Protecting wave solder machines from the corrosive effects of Pb-free solders

Lost in the conversion to lead (Pb)-free wave soldering is the actual process of assuring that a wave solder machine is compatible with lead-free solder alloys. Determining compatibility can be a time consuming and expensive process. Several methods have evolved for protecting wave solder machines from the corrosive effects of high tin content lead-free solder alloys. While some of these methods address certain unique requirements of lead-free wave soldering, this has created the need for an alternative solution that is total compatible with prolonged use of highly corrosive lead-free solder alloys.

One recurring discussion with lead-free wave soldering is the use of surface coatings versus alternative base metals for machine elements in contact with molten lead-free solder. This article analyzes the difference between these two material alternatives and compares they're performance, longevity and cost. The cost and performance benefits are explored and methods of determining which material alternative offers greater service life, requires less recurring maintenance, and is therefore less expensive to operate. It also addresses the benefits of field retrofitting this alternative base metal solution within existing wave solder machines, eliminating the replacement of wear parts and minimizing equipment downtime for lead-free wave soldering.

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Table 1. Characteristics of lead-free solder alloys.

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

Introduction

An increasing number of manufacturers are implementing lead-free wave soldering processes in compliance with pending regulations. As has been discovered, lead-free wave soldering involves more than the simple replacement of one solder alloy with another and requires a complete examination of the process capabilities of the entire wave solder process. For lead-free wave soldering to be successful in a production environment, necessary changes to the entire process must be considered.

Lead-free processing requires a somewhat tighter process window than lead-bearing processing, making robust process control more critical when working with lead-free. Yet the basic elements of forming good quality solder joints remain the same: flux, heat and solder. Therefore, critical variables in the wave soldering process such as flux deposition, preheat and solder temperature, and solder dwell time must be precisely controlled.

The majority of lead-free solder alloys exhibit decreased wetting characteristics and slower wetting times in comparison to tin-lead (SnPb) solders and 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, putting increased demand on flux performance. The use of a higher activity flux may be considered, however, the volume of flux applied to a circuit 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.

Compared to SnPb solder, lead-free alloys oxidize at a more rapid rate when the solder is in liquidous state due to their increased tin content. Tin oxide, consisting of tin-oxygen (SnO) and (SnO2), forms at a high rate due to higher tin content and higher processing temperatures and results in more oxidation and dross. In a standard SnPb wave pot, when 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 these impurities. 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 top surface.With the use of lead-free solder alloys, the situation changes since the density of lead-free alloys is less than that of the CuSn intermetallic *(Table 1)*. As a result, instead of floating on the surface where they can be easily removed, the CuSn 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 SnPb solder. This effect can result in a higher rate of copper build-up and

contamination of the solder pot. During long periods of operation, lead-free alloys can begin to exhibit sluggish behavior caused by the buildup of CuSn intermetallic that forms at the bottom of the solder pot. This problem generally doesn't exist with standard SnPb solders because the CuSn intermetallic floats and is easily removed.

Table 2. Summary of base metals. *Longevity under sustained production conditions in direct contact with molten lead-free solder.

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

Optimized solder flow

The wetting of solderable surfaces does not occur as readily with lead-free alloys as with eutectic solder. Longer dwell times and higher solder pot temperatures are required, and the use of a nitrogen environment is recommended to assist the wetting process. It has become accepted practice to change the characteristics of the laminar solder nozzle since longer contact time is required due to the lower wetting properties of lead-free alloys. The distance between the chip wave and laminar wave is also reduced to increase the time above liquidous, as well as to minimize the temperature drop between contact points, and to allow the solder joint to recover more quickly. Increasing the length of the chip wave also improves wetting, while increasing the preheat output produces a similar effect. Reducing the fall height of the wave decreases the distance of overflowing and reduces the amount of dross generation with lead-free alloys.

Nitrogen inerting of the solder pot is recommended since it minimizes exposure of the liquidous solder to oxygen resulting in decreased dross. Reducing the rate of oxidation and the resulting dross build-up significantly improves the performance of the wave soldering process.

Corrosive effects of lead-free solders

Most lead-free alloys have significantly higher tin contents than their lead-bearing counterparts. Practice has shown many lead-free alloys cause corrosion of the base metals used for solder pot components due to the 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 during prolonged contact with molten lead-free alloys. This leaching process releases iron (Fe) particles into the molten solder and can result in contamination of the solder alloy.

Unprotected solder pump impellers, flow ducts and solder nozzles are subjected to erosion caused by the corrosive effects of high tin content lead-free alloys. Over time, this erosion can degrade the performance of the wave solder machine that will result in an adverse effect upon the stability of the wave solder process. Wave solder pot components such as flow ducts, solder nozzles and solder pump impellers should be replaced with a material that prevents corrosion and ultimate failure.

An approach to alleviate this problem has been the application of a surface coating on solder pot components. However, surface coatings provide minimal corrosion protection and are susceptible to scratching because of the higher maintenance levels needed to remove the CuSn intermetallics that sink to the bottom of the solder pot.

Surface coated versus base metals

Experience has indicated that critical solder pot components such as pump impellers fabricated of unprotected 304 stainless steel can become damaged after only a few months of operation with lead-free alloys *(Table 2)*. The use of high-grade 316 stainless steel does retard this effect somewhat since 316 stainless steel exhibits a reduced rate of iron dissolution since it contains less Fe due to its higher 10-14% nickel (Ni), 10-18% chromium (Cr), and 2-3% molybdenum (Mo) content. Unprotected cast iron solder pots are also prone to high rates of iron dissolution due to the inherent high Fe content of cast iron.

The application of a surface coating on stainless steel or cast iron solder pot components does provide some degree of corrosion resistance, however complications arise from their use. Prior to application of the coating, all base metal components must be subjected to a passivation process that consists of dipping into a

Figure 1. Lead-free retrofit kit with titanium solder pump impellers, flow ducts, solder nozzles and solder pot liner.

nitric acid, phosphoric acid or other similar acid solution to clean the metal surface and rapidly form a chromium oxide on the surface. This necessity complicates the ability to field retrofit components of an existing wave solder machine. A variety of surface coatings can be applied including Melonite, Teflon or other proprietary coatings. Regardless of the type of surface coating, their application thickness is limited and they are particularly susceptible to scratching because of the necessity to remove CuSn intermetallics that sink to the bottom of the solder pot. Over time repeated scratching breaks down the surface coating, and the resulting erosion damages the solder pot components and contaminates the solder alloy.

An alternative base metal that is highly resistant to the aggressive nature of continuous tin scavenging is titanium. Titanium is one material that is 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. Traditionally titanium has been considered expensive to fabricate, but new developments in titanium fabrication techniques have made its use cost competitive with other base metals, and have improved integrity, and quality when forming and welding complex shapes.

The frequency with which solder pump impellers, flow ducts and solder nozzles 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 solder pump impeller, flow ducts and solder nozzles with parts made of titanium that can easily withstand prolonged service in lead-free applications eliminating the periodic replacement of surface coated parts *(Figure 1)*.

End user benefits

With a wide variety of wave solder systems in use throughout the global electronic assembly industry, upgrading existing and new wave soldering machines for lead-free operation has become a complex task.
A titanium solder pot liner is available that can be placed inside of an existing cast iron or stainless steel solder pot to convert an existing wave soldering machine for lead-free use without having to remove the existing solder pot from the machine *(Figure 2)*.
A significant advantage is that the titanium solder pot liner, together with the replacement titanium solder pump impellers, flow ducts and solder nozzles, can be field retrofitted to most major brands of wave soldering machines with minimal downtime. They are equally effective for upgrading existing wave solder machines or equipping newly acquired machines for lead-free operation.
Currently in use, titanium solder pot liners and retrofit kits have successfully met the lead-free requirements of major contract manufacturers and original equipment manufacturers throughout Europe, Asia and North America. Their use represents a cost effective solution to prevent erosion of critical machine components and assure consistent performance when using lead-free solder alloys.

When analyzing the cost considerations of surface coated and alternative titanium solder pot components, cost elements encompassing procurement, installation, operation and sustaining engineering must be taken into consideration. In general, surface coated components may have a slightly lower purchase cost, but installation and shipping of a heavier, surface coated cast iron solder pot is significantly more than titanium. The additional production downtime to physically exchange the surface coated cast iron solder pot is another disadvantage.
When considering the lightweight of titanium, installation costs are substantially less than surface coated cast iron components.

The greater service life of titanium means that recurring maintenance for periodic replacement of wear parts such as solder pump impellers is virtually eliminated. Therefore titanium solder pot components are less expensive than surface coated components when all operational factors are taken into consideration.

Conclusions

The use of titanium as an alternative base metal for solder pot components has demonstrated high resistance to the corrosive effects of lead-free solder alloys. It is capable of consistent performance while eliminating the periodic replacement of solder pot components traditionally prone to wear, such as solder pump impellers, flow ducts or solder nozzles. This movement to titanium solder pot components has brought about manufacturing productivity gains, increased machine performance, and most importantly, lower operational costs critical in today's competitive environment.

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