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Recommendation on the non-use of bismuth for lead substitution

Paper on behalf of European Copper Institute

1 Applications of lead in the automotive and electrical industry

A multitude of small parts used in the automotive and electrical industry are made of low leaded brass. As examples, valve guides, fuel injectors, windscreen washer nozzles, battery terminals, temperature sensor housings, spray nozzles, various mountings, door locks, fittings and connectors. Lead is also used as solder in tin-lead soldering alloys, for example as solder in printed circuit boards and for metallic SnPb coatings.

In all of these applications, the limits of use, as defined in the Directives 2000/53/EC on End-of Life Vehicles (ELV) and 2002/95/EC on the Restriction of use of certain Hazardous Substances in electrical and electronic equipment (RoHS), are not exceeded.

2 Comparison of the technical properties of lead and bismuth

Lead, embedded as tiny nodules in the brass matrix, acts as a chip breaker, a lubricant and a corrosion inhibitor. Thus it favours the formation of short chips which can be easily handled. This is the prerequisite for continuous processing on high-speed automatic lathes. Due to its good mechanical parameters and corrosion resistance leaded brass also has excellent technical properties.

Lead in coatings and solders lowers the melting point of pure tin, reduces susceptibility to whisker formation and acts as a crack stopper. Thus it improves the reliability of the device.

Bismuth has been considered for some twenty years as a possible substitute for lead in two-phase brass without success. One reason is that it substantially complicates production of wrought alloys, i.e. the manufacture of rods, wires and sections. This is due to high residual stress in the alloys caused by the bismuth nodules expanding during solidification. This also explains the much higher susceptibility of such materials to stress corrosion cracking.

Bismuth also adversely affects production of so-called single-phase wrought copper alloys. These are brasses with a copper content of more than 61 % by weight, bronzes, CuNi alloys, etc. A bismuth content of <20 ppm already results in premature material failure during the manufacture of the semi-finished product, in particular during hot forming. In pure copper used for wires and cables the acceptable limit is 5 ppm. The reason is that bismuth promotes grain boundary embrittlement. During solidification, in single phased material, it promotes predominately large grains. This is in comparison to the eutectic, heterogeneous structure of SnPb. Once initiated, fatigue cracks in Bismuth alloys are difficult to stop.

Whether bismuth in coatings and solders permanently prevents reduction of whisker formation is not sufficiently proved. The melting point of bismuth-containing solders and coatings is partly substantially below the melting point of SnPb solders and close to the range of operating application temperatures of electronic components, so that the reliability of solder joints has to be questioned.

The introduction of bismuth would need extensive testing and assessment in order to make sure that it results in the same application reliability as lead containing parts. Furthermore, little is known about the compatibility of bismuth in the environment.

3 Recycling

Lead containing copper alloys are 100% recyclable and are indeed highly recycled because of their intrinsic value. Very little, if any, of these alloys end up in land fills, so additional regulations for leaded brass alloys would provide a negligible benefit while imposing a heavy toll on manufacturers and consumers.

Bismuth does not form solid solutions with most technical metals (Al, Cu, Fe, Mg), it is (nearly) insoluble in these metals in the solid state. In Titanium, there is a limited solid solubility. With Sn, it forms a eutectic at 43 at-% Bi with a melting point of 139°C. With Pb, it forms a eutectic at 55 at-% Bi with a melting point of 125°C. It is more deleterious than Pb or bismuth alone for the hot rolling of Cu, because these eutectics will form at the grain boundaries. High alloyed Brass is reported to be not so sensitive, because in brass PbBi forms droplets.

Due to this specific material behaviour of bismuth, it is absolutely necessary to establish a separate recycling circuit (including casting) for bismuth-containing scrap and swarf. This must be strictly separated from leaded brass and other metals. The use of bismuth in the scrap chain could have a detrimental effect on the Copper Industry. Recycling of bismuth is not considered technically and organisationally feasible and would result in additional handling and significant extra costs and potential loss of workforce.

4 Availability of lead and bismuth

Bismuth is usually a by-product of processing lead ores. In China, it is a by-product of tungsten ore processing [USGS, internet]. It has a metallic lustre and is silver-white with an iridescent tarnish. Bismuth, at an estimated 8 parts per billion by weight, is the 69th element in order of abundance in the Earth's crust and is about twice as abundant as gold. A smaller portion of the production is related to the production of copper or gold or gold with cobalt. Typically, 30 to 200 T of lead are produced to obtain 1 T of bismuth.

Considering this link in production, it is difficult to envisage that a large number of lead containing applications can be covered by the amount of bismuth available. As a by-product of lead, the dominant material (lead) would need to be disposed of as, at that stage, it would have limited commercial value. This would place higher environmental and economic burdens on bismuth. Moreover, the increasing demand for bismuth might result in a strong rise in the bismuth price and consequently in an increase of product costs.

5 Summary

The use of bismuth, as a major alloying element for brass and a substitute for lead in solders and coatings, will have detrimental effects on the life cycles of other metals, mainly cast iron and cast aluminium. Bismuth adversely affects production of so-called single-phase wrought copper alloys.

The effects of bismuth on the environment and human health are not well understood, as little use of bismuth exists. There is not enough bismuth in the world to substitute all lead in brass and coatings/solders. Partial substitution of the lead by bismuth is more dangerous than total substitution as it relates to recycling systems.

A substantial increase in the demand for bismuth could only be met by a substantial increase in lead production (which would have limited commercial use).

For the above mentioned reasons, the European Copper Institute does not consider that bismuth offers the same technical advantages as lead and therefore recommends that its individual members do not use bismuth for lead substitution in their technical applications.

Note: this recommendation does not affect the rights of the individual members in their individual dealings with their respective suppliers and customers.