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IZM

Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS)

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4.3 Exemption no. 3

"Copper alloy containing up to 4% lead by weight"

The evaluation of exemption 3 under the current contract was based on results of former evaluations, case studies, reports and further input and comments from industry stakeholders. Initial answers have been received from stakeholders in the context of the second stakeholder consultation. Further questions have been sent to stakeholders who have sent input. Answers have since been received from ACEA et al. (2009a) as well as a separate joint response from Schrader Electronics Limited and Schrader SAS (Schrader SAS 2009) and discussed in two conference calls. Furthermore comments to the draft report from Öko-Institut have been received from ACEA/JAMA/KAMA/CLEPA et al. Attached to these comments were the results of case studies and additional documents (ACEA et al. 2009b2) as well as a new report by the European Copper Institute (ACEA et al. 2009b3).

The outcome of all this information gathering exercise and of the exchange with the above mentioned stakeholders is reflected in the following.

4.3.2 Description of exemption

There is a wide range of vehicle components which are made of copper alloys: valve guides, valves for tyres, fuel injectors, jet nozzles, battery terminals, temperature sensor housing, carburettor nozzles, mountings for radios, wiper systems, door locks, electric window lifts, parts of the braking system, pins and fittings.

The typical lead content in these copper alloys is between 0,15% and 4% by weight with an average 2% concentration (ACEA et al. 2009b3). The amount of lead-containing copper alloys in vehicles (other than bearing shells and bushes) can be roughly estimated to be 1–2 kg per car. The average amount of lead used in those applications is therefore between 15 and 40 g per car. The total EU27 lead consumption in this application is thus estimated to be between 265 and 710 t/y[12].

However, the weight distribution among the parts made with copper alloys plays a major role. Less than half of the components contains up to 3% of lead. More than 50% of parts are manufactured with alloys containing 3% to 4% of lead. They are mainly used for small parts in safety relevant areas, such as steering, central control unit, fuel pump unit, level sensors, oil pressure switches, starter, electronic-stability-program, and connector pins. Nevertheless, their weight altogether represents only some 25% of the total weight of the lead containing parts (ACEA et al. 2009b3).

[12] For EU27 incl. EFTA (17,7 million cars – i.e. ignoring the current economic downturn – *source: ACEA 2008*)

Lead is a machinability enhancer. The formation of short chips, which can be removed automatically during machining, is facilitated by its presence (similarly to the use of lead in other metals such as steel and aluminium). This allows products to be processed around the clock on fully-automated, fast-turning lathes. Low strength and high ductility are also a result of the use of lead and allow the cutting force to be reduced leading to reduced power consumption during the machining process and increased tool life. Alloyed lead also contributes to the prevention of the formation of any kind of cracks and finally it increases the copper's corrosion resistance. Therefore lead in copper alloys affects safety properties of the car and its passengers.

Lead, however, does not influence the other characteristics and usage properties of the copper alloy, meaning that the copper's strength and electrical conductivity are not influenced significantly by its presence.

An extension of the exemption is requested by the automotive industry.

4.3.3 Justification for exemption

In terms of volume the automotive sector represents a relatively small market for copper and its alloys. Only 6% of the annual global copper demand is consumed by the entire transport sector (ACEA et al. 2009b1).

According to industry, the relative distribution of the weight of the parts according to their lead content (from <1% to 3%–4%) cannot be directly linked to the necessity for an exemption. A much more convincing argument results from the distribution of the number of parts (about 7000 single parts contain leaded brasses (ACEA et al. 2009b2)) made with copper alloys having different lead contents. Less than half of the components contains up to 3% of lead. More than 50% of parts are manufactured with alloys containing up to 3%–4% of lead (ACEA et al. 2009b3). Those are mainly consisting for very small parts or assemblies and used in safety relevant areas, such as steering, central control unit, level sensors, oil pressure switches, connector pins etc.

For the stakeholders it is an utmost concern that the role of lead in copper alloys is multifunctional and not only related the superior machinability aspect. Lead contributes preventing the formation of any cracks, increases the corrosion resistance or reduces friction. Therefore lead in copper affects safety properties. To avoid problems caused by a change of materials like lowering the lead content or finding a lead-free substitute, a full program of test procedures for each one of these applications must be applied. According to stakeholders, even if new alloys and materials would be available in future their validation, availability, testing and qualifying for automotive applications would take a long time (ACEA et al. 2009b1).

Reduction of lead content

During the previous evaluation, Wieland Werke AG stated that a reduction of the maximum value in the exemption wording from 4% to 3% lead content was possible in principle for free cutting leaded brass. The stakeholder provided different machining test results comparing copper alloys at different lead concentrations, as shown in Figure 2 and Figure 3.

Another graph not presented here showed a parabolic relation between lead content and drilling depth after 100 drill rotations. Above 6%, the added effect of increased lead concentrations became unnoticeable, while the drilling depth obtained with 3% leaded copper was about 80% of that attained with 4% leaded copper.

Based on these results, Wieland Werke AG asserted that it was principally possible to reduce the maximum concentration of lead in free-cutting brass from 4% to 3%.

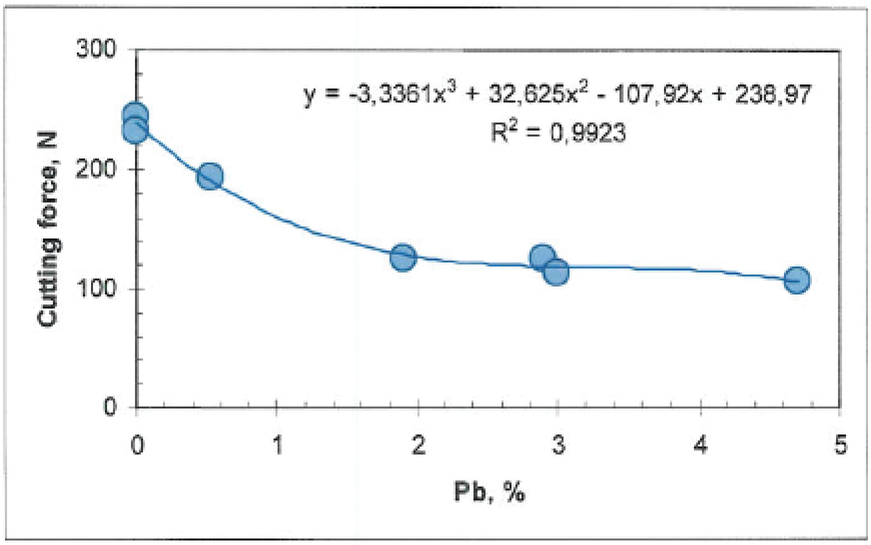

Figure 2 Cutting force for free cutting brass according to lead content (Wieland Werke AG 2007)

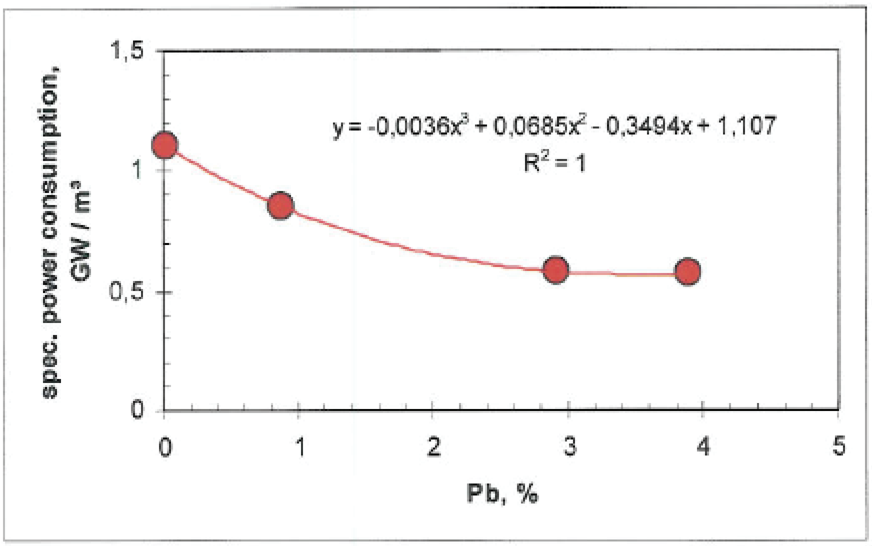

Figure 3 Power consumption per chipped volume for free cutting brass according to lead content (Wieland Werke AG 2007)

When confronted with this during the current revision, stakeholders from automotive industry said that such a reduction depends on the requirements of each individual application and that therefore no general answer on the question of a possible lead content reduction could be given. The automotive industry stressed that optimal lead contents are already in use for each application, making a reduction of the maximum lead concentration not feasible (ACEA et al. 2009b1).

In short, stakeholders explain that simply reducing lead content is not an option; a substitute material with similar characteristics must be developed if the lead content in this application is to be reduced.

Lead-free and alternative alloys

In order to be able to relate research and development efforts to the results of past assessments, several information has been provided on this topic by stakeholders.

Input from current consultation

Stakeholders asserted a certain amount of additional information with evidence (ACEA et al. 2009b2). Data was provided in the form of characteristic comparisons of standard leaded copper alloys (CuZn39Pb2 [1,6%–2,5% lead] or CuZn39Pb3 [2,5%–3,5% lead]) with some of their alternatives, namely Ecobrass (CuZn21Si3 or CuZn31Si1) or the identical standard brass without lead (CuZn37). The silicon alloyed brass Ecobrass is the only suggested replacement material for lead containing brass that might be available in sufficient quantities. But stakeholders state that nevertheless it is a totally different material, which even on initial inspection of the standard performance indicators for leaded brass cannot cover certain areas of material performance at all as explained in the following

Test data provided indicated that:

- The electrical properties of two geometrically identical pieces of copper made from Ecobrass and standard leaded copper alloy were compared. It was observed that the electrical resistance (and therefore the voltage drop) was 2,7 times higher in Ecobrass than the standard leaded alloy.
- The machinability and surface finish of the alternative alloy "M37"[13] was also analysed, and proved to be far less satisfactory than standard leaded copper.
- Another study indicated that Ecobrass was 89% as machinable as the 1,6%–2,5% leaded copper, though only 80% as machinable as the 2,5%–3,5% leaded copper. The main disadvantages of Ecobrass compared to standard leaded copper appeared to be its smaller heat conduction capability and electrical properties, gas-shielded arc weldability and hard solderability. These drawbacks were even more contrasted with the 2,5%–3,5% leaded alloy.
- The lubricating effect of lead in copper alloys is also stressed by tribological tests. In contact with steel CuZn39Pb3 mostly shows a considerable lower friction coefficient than lead free alloys or Ecobrass.
- Negative effect on formability and sealing (e.g. fittings in the fuel feed systems) showed a significant difference between the silicon-alloyed and the lead-alloyed brass. Equally assembled fittings with an approximate torque 25 Nm were tested under pressure and temperature. The residual torque after testing was about 1,3–1,6 times higher for a conventional alloy than for the Ecobrass fittings. Values under 10 Nm (e.g. Ecobrass) can not be accepted for this test.
- In a hot forging trial with lead free material (Ecobrass) on production process with varying electric current condition for electrical resistance heating it was not possible to reach proper forging results. This was allocated to the increased deformation resistance and to the higher hardness of silicon-alloyed compared to lead-alloyed brass.

These tests revealed that the addition of silicon to copper, contrary to the addition of lead, affects the alloy's electrical properties significantly. Stakeholders thus conclude that Ecobrass can therefore not be used where electrical properties are of importance. Furthermore, the machinability of Ecobrass is worse than that of leaded copper alloys.

[13] No reference to this alloy was found in the Copper Institute's database. It was therefore not possible to verify, although it was insinuated by stakeholders, if this alloy is lead-free.

Apart from this, further industry stakeholders asserted a certain amount of additional information, without supporting it with evidence. The following summarizes the provided information.

Schrader SAS and Schrader Electronics Ltd. (SEL), which provide tyre valves, fuel injection valves and air conditioning valves, underline that the surface of the brass must be free of chips or other anomalies in order to ensure proper adhesion of the rubber coating on valve stems. Additionally, in the case of wireless direct Tire Pressure Monitoring Systems (TPMS), the valve is used as the antenna. A change in material would require the retuning of the TPMS circuitry with the valve's new electrical properties (impedance). TPMS has the potential to substantially increase driver safety and vehicle fuel economy (up to 2,5% improvement depending on TPMS accuracy). These devices will become mandatory in new vehicles in 2012 in the EU and are already mandatory in the USA.

Stakeholders state that research on lead-free copper alloys has been carried out for many years without finding technically and economically equivalent alloys. They explain that lead-free copper alloys have different material characteristics and entail much higher costs due to increased copper content. Users of those materials in the testing phase apparently report higher wear of machines and tooling as well as a lack of long term experience in production and use of parts. Higher cycle times for semi-finished parts in lead-free alloys allegedly limit the production capacity which may lead to a bottleneck in supply.

Explanations were also given as to why bismuth-containing alloys were not suitable alternatives. Embrittlement and lower strength and ductility at high temperatures were cited as some of the main issues. The other major disadvantage in bismuth-containing copper alloys is the high internal stress responsible for frequent stress corrosion cracking. This is caused by the expansion of the bismuth during solidification and thus is fundamentally unavoidable. Furthermore, machinability of bismuthed coppers is also between 66% and 85% that of free-cutting, lead-containing brasses. In addition the complete replacement of lead by bismuth would result in a tenfold increase in the demand of bismuth. For each tonne of bismuth, 30–200 tonnes of lead would have to be produced.

Stakeholders further stated that alloys containing bismuth were also more difficult to recycle, because recycling must be done separately and so far fully developed recycling only exists for lead-containing copper alloys.

The mixture of chemical composition in very different copper based alloy scraps may end in difficult material recycling and the energy consumption for the recycling of these scrap mixtures will increase enormously. Current copper based scraps derived from end-of-life-vehicles are a valuable resource for secondary copper or brass applications. The discussed silicon or bismuth containing alloys are incompatible to be recycled into alloys which are free of these elements. A mixture may end up in a loss of recyclability.

Input from last consultation

During the previous consultation in 2007, stakeholders had already indicated that bismuthed copper was not a reliable alternative, but that CuZnSi and CuZnSiX alloys were the most promising alternatives.

A publication provided during this consultation (Oishi et al. 2007) indicated the following on Ecobrass (a CuZnSi alloy):

- Silicon is a widely abundant and safe material
- Effect of lead contamination on mechanical properties is minor (i.e. high recyclability and separation need of lead-containing and lead-free alloys reduced)
- The lead-free alloy has excellent hot workability and castability
- Thin wall casting is possible and a wide variety of casting methods are selectable
- No lubricant is required for processing, chips are easily handled and thin wall cutting is possible
- Increased strength and equal ductility allow for smaller and lighter products and corrosion resistance is increased.

However, this study seemed to mainly focus on plumbing applications (tested items were plumbing-related).

Another study on low lead alloys was also supplied (Sadayappan et al. 2007). This study, in the context of plumbing applications as well, compared low lead alloys with 4,0%–6,0% leaded copper alloys. The low lead alloy contained less than 0,25% lead and 1,5%–3,5% bismuth as well as 4,0%–7,0% tin. This alloy performed well at room temperatures, having a lower strength than 2,5%–3,5% leaded copper alloys and a typical elongation of 30%, that is to say 75% that of 2,5%–3,5% leaded copper alloys. Despite these promising results, it appeared that the mechanical properties of the low lead alloy quickly deteriorated as temperature was increased above 150°C, more than halving the previously cited characteristics.

Additional information was provided on the outcome of copper alloys in automobile shredder scrap. Copper alloys from automobiles end up in the shredder heavy fraction and will be transferred to metallurgical processes. Recycling of lead-containing copper is possible and widely used in copper recycling plants. Lowering the lead content in copper alloys is possible and takes place in Belgium but would severely increase the costs in the whole material chain in order to keep metal streams separate. Stakeholders argue that it would therefore have a strong negative effect on the very well established and functioning recycling processes, which would need a complete redesign.

4.3.4 Critical review of data and information

Provided information will be analysed in order of presentation.

Reduction of lead content

Stakeholders seem to have contradicting opinions. As explained earlier, during the previous consultation, Wieland Werke AG claimed that a reduction from 4% lead to 3% lead was principally possible considering the relatively limited impact on machinability for free cutting brass. Other automotive industry stakeholders explained that only a component-by-component test would be able to say whether or not such a reduction is possible. They stressed that leaded copper alloys are already at their optimal concentrations and that any change would require long, costly and demanding development and qualification procedures and testing.

The ELV Directive's interest is not whether or not an alternative is optimal or equivalent to current technology but whether or not the use of selected metals is unavoidable or not. As this is a matter of interpretation, it could be considered that the costs, duration and complexity of procedures necessary for substitution efforts are irrelevant. In that case, such matters would only be relevant for the choice of an exemption's expiry date or the definition of a needed transition period before expiration comes into force.

Stakeholders have implied that the complexity, the amount and distribution of 3%–4% leaded alloyed parts as well as costs of administrative procedures have discouraged them from conducting a study or invest into R&D, and that the environmental benefits of a reduction from 4% to 3% would be minimal. Nevertheless, it is unclear how important from technical point of view a 25% reduction in machinability really is. Stakeholders stress its impact but fail to provide substantial evidence proving that this situation makes the use of 4% leaded copper unavoidable.

No fact-based evidence on the technical feasibility of lead concentration reduction was provided and may not exist.

Lead free and alternative alloys

During the last consultation, stakeholders provided an extensive study (Oishi et al. 2007), which concludes that Ecobrass is a good machinable material presenting excellent corrosion resistance, good wear resistance, hot workability and castability and is less brittle than leaded coppers at higher temperatures.

The test data provided revealed that the tested electrical properties of Ecobrass are significantly affected by the presence of silicon in the copper, namely electrical conductivity and resistance. It can therefore be concluded that Ecobrass is unsuitable for applications requiring the conduction of electricity. The data also confirms that the machinability of Ecobrass is between 70% and 82% that of two typical leaded coppers, containing 2,5%–3,5% and 1,6%–2,5% lead respectively. Furthermore, engine tests showed that lead free brasses like Ecobrass or Diehl 474HT[14] were suitable for valve-guide in some cases but failed in some other cases due to friction, wear, and fretting.

Additionally, some of the data provided contradicts previously mentioned test data, namely on the plasticity of Ecobrass. Test data provided during this consultation states a 10%–20% elongation of Ecobrass vs. 10%–45% elongation in traditional leaded copper alloys. Material plasticity is a crucial aspect in material machinability. However, study (Oishi et al. 2007) explains that elongation of Ecobrass reaches 32% and can be further increased through the addition of zirconium and phosphorous to 45%, thus equalling the plasticity of the most machinable leaded copper alloys. Such contradictions should be remedied, considering the importance of this factor in discriminating Ecobrass as an alternative.

Stakeholders affirm that Ecobrass is not suited for use in fittings in vehicles. However, study (Oishi et al. 2007) explains that lead-free fittings for drinking water pipes will be mandatory in the USA[15] started from January 2010. Equally the new Cu-Si-alloy[16] for drinking water applications is completely reusable and has extraordinary mechanical properties. It is however clear that drinking water fittings and automotive fittings do not operate in the same requirements and that results can thus not automatically be transferred to automotive industry as supported by automotive industry (ACEA et al. 2009b2). Nevertheless, it shows that new lead-free materials are principally possible and that it could be worthwhile investigating these further.

Study conducted on low lead alloys can be viewed as a look into possible synergies between lower lead concentrations and possible substitutes, in this case bismuth (Sadayappan et al. 2007). A bismuth-lead synergy as presented in this study does not seem to be beneficial for automotive applications given the possibly high temperatures, which quickly degrade the alloy’s properties.

In short, the copper industry argues that intensive research on lead-free copper alloys has been carried out for many years without finding technically and economically equivalent alloys.

Apart from having received answers from many different stakeholders, they all asserted the same information as explained above. Certain claims are contradicted, at least partly, by

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[14] http://www.diehlmetall-messing.de/index.php?id=207

[15] It is only mandatory in California and Vermont. The Californian and Vermont legislation define „lead free“ as not more than 0,25% lead weighted in average for the weighted surface in contact with the drinking water.

[16] http://www.cuphin.com/index_en.html

provided evidence. In order to give an overview on these claims the following Table 7 lists some important properties for selected copper alloys (Data sheets alloys 2010).

Table 7 Copper alloys properties

	Lead free and low leaded		Leaded	
	ECOBRASS CuZn21Si3[17] C87850	CUZn37 C27200	CuZn39Pb3[18] CW614N	CuZn39Pb2 CW612N
Chemical Composition				
Cu	≈ 76%	≈ 63%	≈ 58%	≈ 59%
Pb			≈ 3%	≈ 2%
Si	≈ 3%			
Zn	≈ 21%	≈ 37%	≈ 39%	≈ 39%
Fabrication properties				
Machinability Rating	70-80%	35%	100%	85%
Cold Working	+	++	-	0
Hot Working	++	+	++	+
Soldering	++	++	++	++
Brazing	++	++	0	+
Oxyacetylene Welding	+	0	+	-
Resistance Welding	+	+	0	0
Beam Welding	+	0	0	-
Polishing	+	+	+	++
Electroplating	+	++	++	++
General Properties				
Corrosions resistance	+	0	+	+
Mechanical Properties (*Tensile Strength, Yield Strength, Elongation, Hardness*)	+	0	++	+
Density (g/cm³)	8,3	8,44	8,5	8,4

The comparison in Table 7 with four different copper alloys represents only a few existing copper alloy types. Nonetheless, those four alloys compose a representative sample from lead-free up to the standard copper alloy material for machining. The overview intends to gather the different general properties and to clarify the difference between the single materials. The lead-free copper alloy, namely Ecobrass has in some properties better characteristics than the more often used copper alloy CuZn39Pb2. Ecobrass might also be considered equivalent to the standard leaded copper alloy CuZn39Pb3. For example, a

17 http://www.greenalloys.com/specs/C87850.pdf

18 Standard material for machining (machining index 100%)

70%–82% machinability compared to current materials could be considered sufficient for lead used in copper alloys to be avoidable. However, considering that the statements on properties are incomplete, the question arises, whether and how the automotive industry – despite the above mentioned claims – would be willing to put additional effort into research, process technology, investigations and development work.

4.3.5 Final recommendation

Considering the fact that the ELV Directive doesn't allow for exemptions until technically equivalent alternatives are available but until the use of selected materials (lead, cadmium, mercury, hexavalent chromium) is no longer unavoidable, it is very unclear what level of technical equivalency must be achieved by alternatives for the original material to no longer be considered unavoidable.

Concluding on the above described technical discussion on feasible lead-reduced or lead-free alternatives. The contractor cannot support an extension of this exemption without any expiry date or a review date. It is therefore recommended to continue the exemption and to set a review date 5 years after the revised Annex II comes into force. This period of time should allow industry stakeholders to carry out the necessary research and development work, to gather more fact and evidence based information as well as to encourage the corresponding implementation of the process technology for lead-free copper alloys.

4.3.6 References

ACEA et al. 2009a — ACEA/JAMA/KAMA/CLEPA/EAA/OEA et al.; Joint response document "20090804_Global AI_exe 3.pdf"

ACEA et al. 2009b — ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Insitute document "Frame Document_-Recommendation Exemption 3_FIN_.pdf"

ACEA et al. 2009b1 — ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Institute document "2_Annex 1 Comments to draft report_FIN.pdf"

ACEA et al. 2009b2 — ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Insitute document "ANNEX 2 Case studies and additional documents_ fin.pdf"

ACEA et al. 2009b3 — ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Institute document "ANNEX 3 New Report by the European Copper Institute:_The role of lead as an alloying element in copper alloys_ FIN.pdf"

Data sheets alloys 2010 — Data sheets on different alloys (own internet investigation, e.g. with Deutsches Kupferinstitut)

Oishi et al. 2007	"Development of A Lead Free Copper Alloy 'Ecobrass'"; Proceedings of the Sixth International Copper-Cobre Conference, August 25-30, Toronto, Ontario, Canada, Volume 1, Plenary, Copper and Alloy, Casting and Fabrication, Copper-Economics and Markets, J. Hugens et al., Canadian Institute of Mining, Metallurgy and Petroleum, Quebec, Canada, 2007, p. 325-340.
Sadayappan et al. 2007	"Development of New Low Lead Alloy for Plumbing Applications"; Proceedings of the Sixth International Copper-Cobre Conference, August 25-30, Toronto, Ontario, Canada, Volume 1, Plenary, Copper and Alloy, Casting and Fabrication, Copper-Economics and Markets, J. Hugens et al., Canadian Institute of Mining, Metallurgy and Petroleum, Quebec, Canada, 2007, p. 317-325.
Schrader SAS 2009	Schrader SAS and Schrader Electronics Limited joint response document "20090803_SAS response ELV consultation ex2c and 3.pdf"

4.4 Exemption no. 4b

"Lead in bearing shells und bushes for engines, transmissions and A/C compressors: 1 July 2011 [Review date: 07/2009]"

This chapter is the result of an update and review of the former evaluation results. Stakeholders have provided information in the context of the second stakeholder consultation. This information was evaluated and some further exchange took place to clarify open questions. As a result, the final recommendation below was drafted.

4.4.2 Description of exemption

In its current form, Exemption 4b includes lead used in bearing shells and bushes in engines, in transmissions and in air conditioning compressors and is due to expire on 1 July 2011. Exemption 4a exempted the use of leaded bearings in general until 1 July 2008. Spare parts remain exempted for vehicles produced before these expiry dates, respectively.

Several industry associations (ACEA, CCFA, VDA, JAMA, KAMA) submitted an identical contribution to the 2009 stakeholder consultation requesting that exemption 4b not be modified. An independent response was also received from Federal Mogul with the same request.

Originally, exemption 4 governed all leaded bearing applications and was due to expire on 1 July 2008. During the previous Annex II Revision, stakeholders supported that certain