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Are You Ready for Lead-Free Assembly?

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Introduction

In the 1980s, the shift to unleaded fuels forced auto makers to redesign power plants and engine controls, which resulted in more efficient vehicles and a cleaner environment. The current shift to lead-free solders in the electronics industry is inevitable and will have similar results. In Japan, consumer goods manufactured with lead-free solders are already in production. In Europe, solder alloys containing lead will soon be banned. In the United States, where lead-free solder legislation originated, assemblers of electronic assemblies will be forced by the necessities of the global marketplace to adopt lead-free solders.

The third in a series of articles reviewing the topics manufacturers need to consider in order to ensure a successful transition to lead-free assembly. This article focuses on thermal process management; previous articles have covered the evaluation and selection of lead-free solder paste, as well as lead-free reflow.

The adoption of lead-free solders will require electronics assemblers to allocate greater resources to their thermal processes. Lead-free solders reach liquidus at temperatures 20-50°C higher than the lead-based solders currently in use. Because many components cannot tolerate peak temperatures above 235°C, one result of the shift to lead-free solders will be drastically reduced thermal process windows. Strategies for minimizing the pain associated with this reduced process window and the opportunities for optimizing the thermal process are the silver lining in the lead-free cloud.

Current Situation

As recently as the SMTA conference in September 1999, there had been some question whether the European and Japanese initiatives to remove lead from electronic assemblies would be followed by the United States and the rest of the world. Following IPC Works99, an International Summit on Lead-Free Electronics Assemblies, there can be little doubt that lead-free soldering is not just coming, but is here. Participants at IPC Works99, held in Minneapolis in late October 1999, included major electronics manufacturers and assemblers, most solder paste manufacturers and representatives of the automotive industry's electronics subsidiaries. Papers were presented that covered all aspects of the shift to lead-free assemblies, which was approached from three principal angles: legal, marketing and technical issues.

Legal Considerations

Europe: The final draft of the WEEE (Waste from Electrical and Electronic Equipment) Directive is expected to be completed in January 2000. The document is still changing, but it is certain that electronic assemblies containing lead will be banned from the European Union as of January 2004. The motivation behind this ban is that electronic waste is growing a rate three times greater than other solid wastes, and this huge increase in the amount of electronics waste has raised concerns about lead leaching into water supplies.

Japan: The Japanese have an even worse waste problem than the Europeans and are aggressively working towards lead-free electronics assemblies. In 1998, the Japanese Electronics Industries Association made the decision to voluntarily eliminate lead from electronic assemblies. The goal of the association is to have half of Japanese electronics production lead-free by 2002 and to be completely lead-free by 2004. Panasonic is currently producing a completely lead-free mini-disc player. Most Japanese companies will have lead-free products in production by the end of 2000, including the Hitachi Flora lead-free PC.

United States: Ironically, the initial impulse for lead-free electronics originated in the United States. Following the ban on leaded plumbing solders in the early 1980s, electronic assembly was seen as the next logical industry target for lead removal. The Reid Act of 1992, an omnibus environmental bill, would have done that, but it was defeated when control of the Congress shifted from the Democrats to the Republicans. Currently, there is no legislation proposing a ban on leaded solder, but there are some legal threats on the horizon. The EPA may drop the regulatory limit on lead as a hazardous material from 10,000 pounds per year to 10 pounds per year. This would make almost every user of leaded solders subject to EPA regulation, reporting and inspection. There is very little chance that leaded solders will be banned in the United States in the near future, but there are many compelling reasons that will cause the majority of American electronics assemblers to go lead-free.

International: One issue of concern to all electronics manufacturers is the prospect that the European ban, which is as close to a done deal as anything can be, will touch off trade disputes. To anyone who has followed the disputes over relatively insignificant products like bananas, the prospect of a major trade war involving one of the world's largest and most critical industries is something to be avoided.

Marketing Considerations

Many prognosticators on the adoption of lead-free solders feel that the legal issue is a moot point, and that marketing considerations alone will force a change to lead-free electronics assemblies in the near future. Marketing research presented at IPC Works99 by Dr. Iwona Turlik, Director of the Motorola Advanced Technology Center, indicates:

> 20% of consumers actively consider the environment when making a purchase
>
> 45% of consumers have bought a product because it is environmentally safe
>
> 50% of consumers have switched brands upon finding that a product hurts the environment
>
> 76% of consumers would switch to an environmentally safe product if price and quality were comparable

Japanese electronics manufacturers have taken the lead in "green" marketing. Panasonic's lead-free mini disc player, packaged with a green leaf environmentally safe symbol and released in October 1998, has gained significant increases in market share, moving from 4.7% to15% of the mini disc market. In the United States, Ford Motor Company has launched what is perhaps the largest "green" marketing campaign to date. Ford has gone on record that their electronic assemblies will be lead free by 2002 and vehicles, aside from batteries, will be lead-free by 2004.

Technical Considerations

Controversy over lead-free solders has shifted, from whether they are adequate replacements for traditional Lead/Tin solders, to which of the hundreds of possible replacement alloys will be selected as a new standard. This will be critical. Currently, electronic assemblies can be repaired worldwide with standard leaded solder. There are numerous solderability and wetting issues between lead solders and lead-free solders — lead-free solders wet poorly to components with leaded leads, for example. Further muddying the waters are compatibility issues between various lead-free alloys. It is imperative that the global electronics industry settle on a single standard alloy to make sure that assemblies can be repaired expeditiously and reliably. Another downstream issue is recyclability of assemblies — a single standard alloy will make it much more feasible to recover and recycle the base metals in these assemblies.

As of this writing, most paste manufacturers and many electronics manufacturers have developed proprietary alloys. Obviously, it is in the best interests of the holders of these patents to have their alloy selected as the standard, and an enormous amount of research is being done to establish a winner. Many alternatives are unpatented, but most of the promising alloys are.

The alloys that look most promising to become the industry standard are Sn/Ag/Cu (Tin/Silver/Copper) and Sn/Ag/Bi (Tin/Silver/Bismuth). In the choice between the two lies a trade off. Sn/Ag/Cu provides solder joints that are more reliable than the current Pb/Sn alloys and has liquidus temperatures around 217°C.

Bismuth alloys, which have liquidus temperatures in the 206-213°C range, provide solder joints that are inferior to those provided by current leaded solders, mainly due to a phenomenon known as "fillet lifting," although they are considered to provide adequate reliability for consumer applications. Bismuth alloys are preferred by some because they are the closest thing to a "drop-in" replacement for leaded solders, are favored by the Japanese and are currently used in the lead-free electronic assemblies that are on the market. They are more expensive than Sn/Ag/Cu alloys and there are concerns whether the world's current Bismuth resources are adequate to fulfil the entire market's needs.

Americans and Europeans favor an Sn/Ag/Cu alloy as the standard because of its greater reliability and lower cost, but acknowledge that the higher process temperatures these alloys require present a challenge for electronics assemblers. Both types of alloys have been extensively tested and will be used in volume production by 2000. An additional factor in the in the choice of a standard alloy is that the Sn/Ag/Cu alloys are favored by the automotive industry, as their higher melting points will give better reliability in under-hood applications. The more robust joints will also be favored for military and aviation applications.

The Challenge

Whichever alloy becomes the world standard, if indeed it is possible to settle on a standard, the primary challenge that lead-free solders will present to electronics assemblers is higher process temperatures. The current thermal process window is a wide one, with the lower limit set at 183°C, the liquidus temperature of leaded solders, and the upper limit at 235°C, which is the maximum temperature that some sensitive components can withstand. These process limits provide a Delta of more than 50°C — wide enough that a carefully monitored process can be expected to produce low defects and high yield with little fear of defects caused by process drift.

For lead-free assemblies, the process window will shrink dramatically (Fig. 1). With the Bismuth alloys favored by Japanese assemblers (206-213°C liquidus), the window will shrink by half, to 22-29°C. Using the more reliable Sn/Ag/Cu alloys (217°C liquidus), the window will be cut by 65%, to 18°C. Given that few assemblers want to get within 5°C of their control limits, the true process window with Sn/Ag/Cu alloys

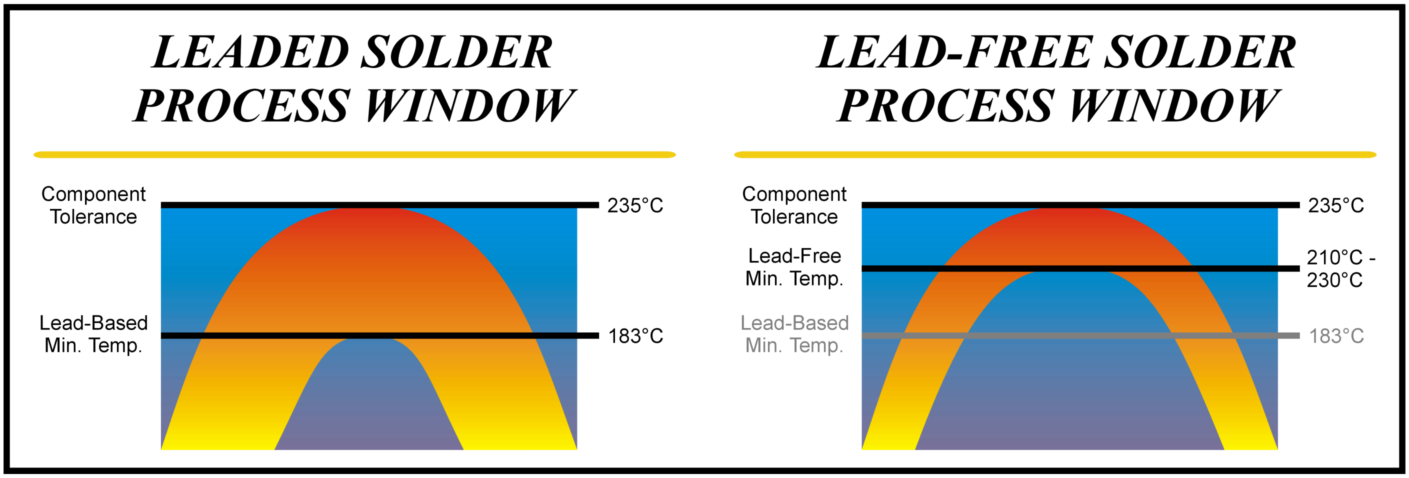


FIGURE 1: There is a dramatic shrinkage in the reflow process window when lead bearing solders are replaced by lead-free solders.

will be 8°C. This very narrow process window is the challenge that will confront electronics assemblers making the shift to lead-free production.

The window is unlikely to expand in the near future. It is widely acknowledged that the component sector is lagging behind other sectors — assemblers, soldering materials suppliers and soldering equipment manufacturers— in being prepared for the shift to lead-free assemblies. Component manufacturers are faced with a three-part challenge: they must remove lead from their products, they must develop leads that are compatible with lead-free solders and, eventually, they will need to develop components with higher temperature tolerances. The first two tasks must be completed in order to successfully assemble products that meet the European standards. This leaves the question as to whether component manufacturers will be able to raise temperature tolerances in the short term. In the longer term, the question will be whether raising the process temperature limits of components will be economically justifiable or even necessary.

The problem of narrow process windows will be further exacerbated by the trend to more complicated assemblies with increased component density. Finding a profile that will reliably reflow these assemblies, especially larger ones that can experience large peak temperature Deltas across the board, has never been easy. Real-world production issues, such as maintaining high throughput and minimizing oven changeover times between production runs, also figure into the equation. The lead-free challenge will be to find and utilize technology that allows electronics assemblers to define and maintain optimal thermal processes in the drastically reduced lead-free process window.

The Solution

For more than a decade, the key to a reliable and repeatable thermal process has been real-time continuous thermal monitoring. An automated thermal management program allows electronics assemblers to obtain and analyze real-time live data on their soldering process. Critical process temperature variations are detected and revealed as they occur, allowing deviations to be corrected immediately. Given the tight process windows required by lead-free soldering processes, real-time monitoring has become an essential process control tool.

In addition, state-of-the-art software that greatly simplifies the task of converting to lead-free electronics assembly is now available. An automated profiling program, which has the capability to communicate with the oven controller, allows manufacturers to handle the lead-free challenge and optimize

FIGURE 2: Screenshot of self-profiling oven software

their thermal processes. An even more revolutionary tool is a self-profiling software option that automates oven set-up, allowing even minimally-trained operators to perform error-free profiling using any solder paste, lead-based or lead-free (Fig 2).

When used with modern thermal processing equipment, this combination of process control tools allows manufacturers to resolve many of the technical challenges posed by the smaller process window required for lead-free soldering. The issues of meeting legislative mandates, responding to market trends and selecting appropriate lead-free solder pastes remain matters to which each manufacturer must respond individually.

The Lead-Free Future

Lead-free electronics assembly is coming, and coming faster than anyone had anticipated. The shift to lead-free solders will present electronics assemblers with significant challenges, but higher process temperatures and reduced process windows don't have to be among them. Twenty-first century thermal profiling technology is available now and, with the proper tools, most assemblers should be able to produce high-quality products with only moderate changes to their thermal processes.

The benefits of lead-free electronic assemblies include the obvious environmental ones, the marketing advantages associated with "green" products and the potential for more robust and reliable soldered connections. The benefits associated with advanced thermal management and profiling systems are also readily apparent: higher quality products, combined with greater throughput and reduced manpower requirements, equals a better bottom line.

Tools for Thermal Process Management

To optimize any thermal process, using either lead-based or lead-free solder, a number of sophisticated software tools are available. Using one or more of these programs helps to ensure highly productive assembly processes.

An automated thermal manager that continually monitors process temperatures in the reflow oven allows users to obtain and analyze real-time live data on the soldering process. Thirty thermocouples embedded in two slim stainless steel probes are permanently mounted just above or below the conveyor (Fig. 3). These thermocouples, twice the number found in a typical oven, provide process data from the belt level, rather than from the heater element.

The probe thermocouples monitor process temperatures continuously, taking readings as frequently as every five seconds. These temperatures are displayed as "Process Profiles" on the oven controller's PC screen. All data is recorded permanently to the hard drive, giving users the ability to review process data from any previous production date. The real-time thermal manager detects critical process temperature variations that oven control thermocouples cannot, and immediately reveals these temperature drifts and their location on the user's PC screen. Given the tight process windows required by lead-free soldering processes, real-time monitoring becomes essential.

The real-time thermal manager provides a product profile for every board processed by creating a mathematical correlation between product profile, as measured by a pass-through profiler, and process temperature, as measured by the real-time thermal manager thermocouple probes. This "Virtual" product profile is calculated every 30 seconds, and Virtual Profile statistics such as peak temperature are also calculated and continuously updated. The Virtual Profile gives real-time monitoring, above and beyond the simple heater core thermocouple data provided by the oven controller (Fig. 4).

In addition, new state-of-the-art software greatly simplifies the task of converting to lead-free assembly. The Navigator, an integrated software package, includes an automated profile prediction tool that is exponentially more powerful and accurate than any product currently on the market. The software incorporates a comprehensive database of specifications for solder pastes, including the new lead-free solder pastes from all major manufacturers. This powerful tool allows users to define optimal profiles in a matter of minutes. The operator selects the

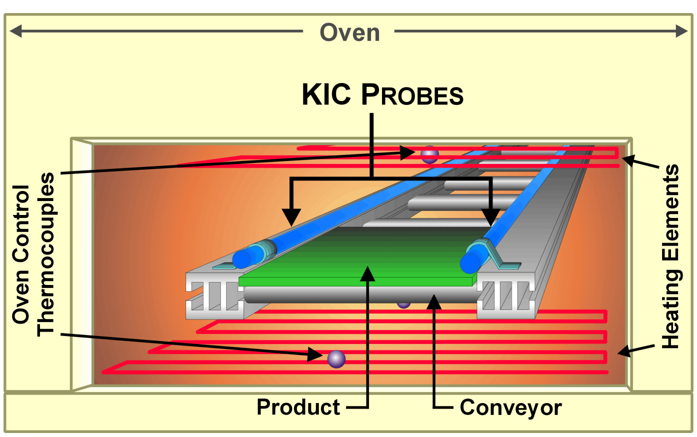
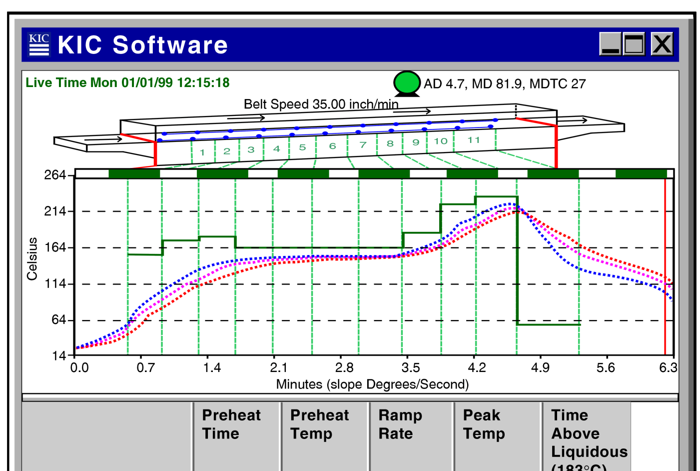


FIGURE 3: An automated thermal management program continuously monitors process temperatures at the level of the board as it travels through the reflow oven.



	Preheat Time	Preheat Temp	Ramp Rate	Peak Temp	Time Above Liquidous (183°C)
TC Board LEFT	42.68	109.6	1.94	212.9	65.79
TC Board RIGHT	42.89	114.2	2.37	217.1	66.20
TC Board CENTER	43.12	118.1	3.03	225.8	69.14

FIGURE 4: Virtual Profiling software provides real-time monitoring.

solder paste being used from a drop-down menu, starts the automated prediction tool and, in a few minutes, has an optimal profile that is custom-designed for both the oven and the product.

The automated prediction tool is designed to center the profile in a process window designated by the user, who may set limits particular to a specific process. As an example, for components that cannot withstand temperatures higher than 230°C, the automated prediction tool finds a profile that not only remains below the upper limit, but is also centered between the high and low limits. With selected ovens, the profiling software can communicate with the oven controller, automatically exchanging zone setpoints and beltspeed to eliminate any potential for data entry errors.

An even more advanced tool, the Pilot, is an automated, self-profiling software option. This program allows a minimally-trained operator to set up a profile by merely selecting a pre-profiled product from a menu. If a new product needs to be profiled, the same operator can set up the solder reflow oven without having to understand thermal profiling or terms such as "peak temperature," "time above reflow" or "max slope." Nor does the operator need to know how to input a zone setpoint temperature or beltspeed.

The only knowledge needed is how to attach thermocouples to a PCB, run the PCB through the oven and catch it at the other end. The operator also needs to be able to input the product name and PCB dimensions, then later chose this name from a list. This revolutionary product utilizes the new-generation, automated prediction software discussed above and delivers a profile centered in the process window every time.

Once the optimal profile has been found, the real-time thermal manager automatically works 24/7 to ensure that the thermal process remains centered in the process window. It has the ability to sound an alarm should the process drift and to shut down the feed conveyor should it go completely out of spec. It gives users the capability to record a permanent record of the thermal profile for every board produced, and can feed data to an external SPC package for real-time process control.

The data from the real-time thermal manager can also be distributed to remote locations via the Internet, allowing data to be viewed from an individual oven, or multiple ovens, at any given time. Distributing data from the thermal manager via an Intranet allows users to maximize the value of scarce engineering resources.

With this full range of benefits, the use of a real-time thermal manager has become an industry-wide indicator of dedication to quality. In fact, many leading contract manufacturers use it to assure customers that their production meets the highest quality standards.

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