THE Ames Laboratory

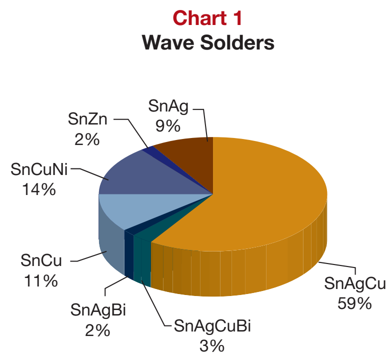
Creating Materials & Energy Solutions

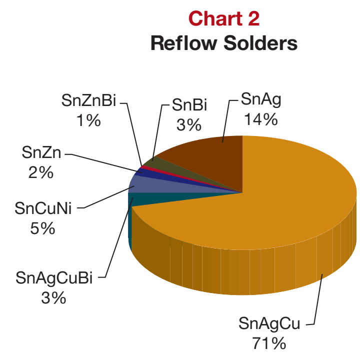
Alternatives to Lead-Based Solders

Composed of lead and tin, traditional solder is widely used in the electronics industry because as it heats up, it will suddenly melt. This is in sharp contrast to many metals that undergo a slow transition from solid to liquid. A solder blend of 63 percent tin and 37 percent lead acts like a pure metal with a single melting and solidification point. In addition, tin-lead solder is able to wet and adhere to both surfaces it is attaching, and once hardened, it conducts electricity efficiently and stands up to long-term use.

Despite these abilities, lead has long been recognized as a highly toxic material that can cause brain damage. Its use in paint was banned in 1978, and it was later removed from gasoline. Most recently, concerns have been raised over lead contained in toys and other children's products.

Meanwhile, the increasing amount of lead from electronic waste has come to pose a threat to the environment and public health. Our cell phones, computers and appliances all contain small amounts of lead. But because of their widespread use, roughly 3,000 tons of electronics are discarded in the United States alone, each day. Some 176 million pounds of tin-lead solder was used throughout the world in 2002, according to the U.S. Environmental Protection Agency.





The Ames Laboratory's lead free solder alloy, composed of tin-silver and copper, holds a commanding lead over all the lead free solder alloys used today in the U.S. Asia and Europe, as the two charts above show. Chart 1 highlights the market share for wave soldering. Wave soldering is a process by which electronic circuit boards are slid over a pool of liquefied solder so that chips may then be attached. Chart 2 reveals the market share for reflow soldering. In the case of reflow soldering, electronic circuit boards are screen printed with solder. The solder is then heated in order that chips can be adhered to the boards. Source for all charts: Lead-free Soldering status Survey 2006, *European Lead-Free Soldering Network, released March 2007.*

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With these concerns in mind, in 2006, the European Union put strict limits on the amount of lead permitted in electronic devices sold there. Given the global nature of the electronics industry, the EU ban is in essence international in scope. Estimates cited by the EPA show that American companies could forfeit $240 billion in sales of electronic components over a three-year period if the nation does not continue its development of lead-free solder alternatives that meet environmental regulations imposed by the EU and other governing bodies. Public pressures for greener, safer products could boost that figure even higher.

The search for a safer solder

Of the lead-free alternatives tested, a family of solder alloys developed by researcher Iver Anderson and his team at the U.S. Department of Energy's Ames Laboratory has shown great potential for broad use in industry. The Ames Lab alloy has a melting point of 217 °C. At this temperature, it melts about 34 °C higher

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than the tin-lead alloy which has a 183 °C melting point.

In their search for a safer alternative, Anderson and his colleagues continued to use tin as the base for their solder. But in place of lead, they added silver and copper. The latter two elements were chosen because neither is oxidation or corrosion sensitive. Silver and copper also produce very hard intermetallic phases that act to reinforce tin, allowing it to become a much stronger solder than typical tin-lead combinations.

Patented in 1996, today more than 60 companies have licensed the Ames Lab alloy for production and distribution worldwide. Non-exclusive licensing rights remain available.

Ongoing research

The Ames Lab solder is just one of several lead-free alternatives on the market. The type and specific composition of lead-free solder a user opts for also depends on the soldering technique employed and the end application. In addition to the tin-silver-copper alloy, Ames Lab researchers have patented alloys that add iron, cobalt and other similar elements to the mix in order to create a solder that is suitable for higher temperature applications.

One problem with lead-free alternatives is a tendency to get brittle over time after repeated or prolonged heating cycles. This potential drawback has become an increasingly important factor as technological advances have boosted the operating temperatures of common electronics devices. For example, the steady climb in computer-processor speeds has meant a corresponding increase in the amount of heat that computers generate.

To combat this solder "aging" problem, Ames Lab researchers are studying additional additives to the tin-silver-copper formula, including silicon, titanium, chromium, manganese, nickel, zinc and germanium. Joints soldered with the different alloys were subjected to 150 °C for 1,000 hours, then tested for both shear strength and impact strength.

For long-term joint reliability, modifying a strong (high copper content) tin-silver-copper solder alloy with a substitutional alloy addition for copper seems effective for producing a solder joint that retains both strength and ductility after at least 1,000 hours of aging at temperatures up to 150 °C. Of the choices tested, cobalt, iron, and zinc substitutions for copper seem most attractive from the standpoint of the microstructure. Although nickel has the same strong interfacial segregation behavior as the others, the discovery of a brittle failure case and the reduced impact strength on thermal aging seem to take it out of prime consideration.

Both iron and zinc have minimal cost. But if reduced amounts of cobalt prove effective, it may also have an acceptable cost. At this point, only anecdotal evidence can be reported regarding the effective solderability (wetting, oxidation, and melting range) of cobalt, iron and zinc. Quantitative studies are needed to facilitate extensive application testing.

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