures reduces the risk, but its removal from the manufacturing process has to be seen as a sensible and positive move for any organisation whose concern with the health and safety of their operatives is paramount.

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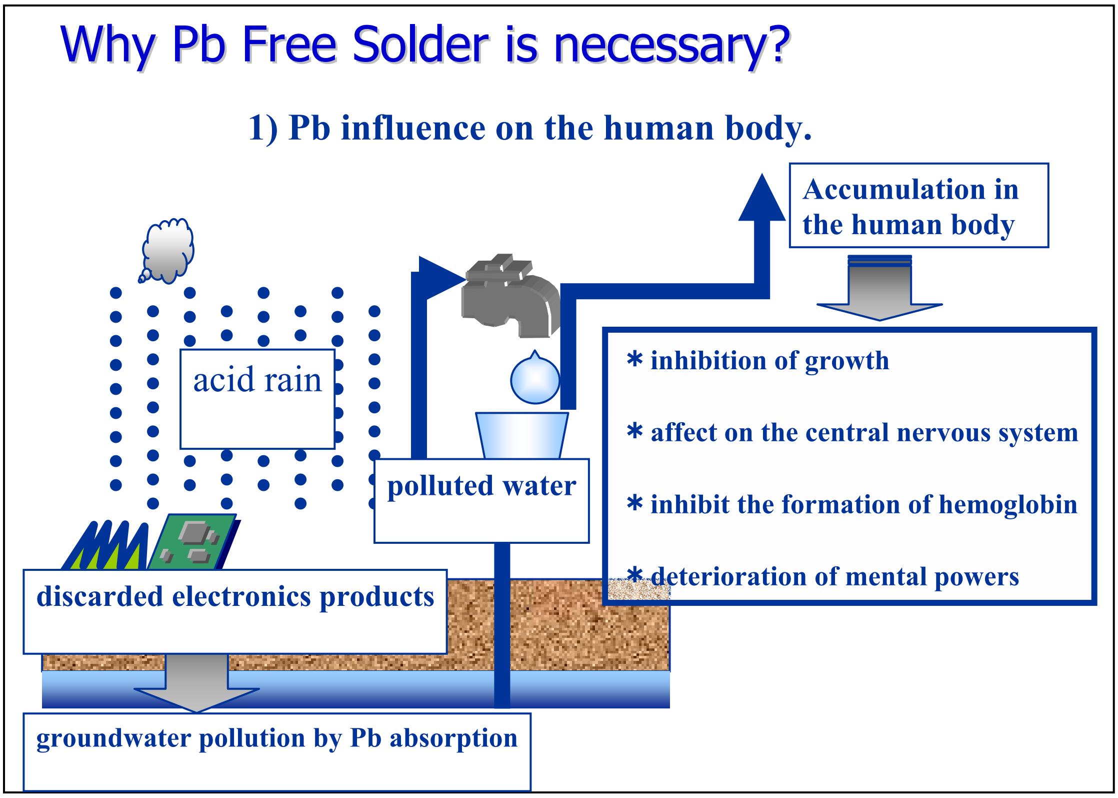
Environmental concerns

What is not so apparent is the wider environmental effect of any product using traditional Tin/Lead solder alloy or any form of Lead, when it reaches the end of its useful life.
Recycling back to base metal is currently carried out by just five companies worlwide, the logistics of the supply chain from last user to recycler proving somewhat difficult. The majority of recycled Lead seems to finish up in car batteries. Solder suppliers prefer virgin material, although as Lead is phased out this supply will diminish.

It is estimated that scrap electronic material accounts for over 6.5 million tons per annum, of which approximately 24,000 tonnes are made up of Lead in the solder joints.
(*Based upon an annual world consumption of 60,000 tonnes of 60/40 solder).*

The bulk of this material currently ends up in landfill sites, and since rainfall has become more acidic, this acid rain is leaching more and more of the Lead into the ground water and ultimately into water supplies of both plant and animal life. Since we are at the top of the food chain, it all ends up in us.
There is little that can be done with current waste levels. However, the sooner Lead is removed from the production process and subsequent waste streams, the sooner Lead levels will start to fall.
Water companies remove Lead and other heavy metals from domestic supplies with a target level of 10 parts per billion. Recent reports indicate that levels of Lead in the bloodstream have fallen with the introduction of Lead-free petroleum.



What action should a manufacturer take?

Depending on the infrastructure of your company and how important this issue is to the daily operations, there are a number of possibilities:

1. You could wait until legislation requires implementation and then be forced into action.

2. You could keep up-to-date with developments, seek advice from Lead-free solder manufacturers and run pilot schemes until legislation makes action mandatory.

3. Carry out the above and run your pilot schemes through to full production builds.

Legislation, which most observers feel is inevitable, will almost certainly allow a period for changeover. Like all new technology, it will have imperfections but will, no doubt, be refined as experience is gathered.

Toxicity

The alloys of Lead, Thallium and Cadmium, although possessing excellent properties are excluded on the grounds of toxicity.
Tin, Copper, Silver, Bismuth and Antimony have, on the other hand, been given a clean bill of health.

Tests on the *Almit* low-Lead solder have shown that leaching of Lead into ground water is so low as to be disregarded. The position of low-Lead solder is yet to be defined, so at this stage zero Lead content has to be the option.

Low-Lead solders are, however, an environmentally-friendly option until a full ban is imposed.

The choice and availability of metals

The world consumption of Tin/Lead alloy is in excess of 34,000 tonnes and increasing. Thus, each 1% addition of a replacement metal will require in excess of 340 tonnes per annum. It can be seen from the table below that this eliminates Indium (and also Gallium) as major constituents of a “global” alloy, aswell as their high cost.

Recently, Indium stood at $150/lb whereas, Tin cost $3/lb. The addition of high levels of Indium reduces the melting point, but is detrimental to fatigue strain properties. Additionally, a low temperature soft phase is created.
The position with Silver and Bismuth is less clear; Silver has always been an expensive metal and an increase in demand will see prices soar. Other metals, such as Zinc, Tin, Antimony, Copper and Magnesium are readily available in sufficient quantities to meet the anticipated new demands.

Bismuth is a by-product of Lead extraction, so prices may rise as the mining of Lead decreases.

As electronic assemblies become smaller, it is logical to assume that solder usage will also be less. However, this is negated by increasing production. Any new alloy must be available in the long term and at prices that are generally acceptable to the manufacturer. Initially, costs will be higher but should eventually reduce as volume increases.

Metal	***Cost Ratio****	***Spare Capacity***	***Potential***
Lead	1.00	Unlimited	*Unlimited*
Tin	7.88	180	*Available*
Copper	2.04	4900	*Available*
Indium	460.00**	0.2	*Scarce*
Silver	138.7	3.5	*Limited*
Bismuth	6.50	9	*Limited*
Antimony	2.4	100	*Available*
Zinc	0.96	1560	*Available*

* based on approximate figures London Metal Exchange, August 1998
** highly volatile

What is certain, however, is that manufacturers of components and PCB fabricators should be approached as to what action is being taken, bearing in mind that Lead content components may be in the supply chain for some years. Stocks may become unusable by law unless a minimum Lead level is permitted.
The current legislation projection is zero.

Board level decisions will be required concerning Articles 5,6,7 and 8 WEEE 27th July 1998 as the financial burden may be substantial. Recycling is to be the manufacturer’s responsibility at NO COST to the consumer.

Which Alloy?

The family of Tin/Lead soldering alloys has been around since the dawn of electronics, and it is almost impossible to imagine the industry without it. In fact, the almost 100% dependance on a process that until recently had no commercially viable alternative is probably unique in manufacturing.
For electronics assembly, solder has a list of attributes that make its exact replacement difficult, if not impossible. Its many characteristics makes a hard act to follow for any replacement alloy. It’s true to say that the electronics industry has been built around Sn/Pb solders and could not exist without it, at least in its present form.

One factor often overlooked is solders’ universal application

An electrical assembly manufactured, say in America 60 years ago, can quite easily be repaired in Japan using vitually identical methods and materials to produce a 100% compatible joint. The traditional Sn/Pb family of alloys are to all intents and purposes identical and interchangable, and together represent almost 100% of solder used worldwide.

Speaking at a “Lead-Free” summit in Minneapolis USA, in 1999, Jim McElroy, Executive Director and CEO of the National Electronics Manufacturing Initiative (NEMI), a consortia of US companies called for a single standard (Lead-free alloy) solution with which to move forward. Currently, the choice is Tin, Copper and Silver.

Reference: SMT Magazine, December 1999, p42

The Importance of Commonality

Most of the larger electronics manufacturing companies operate on a global scale and place large volumes of assembly work to contract manufacturers and sub-contractors. If they use, say alloy “A” in Taiwan, they will also wish to use the same alloy in both Europe and the USA. If a range of incompatable alloys emerges, then this will, no doubt, lead to a chaotic situation and field repair will become untenable. Any potential Lead-free solder alloy must fill as many of the criteria as possible. One of the most important being liquidus/solidus temperature around 180-230 degrees centigrade, and to be eutectic, (an alloy whose liquidus and solidus are at the same temperature, that is with no pasty stage).

It should possess adequate mechanical strength over extended periods; temperature ranges and service conditions at least as good as current Sn/Pb alloys, (which under certain situations are at best marginal); and must have a low toxicity. The alloy must comprise of metals that are in abundance to totally replace the present Lead, but at a price which is ultimately acceptable to the consumer. It should also have an adequate wetting performance with RMA type fluxes, particularly with the move away from the more aggressive water soluble and water washable fluxes. Any serious contender must be useable and available in solder cream, cored wire and solder bar for flow solder usage.

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Currently – What's the best alloy?

Almit's research and efforts to date indicate that any Lead-free or low-Lead solder will almost certainly be based upon Tin and that due to the shortage of suitable alloying elements the exact "drop-in" replacement does not exist. Tin melts at 232 degrees centigrade, and additional alloying elements must be added to reduce this to an acceptable figure.

To avoid so-called "hot tearing", any alloy composition must lie close to the eutectic. Hot tearing, or lift-off, is caused when there is a segregation of the low melting point phases. This is particularly noticeable with high Bismuth content alloys, combined with the use of components having Lead bearing terminations.

The chosen alloy should be, or lie close to the eutectic so that a high percentage of the joint freezes more or less at the same time/temperature. Three contenders are Tin/Copper (commonly called 99C), Tin/Silver and Tin/Antimony alloys.

The main disadvantage of these alloys was their high melting points. However, the addition of a small amount of Bismuth gives a drop-in liquidus temperature, and has not shown a tendency for hot tearing, even when used with Lead terminations on surface mount components.

The next logical step was to develop a ternary, or three part alloy, and the Sn/Ag/Cu (i.e. Tin, Silver, Copper), has proven to be the best choice with a typical composition of Sn95.5/Ag3.5/Cu0.7. This has a sharp melting point of 217 degrees centigrade and is eutectic.

Additional advantages of this alloy are low cost, since it is almost all Tin, low toxicity and its constituents are available in volume.

Companies carrying out development work on the ternary alloy Sn/Ag/Cu (the so-called SAC alloy) have concluded that it is not suitable for flow soldering and that an Sn/Cu alloy is to be preferred. This exactly parallels current practice, where it is uncommon to see Silver bearing alloys in a solder bath, but normal to see Silver used in solder creams and cored wire.

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Lead-free solder performance

A major concern governing the performance of Lead-free solder has been its wetting ability, or how well it solders. The “zero cross time” for Lead-free is relatively poor when compared to Sn83, but significant improvement can be made by the addition of a small amount of Lead (<4%). The UTS of Lead-free is slightly better than Sn/Pb and so is the creep resistance.

Overall, the *Almit* range of Lead-free and low-Lead alloys have superior mechanical properties than that of standard Sn/Pb. The addition of a small amount of Copper refines the effective grain size. Where accurate performance details are required, reference should be made to the suppliers’ data sheets. The addition of very small amounts of alloying metals can have significant effects, and comparison with “something very near” can be misleading.

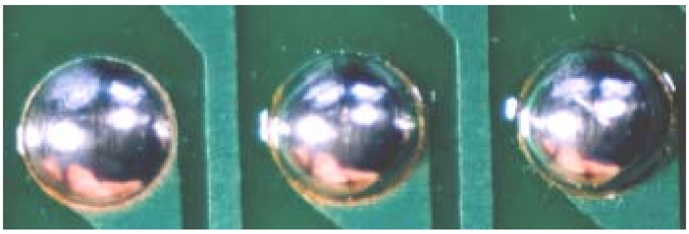
Temperature cycle testing of Lead-free alloy (-85c to 150c) over 2500 cycles showed no failure or internal cracking. The Indium and Bismuth doped Lead-free alloys exhibit a greater tensile, but lower peel strength, due to poor fatigue resistance.
The Ford Motor Company have completed a thorough thermal and fatigue test study of Sn/Ag alloy at -40c to 140c, which showed reliability equal to or better than Sn/Pb. Motorola have also published similar results.

All the research work accomplished to date indicates that the ternary Lead-free alloy of Sn/Ag/Cu is at least as good, if not better than, current Sn/Pb materials.

The differences of Solder surfaces

White-tinged phenomenon

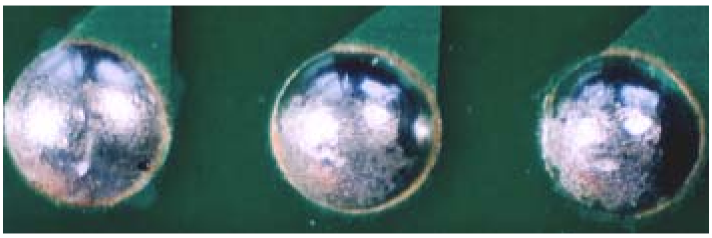
Sn60 Solder



The smooth surface with luster

Solder Quantity — Small — Middle — Big

PbFreeSolder



The rough surface with white parts

It is NOT a defect even if the white-tinged phenomenon occurred on the surface.

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Does Lead-free solder alloy have any shortcomings?

The two most serious problems facing the change to Lead-free solder are contamination of the joint by Lead and the rise in process temperature. A large proportion of PCBs use the HASL (hot air solder level) Copper land coating. It gives very good solderability, is cost-effective and is mechanically strong and abrasion resistant.
However, the main problem with HASL lies with the lack of flatness and inconsistency, usually traced to process faults. This form of soldering is slowly going out of favour.
Any move to Lead-free must be accompanied by a Lead-free land coating; OSPs, Gold over Nickel, Silver, Palladium and, of course, Lead-free HASL.
For sub-contractors who do not or cannot specify the board finish this could be a major problem.

The addition of Antimony has been shown to prevent "Tin Pest" (tin turns to powder at low temperatures i.e. -30c), and increases tensile and creep strengths, but does not extrude well. Where non-Bismuth solders are expected to have better fatigue resistance characteristics, pick-up of Lead may change the properties and remove any benefits gained.
Much more work is required to establish just how much Lead can be tolerated in a Lead-free solder alloy. Lead-free solders do however, seem more tolerant of Gold contamination, ranging from 4% up to 10%.

The production contamination of Sn60/Pb40 alloys by metals commonly found in the flow soldering process is well documented, and control of these contaminants forms an integral part of any respectable process control system. There is insufficient information currently available to predict the results of this contamination on the new alloys and at what levels they may start to become a problem. If these acceptable levels are of a very low order, then constant replacement of a contaminated solder bath could prove both time consuming and expensive. A nominally Lead-free solder bath will accumulate unwanted Lead when HASL and Leaded components are flow soldered.
Current research shows that Sn/Ag/Cu alloy picks up Copper at a lower rate than Sn60/Pb40, whilst Sn/Ag and Sn/Ag/Bi picks up Copper faster, giving rise to earlier "pot dumping".
Sub-contractors will face difficult decisions regarding alloy selection for flow soldering. It will be almost impossible to run with more than one alloy and it may come to a point of saying to customers "this is the alloy we use – take it or leave it!"

Unless the entire production process moves towards standard Lead-free alloy, control of cored wire and solder paste will, at best, be difficult and, in some, vitually impossible. Turning to reworking and field repairs, the question arises " *Will the board need to be marked as Lead-free and of which alloy?*", " *Will part or all of it be Lead-free?*", " *Can you supply all of your field maintenance staff with Lead-free wire, and what about confusion with existing product?*".

Where components are concerned, the terminations will need to be Lead-free too, but what is the timescale for this change? Will Lead-free components be identified as such? Some slow moving items may remain in stock for years and only trickle out into the supply chain. These may need to be written off to prevent confusion. It may be prudent to commence buying procedures for Lead-free now!

The option of a low-Lead solder removes most, if not all, of these problems as it is 100% compatible with HASL, PCBs and Tin/Lead coated components.
It is also as close to a "drop-in" replacement as we are likely to get at this stage of development.
We may well see a 10 year change-over period once the global decision has been made to go Lead-free.

Process equipment

As far as printing and placement are concerned, the alloy used may be regarded as transparent. It is the solder bath, soldering irons and reflow ovens that require serious scrutiny. Can your current equipment cope with the elevated temperatures required, and with the additional energy cost? These, and many other, questions will need to be addressed.
It would be prudent not to purchase any new equipment that is not Lead-free compatable.

High temperature alloys

For non-SMT applications, such as power packages, die-mounting, Lead-free attachment, solder spheres for ceramic array packages and flip chips, high temperature alloys are required.
Most, if not all, existing alloys are high in Lead content and new alloys will need to be sourced.

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Conclusion

The major problem facing industry is sourcing Lead-free components.
PCBs and solder materials are readily available and their performance is not an issue.

On the assumption that full implementation of a Lead-free programme may take up to two years, and the cut-off date is projected at December 2004, then this leaves precious little time in which to reach fullfillment stages.

Companies wishing to change to a Lead-free solder should, in the short-term, seriously consider *Almit's* proven range of low-Lead solder (3.5%Pb). This is recognised as a suitable "drop-in" replacement for traditional Leaded alloys and will give full performance with or without Lead contamination. Additionally, this will make a positive impact on environmental and process Lead levels. Those wishing to go straight into Lead-free should consider *Almit's* LFM-48 range of alloys. Alternatively, look at the addition of either Bismuth or Antimony, the choice being dependant on temperature or strength requirements.

Footnote: On February 3rd 2000, European legislation approved the requirement that motor manufacturers were to recycle all cars built since 2000. Targets of 85% by 2006 and 95% by 2015 are posted. It is safe to say that this will almost certainly be applied to electronics aswell.

ALMIT developed PbFree metal

- LFM- 8 — Sn+Ag3+Cu0.7+Bi3
- LFM-22 — Sn+Cu0.7
- LFM-23 — Sn+Cu0.7+Ni
- LFM-27 — Sn+Ag2.5+Cu0.5+Bi1
- LFM-31 — Sn+Zn8+Bi3
- LFM-37 — Sn+Ag2.8+Cu0.7
- LFM-38 — Sn+Ag2.95+Cu0.5
- LFM-39 — Sn+Ag4+Ni0.1
- LFM-41 — Sn+Ag0.3+Cu2
- LFM-48 — Sn+Ag3+Cu0.5
- LFM-50 — Sn+Ag+Cu+Ni+Ge
- LFM-51 — Sn+Bi+Ag+Cu+Ni+Ge