Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Fraunhofer Institut
Zuverlässigkeit und
Mikrointegration

Adaptation to scientific and technical progress under Directive 2002/95/EC

Final report

Freiburg, 20 February 2009

Öko-Institut e.V.

Dipl.-Ing. Carl-Otto Gensch
Dipl.-Ing. Stéphanie Zangl
Dipl.-Geoök. Rita Groß
Dipl.-Biol. Anna K. Weber

Fraunhofer IZM

Dr.-Ing. Otmar Deubzer

Öko-Institut e.V.
Freiburg Head Office
P.O. Box 50 02 40
79028 Freiburg, Germany
Street Address
Merzhauser Str. 173
79100 Freiburg, Germany
Tel. +49 (0) 761 – 4 52 95-0
Fax +49 (0) 761 – 4 52 95-88

Darmstadt Office
Rheinstr. 95
64295 Darmstadt, Deutschland
Tel. +49 (0) 6151 – 81 91-0
Fax +49 (0) 6151 – 81 91-33

Berlin Office
Novalisstr. 10
10115 Berlin, Deutschland
Tel. +49 (0) 30 – 28 04 86-80
Fax +49 (0) 30 – 28 04 86-88

The views expressed in this final report are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

The recommendations given by the authors should not be interpreted as a political or legal signal that the Commission intends to take a given action.

[9] JBCE partially confidential submission to exe. 5 "Exemption-5_JBCE_1_April_2008.pdf"

[10] PerkinElmer submission to exe. 5 " Exemption_5_PerkinElmer_1_April_2008.pdf"

[11] Schott submission to exe. 5 "Comparison of different solder glasses_22.08.2008.pdf"

[12] Sensata submission to exe. 5 "Sensata presentation for Stakeholder Meeting (2).ppt"

[13] JBCE submission to exe. 5 "JBCE_(File No,2)Summary of data Lead glass .pdf"

[14] T&M Coalition email to exe. 5 "TM coalition response to RoHS exe. 5 follow-up_7.08.08.msg"

[15] Pecht, Michael; Review of High-Lead Solder and Lead-Glass RoHS Exemptions. CALCE Electronic Products and Systems Center. University of Maryland. 25/03/2008

[16] HP Letter to the Öko-Institut. June 30, 2008

[17] Jäger, Ralph; Technical information on (1) Black and white CRT for viewfinder of professional-use camera, (2) Color CRT Monitor for professional-use

4.9 Exemption No. 6

"Lead as an alloying element in steel containing up to 0,35% lead by weight, aluminium containing up to 0,4% lead by weight and as a copper alloy containing up to 4% lead by weight"

4.9.1 Description of exemption

Lead is used as an alloying element in steels, aluminium and copper. The main effect of lead in these metals is an improved machinability. Lead acts as a lubricant and the addition of lead results in better chip fracturing and surface finish as well as in higher cutting speeds and a longer tool life.

In view of consistency in environmental legislation it should be noted that Annex II to the ELV Directive[27] also includes exemptions for the use of lead up to 0,35% in steel, (entry no. 1), up to 0,4% in aluminium, (entry no. 2) and up to 4% in copper (entry no. 3). Information and data provided in the context of the recent adaptation to scientific and technical progress of ELV Annex II [1] have been taken into account in the present adaptation of the RoHS Directive.

In the following sections the use of lead as an alloying element is discussed separately for each of the three metals steel, aluminium and copper.

---

[27] Directive 2000/53/EC on end-of-life vehicles (ELV Directive)

4.9.1.1 Lead as an alloying element in steel containing up to 0,35% lead by weight

In steel, lead is both used as an alloying element for machining purposes and for the production of galvanised steel.

Steel for machining purposes:

Lead is added to steel for an improved machinability: Through the lubrication effect of lead better chip fracturing, automation of the production process, high cutting speed and federates (low cycle times), longer tool life, better surface finish and more accurate dimension control can be achieved.

The main production countries of leaded steels are UK, Germany, France and Spain. The total production volume of leaded steel in the EU is estimated to be 1,3 Mt per year [2]. It is, however, not possible to accurately say how much of this material is used for applications covered by RoHS due to the length of supply chains and sales to stock-holders and intermediate processors selling steels to different applications. Within EEE, leaded steels are mainly used in larger equipment with smaller volumes. Therefore, yearly quantities are expected to be some tons at maximum [2].

Machining steels are used in a diverse range of final applications within electrical and electronic equipment. For example, leaded steels are used in bolts, screws, nuts, valve pins, bushings, housing, axles, shafts of electric motors, rotors etc.

Galvanised steel

Galvanisation is a metallurgical process that is used to coat steel with zinc. This is done to prevent corrosion (rusting) of steel.

The most common form of galvanisation is “hot dip galvanisation” where iron or steel articles are galvanised by dipping in a molten bath of zinc or zinc-alloy at a temperature of around 450°C. Hot dip galvanisation can be done in continuous or batch operation: Steel strip are usually hot dip galvanized in a continuous line by drawing the steel continuously through a bath with a liquid zinc alloy. Individual metal articles are hot dip galvanized by a process called batch galvanizing. The coatings of steel sheet/strip in continuous coating lines are typically thinner than the coatings obtained by general (batch) galvanizing.

Both the continuous and batch processes of hot-dip galvanizing result in a metallurgical bond between zinc and steel. The bonding region is an intermetallic compound, termed the “alloy layer”. However, continuously galvanized steel has a thinner alloy bonding zone which is usually only 1 to 2 µm thick with the total zinc coating being approximately 10–30 µm thick.

The batch galvanized steel has a thicker coating and the alloy layer comprises a higher proportion of the coating (approx. 40-60%). In some cases, the alloy layers comprise 100% of the coating. The zinc bath used in general (batch) galvanising can contain lead at levels up to 1,1%, dependent on the specific process type . The concentration of lead in the zinc bath used in continuous galvanizing is typically between 0,05 and 0,10% [3], [4]. The main function of lead in the zinc bath for general galvanizing is its influence on the viscosity of the molten zinc. Lead is beneficial to accommodate "free drainage" of excess zinc when the parts are removed from the zinc bath. Due to the lower viscosity of molten zinc, it is difficult to avoid small sags and ripples in the zinc coating in the absence of lead. The thicker the coating, the greater the tendency to form sags and ripples. The result is that the surface is not smooth and the coating is composed of locally thick and thin regions. Further beneficial effects of lead in the zinc bath can be summarised as:

- Ease of drossing – to aid recycling of the zinc bath;
- Avoidance of "floating dross" during galvanizing of complex geometries which may lead to adverse surface finish;
- Protect kettle from uneven heat distribution from burners – preventing dangerous "run-outs" of molten zinc.

Applications of galvanized steel in EEE include bolts, nuts, brackets and other small parts use in electrical assemblies that need to be prevented from corrosion.

EGGA (European General Galvanizers Association) has proposed to re-word exemption no. 6 in order to be consistent with the wording in the ELV Directive [17]:

"Lead as an alloying element in steel *for machining purposes and galvanized steel* containing up to 0,35% lead by weight, aluminium containing up to 0,4% lead by weight and as a copper alloy containing up to 4% lead by weight".

EGGA further argues that the current wording is vague compared to the ELV entry and it is unclear that it includes the presence of lead in galvanised steel.

4.9.1.2 Lead as an alloying element in aluminium containing up to 0,4% lead by weight

With regard to the presence of lead in aluminium three different cases need to be distinguished:

- Aluminium alloys where lead is intentionally added for improved machinability.
- Aluminium alloys where lead is intentionally added for corrosion prevention.
- Aluminium alloys that contain lead unintentionally due to their production from scrap metal.

Aluminium alloys are typically far easier to machine than steel alloys and as a result additions to enhance machinability are not as widely used as for steel. Thus, the biggest share of aluminium alloys contains lead unintentionally due to the production from scrap metal.

Leaded aluminium is used in bushing gears for motors, die-cast aluminium parts (e.g. RF filters, chassis) and in heat sinks.

In the EU currently ca. 2,7 million tons of aluminium casting alloys are annually produced from scrap. Majority of these is used in applications other than ICT[28] equipment. Within EEE, these are mainly used in larger equipment with smaller volumes. Yearly quantities are expected to be some tens of tons at maximum. In general, aluminium consumption of EEE industry is only 9% of the worldwide consumption.

4.9.1.3 Lead as a copper alloy containing up to 4% lead by weight

Lead is embedded as tiny nodules in the matrix of copper alloys and has the function of a chip breaker. The formation of short chips, which can be removed automatically, is facilitated by the lead nodules. Thus, lead acts mainly as a machinability enhancer.

Another characteristic of the lead is its function as a lubricant reducing the tool wear and the power consumption of machining processes. Furthermore, by reducing the friction between sliding surfaces, lead provides a better slide functionality for parts with closely fit sliding surfaces.

The typical lead content in copper alloys (brass) is 0,2 to 4,2% in accordance with CEN EN 12164 and 12165.

The average annual consumption of leaded brass in the EU is approximately 1 500 000 t. Figures on the share in the electronic sector have not been provided by the copper industry. However, it is estimated that yearly quantities in ICT[29] equipment are ten tonnes at maximum.

Typical applications of leaded copper in the electronic sector are antennas, connector contacts that are screw machined (e.g. most commercial RF[30] co-axial connectors), connector shells or other hardware that needs milling, valves, valve guides, battery terminals, temperature sensor housing, shafts actuators, pins and fittings.

4.9.2 Justification by stakeholders

4.9.2.1 Lead as an alloying element in steel containing up to 0,35% lead by weight

EICTA et al. [2], Eurofer [5] and ERA [6], [7] justify the continuation of the exemption as follows:

---

[28] Information Communications Technologies (ICT)

[29] Information Communications Technologies (ICT)

[30] RF: radio frequency

Steel for machining purposes:

Machining steel is used where individual components require machining as part of their production route. The specific function of lead in steel can be described in a number of ways. Fundamentally, lead is added to enable improved machinability. Machinability can be considered as meaning any of the following; a reduced cutting force when machining steel, appropriate chip formation (length and form), facilitation of a smooth surface finish, facilitation of good dimensional achievement under commercial production conditions or reduced 'tool wear' during the machining operation. Machining encompasses a number of production operations, including; turning, grinding, rough forming, fine forming, drilling and parting. The specific function of lead in steel is to provide a lubrication effect from the material itself when that material is being machined into a component. Through this lubrication effect, the steel becomes more machinable.

The justification for the continued exemption can be summarised as follows: "All currently identified alternatives to lead as a machinability enhancer in steel have been formally assessed without identifying any addition that effectively replaces lead in all respects. Lead-free alternatives may show acceptable results in single machinability test, but the overall performance of the lead-free steels is worse than that of leaded steel. If a variety of machining operations is required or if deep drilling of material is required, lead is still considered the best machinability enhancer in an industrial production.

Customer demand supports the view that leaded steels are required rather than the alternatives which are currently offered by European steel manufacturers".

Reference is made by the steel industry to different reports investigating the machinability of lead-free steel alloys:

The University of Pittsburgh had developed a non-leaded low carbon free cutting steel (1215) containing 0,04-0,08% tin which they claimed can replace leaded free cutting steel (12L14). A range of machinability tests was undertaken with tin treated steel in order to investigate these claims [8]. The results of these tests indicated that tin treated free-cutting steels showed less favourable results with regard to the different aspects on machinability than leaded steels. It was concluded that tin cannot replace lead in free cutting steels.

The European steelmakers and component manufacturers formed a collaborative research project funded by the European Coal & Steel Research (ECSC) to evaluate potential alternatives to lead for low carbon free cutting and carbon/alloy grades.

The final report of this project summarises the results of machinability tests conducted with different lead-treated and lead-free steel alloys. These machinability tests included measurement of tool life, tool wear, surface finish, chip form, tool force and tool temperature. The steel grades selected for these tests were free-cutting steels (11SMn30), steels for hardening and tempering (C45) and case hardening steels (16MnCr5) with the following machinability enhancing additions:

Lead, bismuth, increased sulphur (with and without tellurium), tin (with low and high copper), phosphorus and calcium.

The general conclusion of these tests is that leaded steels showed the best performance in tests at lower cutting speeds with high speed steel tools and in deep hole drilling. Non-leaded alternative grades generally gave poorer chip form and surface finish. It was shown that of the alternatives bismuth is able to substitute for lead under certain conditions, although the cost of the addition may make it uneconomic, particularly for large scale application.

According to the steel industry, the hot workability of bismuth steels is reduced compared to leaded steels. Hot workability is a fundamental requirement for the steel production [1].

This parameter is of significance when the steel is being rolled to the required size for a customer from a piece with a larger (as-cast) cross sectional area. The reduced hot-workability of bismuth steels effectively means that it is significantly harder for a steel roller to produce a bar with the same machining properties and surface integrity if the steel obtains its machining properties through bismuth rather than lead.

It can be expected that there would be a higher energy cost associated with bismuth as well as potentially higher rejections (waste).

Although the machining properties of bismuth treated steels approach those of lead treated steels for certain machining operations, in the majority of machining operations lead remains the most effective machinability additive through its combination of machining characteristics.

It was further concluded in the report that calcium can substitute lead in C45 steels for use at higher cutting speeds. However, calcium treated steels have higher cutting forces, poorer chip form and have their best performance limited to a narrower range of machining speeds in comparison with the leaded product. It is highly likely that a variety of machining operations are required for many automotive components, such that the more limited benefits of calcium treated grades may not be able to match the benefits of leaded grades in many instances.

Steels containing tin generally did not show good performance in the machinability tests and thus, was not considered as a suitable replacement for lead in steel.

Eurofer states that negative environmental, health and/or consumer safety impacts caused by substitution of lead by alternative machinability enhancers are likely to manifest themselves as increased energy costs associated with a reduced effectiveness of that machinability enhancer in comparison with lead. There may also be influences of increased mining activity (through scarcity of supply) for elements that are less easy to recover and less abundant than lead, most notably bismuth [5].

Galvanised steel

With regard to the galvanisation of steel, the function of lead is not related to the improvement of the machinability or any other performance aspect of galvanised steel, but its influence on the viscosity of the molten zinc in the zinc bath during the galvanisation process itself.

The most common form of galvanisation is "hot dip galvanisation" that is performed in continuous or general (batch) operation depending on the form of steel to be galvanised: Steel strip are usually hot dip galvanized in a continuous line whereas individual metal articles are general (batch) galvanized.

Only the zinc bath used for general (batch) galvanizing contains lead in concentrations that give rise to a need for exemption. In contrast, the continuous galvanizing process does not require the addition of lead to the zinc bath. The main reason that lead was used in continuous galvanizing was that it causes the formation of the typical large spangled surface, which through the years was "the way to identify galvanized coatings". Alternatively, antimony is mentioned as substitute to lead providing the same effect [4] and has allowed steel producers to largely eliminate lead from continuous galvanizing. In general (batch) galvanizing, the lead is beneficial to accommodate "free drainage" of excess zinc as the part is removed from the zinc bath. In some instances today, bismuth is being substituted for lead to achieve free drainage of the excess zinc. Alloys that contain bismuth for use by the general galvanizing industry are available today from a number of zinc suppliers. With regard to the substitution of lead to bismuth EGGA objects that bismuth is a co-product of lead production. There is currently no primary production of bismuth and its availability to meet the needs for all replacements for lead in industry is questionable [14].

A further galvanisation technique is electrogalvanizing (or electrolytic galvanizing or electroplating), which deposits the layer of zinc from an aqueous electrolyte by electroplating, forming a thinner less strong bond. Lead additions are not required in electrogalvanizing. Electroplating is in principle applicable both for individual steel articles and –with certain restrictions- for steel sheet/strip. According to information provided by stakeholders [6] continuous hot dip galvanized steel is used for large panels used as enclosures for equipment such as refrigerators and freezers. These all use large sheets of hot dip galvanised steel that are bent 90° to form the required shapes. Electroplating fairly small parts is straightforward but electroplating large sheets of steel would require very large equipment and is a more expensive process. Hot dipping can be added to the end of steel sheet production lines as the process is quick but it also used as a separate process. Hot dipping takes seconds whereas electroplating takes several minutes at least.

Research is ongoing within the industry to develop new zinc-based alloys for general galvanizing. Principal research goals are *(i)* more zinc-efficient coatings (thinner coatings regardless of steel type) and *(ii)* coatings of more consistent appearance and surface finish. These goals are accompanied with a desire to reduce the presence of hazardous substances, including lead. Due to the fact that current lead prices are sometimes higher than those of zinc, there is no economic advantage to intentionally add lead to a galvanizing bath where it is not technically required. No feasible alternatives are yet available though for lead in general (batch) galvanizing for all types of component that may be used in electrical equipment within the scope of WEEE.

4.9.2.2 Lead as an alloying element in aluminium containing up to 0,4% lead by weight

EICTA et al. [2] and ERA [7] justify the continuation of the exemption as follows:

Aluminium alloys where lead is intentionally added for improved machinability:

By the addition of lead a better chip fracturing, automation of the production process, high cutting speed and federates (low cycle times), longer tool life, butter surface finish and more accurate dimension control can be achieved.

Aluminium alloys where lead is intentionally added for corrosion prevention:

The surfaces of aluminium parts are usually finished anodized for functional reasons since anodizing increases corrosion resistance and wear resistance. The function of lead is the higher resistivity of leaded aluminium alloys compared to tin or bismuth containing aluminium alloys against pitting corrosion in acidic systems e.g. brake systems. A certain lead content in aluminium alloys improves both layer adhesion and layer quality.

Aluminium alloys that contain lead unintentionally due to their production from scrap metal:

Aluminium produced from recycled scrap metal may unintentionally contain lead. The lead may have been added to the scrap stream over years through not accurately separated wheel rims, aluminium for machining purposes, lead from batteries, and other lead-containing applications. Thus, lead is included in the scrap flow as an impurity which cannot be separated during the scrap process phase.

There are two theoretical options to reduce the lead content in aluminium alloys in order to achieve the 0.1% limit:

1. Removal of lead from aluminium by metallurgical processes;
2. Dilution of scrap with primary aluminium.

Ad 1) Removal of lead from aluminium by metallurgical processes:

According to the European Aluminium Association (EAA) and the Organisation of European Aluminium Refiners and Remelters (OEA) the removal of lead from aluminium by a metallurgical process is technically not yet feasible on an industrial scale [1]. Research on the removal of lead from aluminium e.g. by melt purification is currently being conducted. The research activities are still in an early stage and have not yet produced practicable solutions for industrial applications.

Ad 2) Dilution of scrap with primary aluminium:

Theoretically, the lead content of scrap can be reduced by diluting the melt with primary aluminium. To reduce the lead content from 0,35% to 0,1%, it would be necessary to add 2,5 tonnes of primary aluminium to 1 tonne of recycled aluminium. Even with an average lead content of 0,2% in 55% of all aluminium casting alloys, in Europe an additional amount of ca. 1,1 million tonnes of primary metal would be necessary in order to reduce the lead content to 0,1% in aluminium casting alloys.

According to EAA/OEA the primary metal needed for diluting is not available, because the primary aluminium industry is already running at full capacity [1]. It would take years until additional capacities could deliver the material.

Currently, the global aluminium production is around 200 000 tonnes lower than the demand. New primary aluminium capacities, which are in the planning phase, are needed to supply the growing global demand for aluminium (average global increase annually 3,4%).

Diluting with primary aluminium is technically possible, but is restricted by the availability of primary aluminium. From an environmental point of view the dilution of scrap with primary aluminium is not considered to be a reasonable option because the quantity of energy needed to produce primary metal is 95% higher than the amount of energy needed to produce casting alloys from scrap.

From an environmental point of view the dilution of scrap with primary aluminium is not considered to be a reasonable option because the quantity of energy needed to produce primary metal is 95% higher than the amount of energy needed to produce casting alloys from scrap (EAA Energy figures primary recycling).

The recycling rate of aluminium is >95%. Due to the fact that lead is an unwanted tramp element with negative characteristics in the finished products if exceeding certain levels, the aluminium industry has an interest to keep the lead impurities in the secondary aluminium cycle as low as possible. In effect, the presence of lead in the recycling process is not so much an environmental problem but rather a question of product quality which will require compensation by dilution with primary aluminium at least to a certain grade.

EAA/OEA state that there is no risk to the environment and/or human health from aluminium with a lead content up to 0,4% by weight. It is argued that lead exists as an impurity in aluminium. Lead is present in ‘solid solution’ in the metallic crystal lattice or as dispersed constituents of a size smaller than 1µm. As aluminium does not corrode under normal conditions, the lead does not leach out when aluminium is exposed to atmosphere or neutral water during its use or in cases where it is littered in the nature after the end-of-life of a product.

4.9.2.3 Lead as a copper alloy containing up to 4% lead by weight

EICTA et al. [2], ERA [7] and Wieland-Werke AG [9] justify the continuation of the exemption as follows:

Lead is mainly added to copper alloys to enhance the machinability of these alloys. The formation of short chips, which can be removed automatically, is facilitated in the presence of lead. Under these circumstances wrought products can be processed around the clock on fully-automated fast-turning lathes. Another characteristic of the lead is its function as a lubricant. The self-lubricating effect of leaded copper alloys (brass) and the formation of short chips result in a reduced cutting force (Figure 4). A reduced cutting force in turn requires less energy during the machinability process leading to lower power consumption with increasing lead content (Figure 5). In addition, consumption of coolants and lubricants can be reduced during machining of leaded brass.

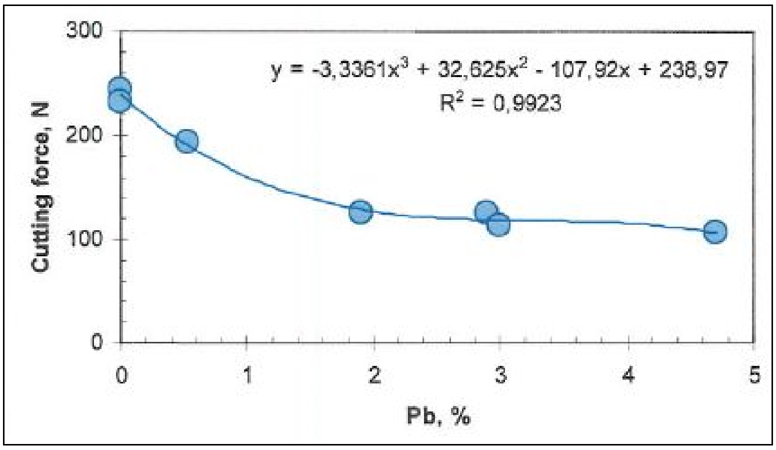

Figure 4 Cutting force depending on lead content [10] [11]

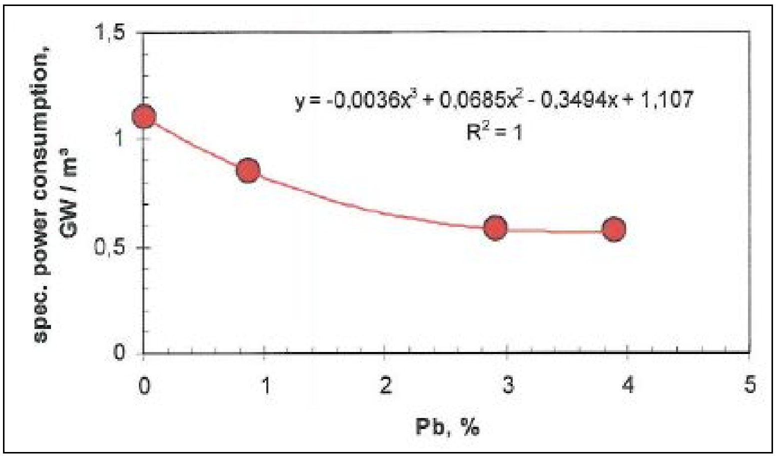

Figure 5 Power consumption per chipped volume depending on lead content [12]

By reducing the friction between sliding surfaces, lead provides furthermore a better slide functionality for parts with closely fit sliding surfaces. This is an important design criteria for valves, bearings, bushings and any parts which require “sliding” surfaces without galling or binding up.

In addition to its main function as machinability enhancer, lead in copper alloys shows further side effect:

Lead particles are able to pin grain boundaries during annealing and hot working. As a result wrought copper alloys containing lead have got a fine grained microstructure which is advantageous for many applications. Particularly a small grain size is necessary when miniaturised components have to be manufactured from copper alloys, for instance in EEE applications. Basically, grain refinement can also be achieved by alloying other elements which have a low solubility in the copper matrix, such as iron. However, iron would change the composition of the alloy and consequently its properties.

For certain copper alloys and certain mediums lead can slightly retard corrosion. The effect is most probably due to a surface film of corrosion resistant lead salts: During the machining and forming processes elemental lead that is present in the copper alloy is lubricated on the surface of the manufactured part forming a thin and more or less continuous coating. The surface layer of lead reacts with ambient mediums like saltwater to hardly soluble salts, which are for instance very stable in seawater. However, this mechanism is not as reliable as an targeted adding of alloying constituents such as aluminium, manganese, nickel etc. and is only considered as positive side-effect of leaded copper alloys.

Both the electrical and the thermal conductivity of copper alloys are not influenced by lead. However, copper alloys as a whole (i.e. regardless of the lead content) have better electrical and thermal conductivity than other materials, for example steel. For that reason they are frequently used for electrical components or thermal sensors.

According to the copper industry, there are no substitutes available having the same effectiveness in machining processes. Research on lead-free copper alloys has been carried out for many years without finding technical and economical equivalent alloys. Lead-free copper alloys exhibit different material characteristics and entail considerable cost increases due to higher copper contents. Users of those materials in the test period report on higher wear out of machines and tooling as well as on missing long time experience in production and usage of parts. Higher cycle times for semi-finished parts in lead-free alloys limit the production capacity which may lead to a bottleneck in supply.

CuZn-alloys (e.g. CuZn37, Cu-Zn-Si (EcoBrass®)) are being tested in some products as lead-free alternatives. Although silicon brasses like EcoBrass® have a high strength and moderately high corrosion resistance, their machinability (tool wear, energy consumption, chip size, surface properties of the work piece) is probably inferior to that of leaded free-cutting brass, and long-term experience (environment, reliability etc.) does not yet exist.

Among others bismuth has been considered as a potential substitute for lead in two-phase brass alloys. However, the use of bismuth significantly complicates the production of wrought alloys, i.e. rods, wires and profiles. Bismuth tends to wet the grain boundaries resulting in severe embrittlement, particularly at high temperatures. Although the embrittlement can be slightly reduced in alloys containing the elements Sn, In, P or Zn > 20%, nevertheless at elevated temperatures tensile strength and ductility (elongation) of bismuth-containing cast alloys are significantly lower than of wrought free-cutting brass containing lead. Furthermore, the internal stress in bismuth-containing alloys is increased caused by the expansion of bismuth during solidification. This is also the reason why these materials are far more susceptible to stress corrosion cracking. Bismuth containing alloys cannot match wrought leaded alloys in terms of machinability indicated by the machinability index of 85% at best. The hard bismuth inclusions are expected to cause higher tool wear. Thus, complex machining operations cannot be realised with bismuth containing brass.

During the stakeholder consultation one US manufacturer (Federal Metals Co.) was named who had developed lead-free copper alloys containing bismuth (Federalloys®). However, these alloys are for casting only and are not suitable for wrought alloys. Most of the applications for leaded copper alloys are as small parts some with complex shapes. These cannot be made by casting. The only uses of cast copper alloys in EEE would be as fittings to connect pipework in refrigerators, freezers and machines that require cooling systems. Connectors, clips, inserts, spindles, etc are made from wrought brass only.

Furthermore, Federalloys® are relatively new alloys which few manufacturers have evaluated and availability is only from one US supplier which would pose a risk if they could not meet demand or experience production difficulties.

The European copper industry summarises that bismuth-containing alloys are not able to substitute leaded copper alloys. The most important reasons are:

- Low ductility of bismuth-containing alloys at elevated temperatures.
- Machinability of bismuth-containing alloys is inferior to leaded copper alloys (only 66-85%).
- Hot shortness of wrought copper alloys due to bismuth-impurities. For that reason the choice of production processes for bismuth-containing alloys is limited.
- Contamination of scrap circuits.
- Poor availability of bismuth.

Recycling of scrap is important as machining creates large quantities of metals that should be re-melted, their composition adjusted and then re-used. However, certain combinations of different alloy types prevent recycling because segregation of alloy types is usually impossible in practice. Copper alloy scrap with both lead and bismuth cannot be used and has to be refined to produce the constituents in high purity forms. In addition to melting, this requires electro-refining of the copper and several complex furnace operations to separate bismuth from other metals. Most metals recyclers set very low upper limits for bismuth as this makes recovery of precious metals much more difficult. There will be a large environmental impact difference between recycling copper alloys without bismuth and copper alloys with bismuth, the former requiring energy only to re-melt it whereas the latter requires many energy intensive process steps.

With regard to the question whether the maximum concentration value of 4% lead by weight in copper alloys is still justified or whether it should it be adjusted e.g. to a maximum concentration value of 3% lead by weight, the copper industry emphasizes that the existing concentration value of 4% lead is still justified and necessary, in order to allow the use of adequate copper alloys in the different applications concerned.

The reason for the retention of the maximum concentration value of 4% lead by weight is as follows:

The machinability of copper alloys is parabolically enhanced with increasing lead content meaning that the benefit from lead diminishes at high lead levels (see Figure 6). A certain limit value of the lead content can be defined above that no pronounced improvement can be achieved. This limit value sensitively depends on the alloy system. For instance, in free cutting brass the value is between 3% and 4%. For that reason the maximum lead concentration of wrought copper-zinc-alloys specified by the standard DIN CEN/TS 13388 is 3,5 %, except for the alloy CuZn38Pb4 with a maximum lead content of 4,2%. On the other hand the specified maximum lead content in high-copper alloys (alloying content < 5 %) is 1,5 %. That is to say that the maximum limit of lead has to be defined for each family of copper alloys separately. To simplify matters the recommendation is to consider all wrought copper alloys listed in DIN CEN/TS 13388 and to take the highest standardised lead content as an over-all limit value, which is 4,5% in CuSn4Pb4Zn4. This is not far from a maximum concentration value of 4% when the rounding rule is applied. Therefore, the copper industry advise a maximum lead content of 4% for all copper alloys.

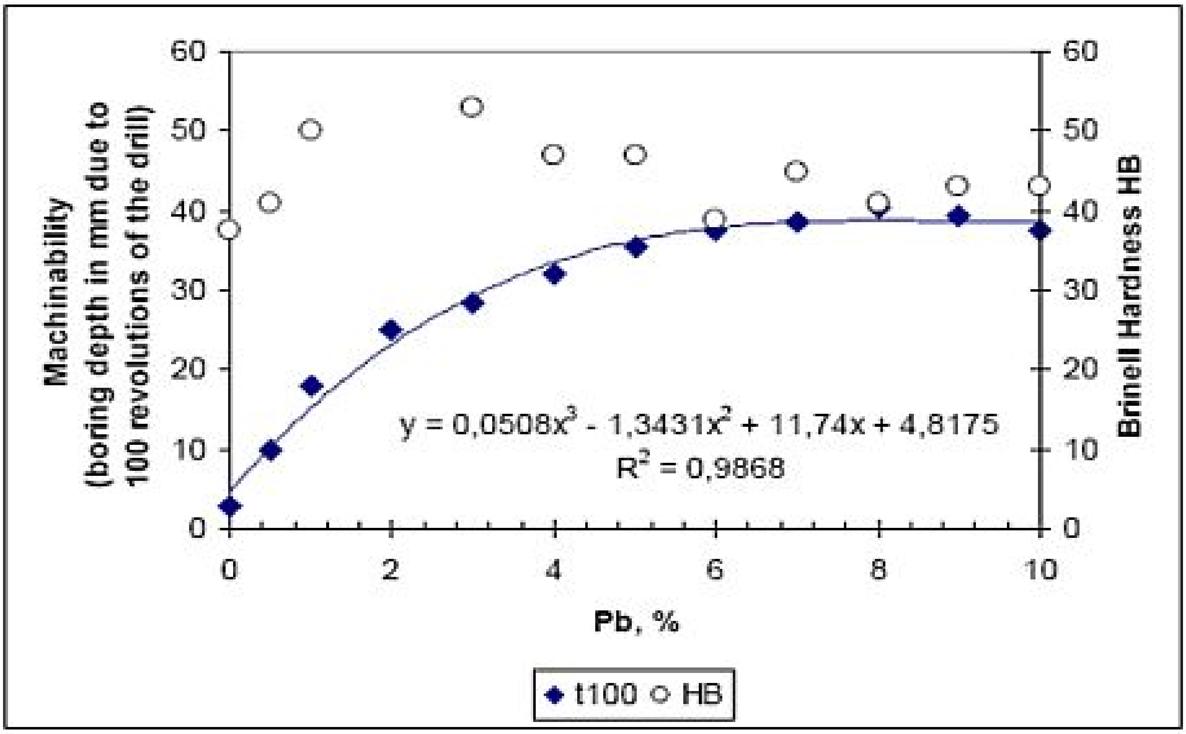

Figure 6 Machinability and hardness of CuZnPb-alloys [13].

4.9.3 Critical review

As already mentioned in section 4.9.1 there is an overlap between RoHS exemption no. 6 and ELV exemptions nos. 1 to 3. Annex II to the ELV Directive[31] includes exemptions for the use of lead up to 0,35% in steel, (entry no. 1), up to 0,4% in aluminium, (entry no. 2) and up to 4% in copper (entry no. 3).

In view of consistency in environmental legislation information and data provided in the context of the recent adaptation to scientific and technical progress of ELV Annex II [1] have been taken into account in the present adaptation of the RoHS Directive. In this context it should be kept in mind that the types of machining operations used for many automotive parts are similar to the processes used to make many parts used by the electronics industry,

---

[31] Directive 2000/53/EC on end-of-life vehicles (ELV Directive)

i.e. many drilling, cutting and turning steps to fabricate each part. Therefore, most of the conclusions drawn in the recent adaptation to scientific and technical progress of ELV Annex II can be transferred to the present evaluation.

4.9.3.1 Lead as an alloying element in steel containing up to 0,35% lead by weight

Steel for machining purposes:

With regard to steel for machining purposes, comprehensive tests indicate that lead-free alternatives are available providing comparable results to leaded steel in single machinability tests (e.g. bismuth or calcium treated steels). For example, the machining properties of bismuth treated steels approach those of leaded steels, but only for certain machining operations. In other operations like hot workability, the performance of bismuth treated steels was shown to be worse than for leaded steels. Due to the fact that steels usually go through a variety of successive machining operations, the overall performance of steels in the various machinability processes (chip form, tool life and wear, surface finish, tool force, hot workability, deep drilling etc.) is of a higher importance than the results of single machinability tests. This applies all the more because a good machinability of steel is not only economically relevant, but also important from an environmental point of view as a reduced machinability may lead to an increased energy demand during the production process. The provided test data indicate that lead-free alternatives do not yet show a comparable overall performance to leaded steels in a variety of machinability tests.

Calcium treated steels may substitute leaded steels in various applications, however a general substitution does not seem possible at the moment because calcium treated steels have their best performance limited to a narrower range of machining speeds in comparison with the leaded grades.

Bismuth is mainly produced as by-product of other metals among others bismuth sources are by-products associated with lead mining. There is currently no primary production of bismuth.

From the above it can thus be concluded that currently a general substitution of lead as alloying element in steel is not yet practicable.

Galvanized steel

Evaluating the above-mentioned arguments of the industry on galvanized steel the following can be concluded:

Lead is only used and required in general (batch) galvanizing of individual steel articles. In contrast, galvanisation of steel sheet/strip by hot-dip galvanisation in continuous line or electroplating of steel sheet or individual steel articles by electroplating does not require the use of lead. From a technical point of view, individual steel articles could be coated by electroplating instead of hot dip general batch galvanizing but the coatings have different performance characteristics. According to information provided by EGGA (personal communication) steel articles that are used for outdoor applications and are exposed to a more aggressive environment require a thicker coating for a better corrosion protection. This thicker, metallurgically bonded coating can only be realised by general (batch) galvanisation and not by electroplating.

During the stakeholder workshop the question came up whether the allowable level of lead in galvanized steel has to be related to the coating as homogeneous material or to the steel part in total as homogeneous material. As the definition of homogeneous material in RoHS applies to the application of the threshold limit of 0,1% lead but not to the requested exemptions within the Annex, this question was not considered as relevant for the further evaluation. It should be stressed that in the context of this exemption request “galvanized steel” is considered as the entity of steel plus zinc coating. The allowable level of lead in galvanized steel is therefore related to the full component i.e. steel plus zinc coating. However, due to the maximum solubility of lead in molten zinc, the amount of lead in the exempted components will be limited by metallurgy to a level significantly below the 0.35% allowed in the exemption.

4.9.3.2 Lead as an alloying element in aluminium containing up to 0,4% lead by weight

The biggest share of aluminium alloys contains lead unintentionally due to the production from scrap metal. There are two theoretical options to reduce the lead content in aluminium alloys to a level of 0,1% lead by weight in homogeneous material (i.e. the maximum concentration value up to which the presence of lead in aluminium would be tolerated without exemption):

1. Removal of lead from Aluminium by metallurgical processes;
2. Dilution of scrap with primary Aluminium.

With regard to option 1, publications are available confirming that in small scale experiments it is theoretically possible to remove lead from aluminium by the electrochemical addition of sodium or potassium [15], [16]. However, up-scaling this method form small scale laboratory experiments to industrial scale application was considered to be difficult, thus confirming the industry position that the research activities have not yet produced practicable solutions for industry applications.

Option 2 is technically possible, but is restricted by the availability of primary aluminium. From an environmental point of view the dilution of scrap with primary aluminium is not considered to be a reasonable option because the quantity of energy needed to produce primary metal is 95% higher than the amount of energy needed to produce casting alloys from scrap.

It can be summarised that removal of lead is technically not yet possible at industrial scale and dilution of aluminium by primary aluminium to a level < 0.1% is not meaningful from an environmental point of view.

Concerning the applications where lead is intentionally added to aluminium for improved machinability or for corrosion prevention lead-free alternatives containing e.g. tin or bismuth were shown to be less appropriate than aluminium alloys containing a certain amount of lead.

Overall, the stakeholders provided plausible information on the necessity of an extension of exemption 6 related to the presence of lead in aluminium.

4.9.3.3 Lead as a copper alloy containing up to 4% lead by weight

The copper industry has provided sound data indicating that intensive research on lead-free copper alloys has been carried out for many years without finding technical and economical equivalent alloys that provide all of the required characteristics of lead additions: Bismuth or silicon copper alloys are named as potential substitutes to leaded copper alloys but still show significant disadvantages.

Due to the fact that machining of copper alloys produces quite large quantities of scrap and swarf, recycling by re-melting and subsequent reuse is common practice. Mixtures of copper alloy with both lead and bismuth cannot be used together but must be separated because bismuth containing alloys are much more brittle particularly at elevated temperatures. Severe cracking has to be expected during hot working or use. Consequently, it would be imperative for the industry not to mix scrap / swarf of copper alloy with both lead and bismuth. But in a transitional period, when two strictly separated recycling loops would have to coexist the probability of scrap mixing would be quite high with possibly dangerous consequences. Therefore, a partial replacement of leaded copper alloys by bismuth copper alloys in selected applications is considered to be impracticable and needs to be considered with caution.

With regard to the maximum concentration value of lead in copper alloys the copper industry provided reliable data indicating that the beneficial effect of lead on the machinability of copper brass reaches is maximum at a lead concentration between 1,5–4% lead by weight depending on the alloy system. Industry, however, did not specify for which applications those alloy systems with the high lead contents of up to 4% are required.

Based on the provided data and information it can be concluded that the use of lead as copper alloy at the current state of the art is not avoidable in all applications. A partial replacement of leaded copper alloys by bismuth copper alloys in selected applications is considered to be impracticable.

Transition period and expiry date

Assuming that the amendment of the Annex in the RoHS Directive will be officially published end of 2009, new exemption 6 should come into force at the same time since no transition period is necessary due to the unchanged wording. The expiry date is proposed to be set at the time of the next revision because as of today no substitution seems technically feasible. Here again assuming an official publication of an amended RoHS Annex by end 2009, the expiry date would be four years later 31. July 2014.

Repair and upgrade

Furthermore, a clause should be added to the new exemption 6 explicitly mentioning that spare parts for what used to be applications covered by exemption 6 are exempted from substance use restrictions.

Inclusion of category 8 and 9

Since the use of lead as an alloying element in steel, copper and aluminium is the same for any electrical and electronic equipment – be it for the current scope or for categories 8&9 -, an inclusion of category 8&9 into the scope of the RoHS Directive would not lead to a need for change in the wording of exemption 6.

4.9.4 Recommendation

It is recommended to continue exemption no. 6 allowing the addition and/or presence of lead as alloying element in steel, aluminium and copper until the next review of the RoHS Directive.

Concerning the use of lead as an alloying element in steel, a change of the wording into “steel for machining purposes and galvanized steel” as proposed by EGGA is supported.

Due to the fact that exemption 6 comprises three quite different applications of lead as an alloying element in metals, it is proposed to split this exemption into three parts.

The new wording of exemption 6 would thus be:

(6a). Lead as an alloying element in steel for machining purposes and in galvanized steel containing up to 0,35% lead by weight
(6b). Lead as an alloying element in aluminium containing up to 0,4% lead by weight
(6c). Copper alloy containing up to 4% lead by weight

Alignment RoHS & ELV

In addition, it is recommended to align with exemption 1, 2 and 3, Annex II ELV Directive. Since the production lines of manufacturers are identical for RoHS applications and ELV applications related to exemption 6, a phase-out of lead will be either feasible for all areas at the same time or for none. Therefore, there should be a common exemption for both ELV and RoHS with the same expiry date, the same spare parts provision and the same review cycle. The above proposed wording for exemption 6 is therefore the same as in Annex II ELV Directive.

4.9.5 References

[1] Lohse et al. Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, 2008

[2] EICTA et al. Stakeholder contribution, exe. 6 (Joint response from EICTA, AeA Europe, EECA ESIA and JCBE to the general and specific questionnaires relating to exemption “6. Lead as an alloying element in steel containing up to 0.35% lead by weight, aluminium containing up to 0.4% lead by weight and as a copper alloy containing up to 4% lead by weight), 31 March 2008

[3] GalvInfo Center Continuous hot-dip galvanizing versus general (batch) galvanizing; GalvInfoNote 2.3; Rev January 2007

[4] GalvInfo Center The spangle on hot-dip galvanized steel sheet; GalvInfoNote 2.6; Rev 1 June 2008

[5] Eurofer Stakeholder contribution, exe. 6; 1 April 2008

[6] ERA Stakeholder contribution, exe. 6; 28 July 2008

[7] ERA Stakeholder contribution, exe. 6; 16 June 2008

[8] Bateson, P.H. & Reynolds, P.E. Machinability evaluation of 1215 steel containing tin; British Steel Limited, Swinden Technology Centre, Moorgate, Rotherham, UK; Report No. SL/MA/R/S2916/16/99/D, 1999

[9] Wieland-Werke AG Stakeholder contribution, exe. 6; 28 July 2008

[10] Kuyucak, S. & Sahoo, M. A review of the machinability of copper-base alloys; Canadian Metallurgical Quarterly, 35; 1996

[11] Gane, N. The effect of lead on friction and machining of brass; Phil. Mag. A; 1981

[12] Stoddart, C.T.H. et al. Relationship between lead content of Cu-40Zn machinability, and swarf surface composition determined by Auger Electron Spectroscopy; Metals Technology, 1979

[13] Kessner, A. 'Die Prüfung der Bearbeitbarkeit der Metalle', Werkstatttechnik 24, 1924

[14] EGGA (European General Galvanizers Association) End of life vehicle Directive – Exemption for lead in galvanized steel; Papers submitted in response to the Öko-

Insitut e.V. request for technical guidance regarding the adaptation to scientific and technical progress of Annex II of the Directive 2000/53/EC (End of Life Vehicles), 2007

[15] Tailoka, F. & Fray, D. J. Selective removal of lead from aluminium, 1993

[16] Tailoka, F. et al. Electrochemical removal of lead from aluminium using fused salts. 1994

[17] EGGA (European General Galvanizers Association) Stakeholder contribution, exe. 6; 1 April 2008

4.10 Exemption No. 7a

“Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead”)

4.10.1 Description of exemption

The lead-containing high melting point solders with 85% of lead and more are addressed as HMP solders in the following. High melting point solders containing no lead will be abbreviated with lead-free HMP solders.

The compositions of HMP solders typically are in the range of 90–97% lead by weight. These alloys can be found in a wide range of products, encompassing WEEE categories 1 through 10.

EICTA [2] indicates several applications of HMP solders:

1. HMP solders are used to form high reliability electrical connections. Examples of applications include large BGA or solder column packages, as well as some discrete devices in high reliability electronics. The lead content facilitates solder joints with a high resistance to thermal fatigue and to electromigration failure.