Lead-Free Wave Soldering: A Cost-Effective Alternative

As growth of lead-free production continues, manufacturers are finding they can save money by upgrading their existing wave soldering machines for lead-free assembly allowing them to remain competitive.

By Tony Gyemant

With the move toward lead-free electronic products, an increasing number of manufacturers are preparing to implement lead-free soldering processes in compliance with pending regulations. A great deal of effort has been placed on converting the reflow soldering process to lead-free due to the dominance of SMT components. Wave soldering must also be changed to lead-free to avoid mixing of lead bearing and non-lead bearing alloys on the same assembly.

Implementing lead-free wave soldering involves more than replacing one solder alloy with another because no "drop-in" replacement strategy exists. A common notion is that one can simply switch from tin-lead (SnPb) to lead-free by dropping lead-free solder into an existing wave machine. Another general misunderstanding is that you need to buy a new wave machine for lead-free processing. Neither of these tactics is correct because there are alternative ways to minimize the cost of implementing lead-free wave soldering.

For lead-free wave soldering to be successful in a production environment, necessary changes to the entire process must be considered. The majority of lead-free solder alloys possess good solderability but exhibit decreased wetting characteristics compared to tin-lead solders. Since wetting is a critical factor affected by solder temperature, contact time, flux, use of nitrogen and wave configuration, changes are required that will affect the majority of machine parameters.

Introducing lead-free wave soldering generally involves two major process changes because lead-free alloys have a significantly higher tin content than tin-lead solder and require higher processing temperatures. Many products will be converted to lead-free over a gradual phase-in, however numerous manufacturers are forging ahead by making their wave soldering machines lead-free compatible now.

Process Parameters

Because the wetting characteristics of lead-free alloys tend to be less than tin-lead solder, using good flux chemistry is critical. Additionally, the higher temperatures needed for lead-free soldering require a flux chemistry that can withstand preheat temperatures up to 130°C and liquidous solder temperatures as high as 280°C for up to 3 seconds. A VOC-free, water-based flux is generally recommended since they meet these higher temperature requirements.

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 PCB. 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 of the PCB when entering the chip wave. Achieving proper preheat temperatures on the top 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.

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. 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 may be required due to the lower wetting properties of lead-free alloys. Often the distance between the chip wave and laminar wave may 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 with lead-free alloys.

Compared to tin-lead solder, most lead-free alloys oxidize more rapidly when the solder is liquidous due to their increased tin content. Tin oxide, consisting of tin-oxygen (SnO) and (SnO^2), forms at a higher rate because of the higher processing temperature and results in more oxidation and dross. Nitrogen inerting of the solder pot is recommended and minimizes exposure of the liquidous solder to oxygen and decreases the amount of dross. Needless to say, reducing the rate of oxidation and the resulting dross build-up significantly improves the performance of the wave soldering process.

Solder Pot Maintenance

With the introduction of lead-free assemblies, many sources of lead bearing material have to be eliminated from the wave soldering process. OSP coating over bare copper are quickly becoming a replacement for traditional hot air solder leveled (HASL) board finishes resulting in a trade off between a potential source of lead contamination and a potential source of copper contamination. As lead-free wave soldering becomes more widespread, questions have been raised over increased solder pot maintenance brought about by the high copper dissolution rates of lead-free alloys.

During long periods of operation, some lead-free alloys begin to show sluggish behavior in the solder pot. This is caused by a buildup of a copper-tin intermetallic (CuSn) that forms at the bottom of the solder pot. The problem didn't exist with standard tin-lead wave soldering because the copper-tin intermetallic floats and can be easily removed.

In a standard tin-lead wave pot, as impurities such as copper build up they form intermetallics with the tin. Reducing the temperature of the solder pot, allowing the pot to sit idle for a few hours, and skimming the top surface can easily remove the intermetallics. The method works quite well since the density of the copper-tin intermetallic (CuSn) is 8.28, and tin-lead (SnPb) is 8.80, allowing the copper-tin intermetallic to float. Periodic maintenance of a tin-lead solder pot can easily maintain copper levels between an acceptable range of 0.15-3.0%. With the increased use of tin-copper or tin-silver-copper lead-free solder alloys, the situation changes since the density of both alloys is less than that of tin-lead (Table).

Table: Characteristics of lead-free alloys

Alloy Composition	Melting Point (°C)	Solder Pot Temperature (°C)	Density
SnCu	227	270-280	7.29
SnAg	221	265-275	7.44
SnAgCu	217	260-270	7.38
SnAgCuSb	217	260	7.24
SnPb	183	250	8.80

As a result, instead of floating on the surface where it can be easily removed, the copper-tin intermetallics sink in lead-free alloys and are dispersed throughout the solder pot. In addition, some lead-free alloys dissolve copper at a faster rate than tin-lead. The effect can be a higher rate of copper build-up and contamination of the solder pot.

The result can be the need to dump the solder pot more often, or a complete changeover of the pot. Studies suggest that solder pots containing lead-free alloys may have to be dumped when the copper contamination levels reach 1.55%. Above this point most lead-free alloys become sluggish and above 1.9 to 2.0% damage can result to the impeller, baffles and solder pot.

Practice has shown many lead-free alloys cause corrosion to the base metals used for solder pots, impellers and baffles because of aggressive nature of tin at high temperatures. The surface of many base metals such as stainless steel or cast iron generally show signs of pitting and start to dissolve after prolonged contact with lead-free alloys. This leaching process releases iron (Fe) particles resulting in increased iron content and contamination of the solder alloy.

Experience so far indicates that solder pot materials such as stainless steel can become damaged after only a few months of operation when using lead-free alloys. The use of high-grade stainless steel can reduce this effect somewhat as does applying a proprietary corrosive resistant surface coating. However, surface coatings are very susceptible to scratching because of the higher maintenance levels needed to remove the copper intermetallics that sink to the bottom of the solder pot. Over time repeated scratching breaks down the surface coating and results in corrosion of the base metal and contamination of the solder pot. Without protection, parts made from these base metals degrade to the point where they may require replacement after only one to two years of operation. In one long-term production application using a tin-silver alloy, it has been reported that the solder became contaminated and was changed once a month, the impeller needed replacing once every six months, and the solder pot required replacement once a year.

Base metals do exist that are resistant to the aggressive nature of tin scavenging but until now the cost of these materials was considered excessive. So what is the solution? Titanium is one material that is ideally suited for lead-free solder pots, impellers and baffles since it is impervious to the effects of tin scavenging.

The frequency with which solder pumps and baffles made of traditional base metals wear out and have to be replaced in lead-free wave soldering applications has caused a rethinking of the use of titanium. Retrofit kits are now available that replace the impeller, baffles and solder nozzles with parts made of titanium that withstand prolonged service in lead-free applications eliminating periodic replacement of surface coated parts and prevent contamination of the solder alloy (Figure 1).

Figure 1. A lead-free retrofit kit with titanium impellers, baffles and solder nozzles.

A titanium solder pot liner is available that can be placed inside of an existing cast iron solder pot to convert an existing wave soldering machine for lead-free use (Figure 2). This titanium liner can be universally retrofitted to most models of wave soldering machines. It is a cost effective solution that eliminates iron dissolution, minimizes solder contamination and avoids periodic dumping of the solder pot.

Figure 2. Titanium solder pot liner prevents iron dissolution and increases life of solder pot.

Conclusion

Upgrading your existing wave soldering machine with an external spray fluxer, new preheat modules, solder pot retrofit kit and titanium 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 used wave machine. It provides effective lead-free performance at a fraction of the cost of a new piece of equipment. Upgrading not only reduces capital outlay, but reduces your lead-time since upgrades can be added in less time then the delivery and installation of a new machine. An additional benefit is that operators will have a shorter learning curve resulting in a smoother transition to implementing lead-free wave soldering.

Tony Gyemant, technical director, may be contacted at Specnor Tecnic, 5350 J. Armand Bombardier Street, St-Hubert, Quebec, Canada J3Z 1J1; (450) 462-8651; Fax (450) 462-8654; E-mail: specnor@microtec.net; Web site: www.specnor.com