Exemption Request Form

Date of submission: **16 January 2015**

1. Name and contact details

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2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

X Request for extension of existing exemption in

☐ Request for deletion of existing exemption in:

☐ Provision of information referring to an existing specific exemption in:

X Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: 6c

Proposed or existing wording: existing wording - "Copper alloy containing up to 4 % lead by weight"

Duration where applicable: 5 years

☐ Other: _____

We apply for renewal of this exemption for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. For these categories, the validity of this exemption may be required beyond this timeframe. Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals.

3. Summary of the exemption request / revocation request

Over the last years extensive research on lead-free alternatives to the now used leaded copper alloys has been performed. Manifold requirements have been tested for all available lead-free copper alloys. These requirements are essential for the usability of the alloys in electric and electronic equipment. The priority objectives are the properties which are required for function, safety and reliability of the equipment, but not cost issues. So far no lead-free alternative exists that is suitable to replace the now used leaded copper alloys.

Furthermore leaded brass is to nearly 100% made from recycled material. Without exemption 6c copper alloys for electric and electronic equipment could not, as it is common today, easily be made from recycled copper alloys. Thus the urban stock which is one of the most important sources for copper in Europe could not be used as it is possible today.

All together exemption 6c is required for at least further five years to enable further research on lead-free copper alloys.

4. Technical description of the exemption request / revocation request

(A) Description of the concerned application:

1. To which EEE is the exemption request/information relevant?

   Name of applications or products: _____

a. List of relevant categories: (mark more than one where applicable)

X 1	X 7
X 2	☐ 8
X 3	☐ 9
X 4	X 10
X 5	X 11
X 6	

b. Please specify if application is in use in other categories to which the exemption request does not refer: _____

   Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories. Therefore, we have not completed section 4(A)1.c. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals.

c. Please specify for equipment of category 8 and 9:

   The requested exemption will be applied in

   ☐ monitoring and control instruments in industry

   ☐ in-vitro diagnostics

   ☐ other medical devices or other monitoring and control instruments than those in industry

2. Which of the six substances is in use in the application/product?

   (Indicate more than one where applicable)

   X Pb ☐ Cd ☐ Hg ☐ Cr-VI ☐ PBB ☐ PBDE

3. Function of the substance: **examples only:** chip breaker, internal lubricant, increase of corrosion resistance, prevention of cracks

4. Content of substance in homogeneous material (%weight): up to 4%

5. Amount of substance entering the EU market annually through application for which the exemption is requested: We expect nearly no “new” lead from primary sources will enter the EU market as the alloys (especially brass) are made from recycled material.[1]

6. Name of material/component: copper alloys

7. Environmental Assessment: _____
   LCA: ☐ Yes
   ☐ No

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

Lead is used in copper alloys.

(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

See 4(A)3.

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5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

Closed loop exists. See Attachment1

2) Please indicate where relevant:

☒ Article is collected and sent without dismantling for recycling

☒ Article is collected and completely refurbished for reuse

☐ Article is collected and dismantled:

  ☐ The following parts are refurbished for use as spare parts: _____

  ☒ The following parts are subsequently recycled: items containing copper alloys

☐ Article cannot be recycled and is therefore:

  ☐ Sent for energy return

  ☐ Landfilled

[1] https://www.kupferinstitut.de/de/werkstoffe/system/recycling-kupfer.html

3) **Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:**

☐ In articles which are refurbished ______

☒ In articles which are recycled no data available on the amount______

☐ In articles which are sent for energy return ______

☐ In articles which are landfilled ______

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6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

No alternatives exist. See Attachment1.

(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

See Attachment1.

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7. Proposed actions to develop possible substitutes

(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

See Attachment1.

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

See Attachment1.

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8. Justification according to Article 5(1)(a):

(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)?

   ☐ Authorisation

   - ☐ SVHC
   - ☐ Candidate list
   - ☐ Proposal inclusion Annex XIV
   - ☐ Annex XIV

   ☐ Restriction

   - ☐ Annex XVII
   - ☐ Registry of intentions

   X Registration

2) Provide REACH-relevant information received through the supply chain.
   Name of document: _____

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?

   ☐ Yes. Consequences? _____

   X No. Justification: See Attachment1.

2. Can the substance named under 4.(A)1 be substituted?

   ☐ Yes.

   - ☐ Design changes:
   - ☐ Other materials:
   - ☐ Other substance:

   X No.

   Justification: See Attachment1.

3. Give details on the reliability of substitutes (technical data + information):
   Not given. See Attachment1.
4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to **See Attachment1**
   1) Environmental impacts: _____
   2) Health impacts: _____
   3) Consumer safety impacts: _____

⇨ Do impacts of substitution outweigh benefits thereof?
Please provide third-party verified assessment on this:

(C) Availability of substitutes: None are available. See Attachment1

a) Describe supply sources for substitutes: None

b) Have you encountered problems with the availability? Describe: Not applicable

c) Do you consider the price of the substitute to be a problem for the availability?

☐ Yes ☐ No Not applicable

d) What conditions need to be fulfilled to ensure the availability? _____

(D) Socio-economic impact of substitution:

⇨ What kind of economic effects do you consider related to substitution?

☐ Increase in direct production costs

☐ Increase in fixed costs

☐ Increase in overhead

☐ Possible social impacts within the EU

☐ Possible social impacts external to the EU

☐ Other:

No alternatives exist. Thus this question is not really applicable.

⇨ Provide sufficient evidence (third-party verified) to support your statement: _____

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

_____

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10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

None of the information is proprietary.

Attachment1[2]

Review of exemption 6c according to the prerequisites of article 5(1) of 2011/65/EU

1 Introduction

Lead is soluble in melted copper but it is unsoluble in the solid alloy. Thus lead is spread uniformly through the copper melt while it is contained in form of small nodules in the solid alloy. A consequence is during the machining process short chips are formed which strongly aids the machining process. Furthermore, lead acts as an internal lubricant due to its softness. Machining forces as well as wear of tools are reduced. This reduces the consumed energy significantly. Also a slight increase in the corrosion resistance can be achieved by adding lead to the alloys. Until now there is no other element or compound known which shows similar characteristics in copper alloys like lead.

Lead-free copper alloys have been developed. They can be divided into two categories: lead-free silicon-containing alloys as well as lead- and silicon-free alloys.

The silicon-containing alloys have already been tested concerning their usability as substitutes of the leaded alloys during the last revision of 2002/95/EC and 2000/53/EC.[3] Silicon-containing alloys are normally seen as substitutes for stainless steel and not for brass. It was shown that the silicon-containing alloys are not usable for conductive applications due to their poor conductivity. Also several other applications were named for which the silicon-containing alloys are not usable.

The second category consists of lead- and silicon-free alloys like CuZn42, CuZn40 and CuZn38As. Here lead is replaced by a higher amount of zinc. Arsenic in CuZn38As hinders the dezincification during use in drinking water applications. These alloys have not been tested intensively during the last revision of the named directives.

As the situation was not convincing ─ the lead-free, silicon-containing alloys are not suitable for most of the applications in electro- and electronics industry while for the lead- and silicon-free alloys no deep knowledge was available ─ many tests have been performed in recent years. The tests were performed either in the companies (user´s perspective) or by publicly funded university research. One company provided one engineer and one machine for one and a half years completely for tests on the lead-free alloys.

Exemption 6c has the same wording as exemption 3 of directive 2000/53/EC (ELV directive). The automotive industry and its suppliers have performed a large number of tests on the lead-free alloys. An intensive exchange between the automotive and the electro- and electronics industry was done. In both cases it is not possible to eliminate or substitute the leaded alloys.

[2] The term “lead-free“ is neither in a law nor proprietary defined. In this text “lead-free” means a homogenous material with a lead content of up to 0.1%.

[3] “Adaption to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EG (RoHS)”, Öko-Institut, Freiburg, 2010.

2 Requirements according to 2011/65/EU Article 5(1)(a)

Directive 2011/65/EU describes in article 5(1)(a) the minimum requirements for granting an exemption for basic materials or components and to take up this exemption in annex III or IV. They are:

- Elimination or substitution via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable.

- The reliability of substitutes is not ensured.

- The total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

3 Results for the first indent: elimination or substitution

Is elimination or substitution via design changes or materials and components which do not require any of the materials or substances listed in Annex II scientifically or technically impracticable?

In the guidance document of EU Commission and Öko-Institut[4] this is explained as follows:

> "A substitute material, or a substitute for the application in which the restricted substance is used, is yet to be discovered, developed and approved for use in the specific application (approval would be needed for example for the use of a substitute in medical devices)."

3.1 General considerations on the machinability index

In the report of Werkzeugmaschinenlabor of RWTH[5] Aachen, the author gives several general considerations regarding the machinability index. It is shown that the machinability index is a number that depends on considerations of four different criteria. These are chip form, wear of the tools, machining force and surface quality. These criteria are weighted differently depending on the specific processing situation.

This is a critical point from the user´s view. Depending on the specific processing situation there are differences in the appropriate weighting of the individual criteria. Thus many different and valid results for the machinability index are obtainable. One example is the lead-free alloy CuZn21Si3P (Ecobrass). In the data sheet a machinability index of 80 is given. In the report of RWTH Aachen machinability indexes of 60 to 69 are calculated depending on the weighting of the criteria. Thus it is obvious there are necessarily different results for the same alloy.

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[4] "Standard application format and guidance document for RoHS exemption requests on the basis of Article 5(8) Directive 2011/65/EU", Öko-Institut, Freiburg, 2012.

[5] Schlussbericht zum Vorhaben IGF16867N, S. 90 ff., Aachen, 2013.

Result: During planning and execution of tests at the user´s side the machinability index will be an important criterion for choosing the right alloy. But it cannot be derived from one number in a data sheet. The individual criteria have each to be weighted according to the use. The general statement “Alloy A can be substituted by alloy B because alloy B has a machinability index of X” is not correct.

3.2 Results on the machinability of lead-free alloys

Many investigations on drilling and turning of lead-free alloys have been performed. In the following the results for the investigations of the drilling of the two materials CuZn42 and CuZn21Si3P compared to the original material are shown. **Only 3%** of the required life of the drill was reached during drilling if the tests were carried out under identical conditions with lead-free instead of leaded alloys. The unfavorable behaviour was also shown by significantly higher cutting forces in the case of the lead-free alloys. The silicon-free CuZn42 and the silicon-containing CuZn21Si3P showed nearly the same behavior (Fig. 1).

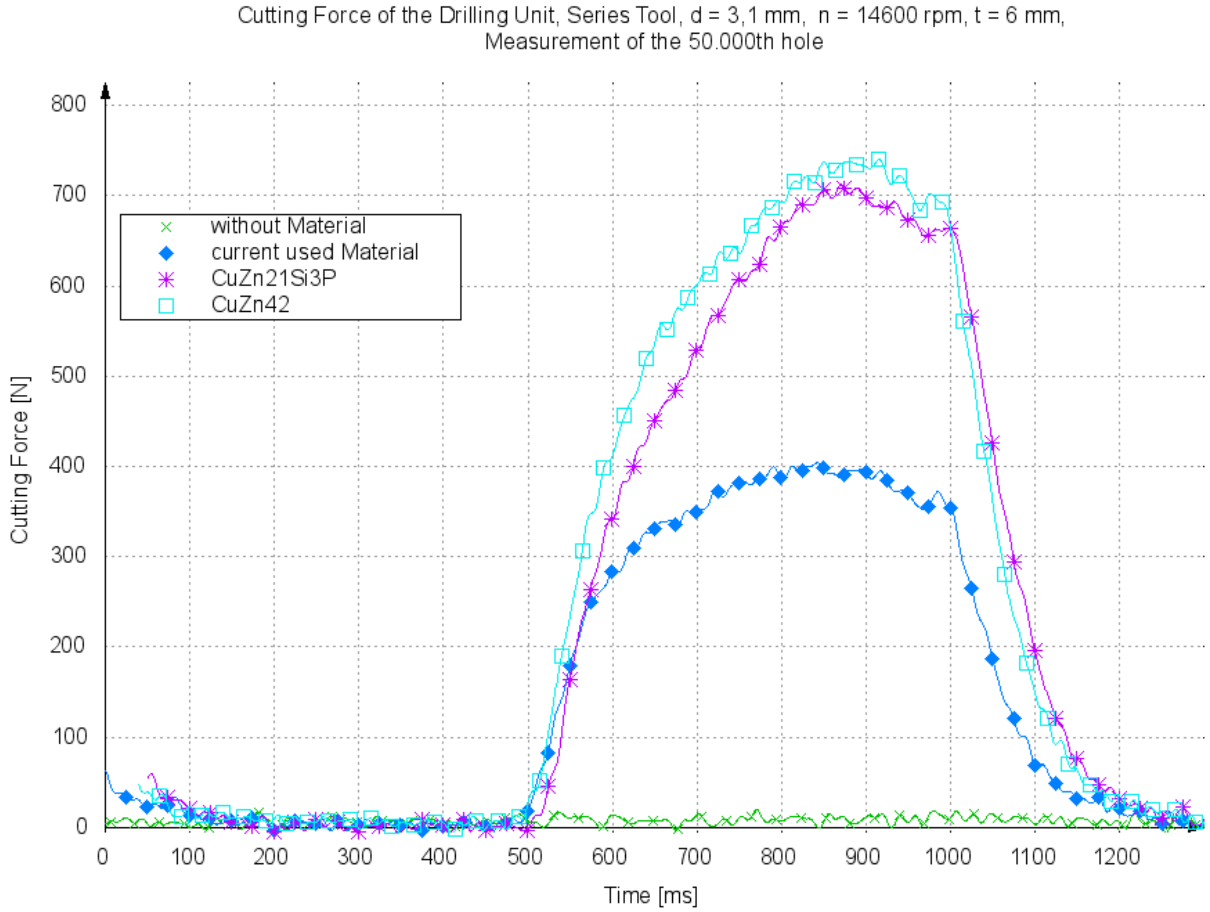

Figure 1: Comparison of cutting forces for original material (CuZn39Pb3) and lead-free alloys.

As the results of the drilling tests not being acceptable, several further drilling tools have been tested in accordance with the recommendations of the tool manufacturers. Unfortunately no combination could be found that gave an acceptable tool life.

Analogous results were obtained for thread cutting tests. Here **only 0.6%** of the required tool life was obtained. In case of using the leaded alloys the required tool life was achieved.

A large number of results on turning have been obtained in the companies and in the Werkzeugmaschinenlabor of RWTH Aachen, respectively. It was shown that due to unfavorable chip forms as well as much higher cutting forces and tool temperatures the lead-free alloys cannot be processed with the available technologies.[6,7] Several concepts for processing lead-free alloys, even including cryo-cooling, have been introduced by RWTH Aachen. However there is no industrial experience with these concepts and cryo-cooling especially seems to be less practicable.

3.4 Maximum allowed lead content of copper alloys

The most commonly used leaded alloys contain two to three percent lead if a mathematically rounding to one digit is allowed. However it must be mentioned that the lead content is normally not adjusted very precisely by the alloy manufacturer. For alloys of the type CuXXPb3, usually a lead content of 2.5-3.5% is given in the data sheets. Thus the 4% border is required as a buffer.
For Japanese copper alloys a lead content up to 3.7% is used due to the desirable recycling. In Japan in other industries (e.g. plumbing) higher lead amounts are allowed for the copper alloys, therefore a high amount of lead is allowed to enable the use of recycled copper. Furthermore there are alloys with a lead content of 4% for which no substitute is offered by the alloy manufacturers.
Thus it is not possible to reduce the maximum allowed lead content in copper alloys below 4%.

3.5 Release Tests (Approval, verification, qualification, …)

If the basic material of an electric or electronic component is replaced work-intensive proofs and releases are required. As an example, for a relatively simple component like a connector pin 1000 labour hours are required. This is especially due to safety reasons unavoidable. In more general it has to be followed that material changes cause very time consuming tests. For considerations dealing with the validity time of exemption 6c this should be taken into account.

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[6] Schlussbericht zum geförderten Vorhaben IGF 16867 N, Aaachen, 2013.

[7] C. Nobel, F. Klocke, D. Lung, S. Wolf *Procedia CIRP* (14) **2014**, 95-100.

4 Results for the second indent: reliability

Is the reliability of substitutes given?

In article 3 of 2011/65/EU and in the guidance document of EU Commission and Öko-Institute[3] this is explained as follows:

> "The probability that EEE using the substitute will perform the required function without failure for a period of time comparable to that of the application in which the original substance is in use."

For the use of materials for components of electric and electronic equipment several characteristics of the material have to be considered. These, mostly mechanical, characteristics have less influence on the processability (shown in chapter 3) while they have direct consequences on the usability and especially on the safety of the components. During the tests it was shown that the higher strength of the lead- and silicon-free alloys has adverse effects.

In general components cannot be seen as independent of their surrounding environment. Thus in any event of changing a material it has to be checked if this is compatible with the surrounding equipment. Often EEE are in scope of several regulations, e.g. EMV, LVD, machinery, etc., and of course the requirements of all these regulations have to be fulfilled. The manufacturer of such EEE is not free in the choice of the material as it has to comply with all the requirements.

4.1 Intrinsic characteristics of the alloys – RELAXATION

A high safety and reliability of electric and electronic equipment requires low failure rates of the single components as well as the related connecting technique and transmission systems. In addition to timely strength and fatigue strength especially for flexible components the relaxation behaviour of the alloy is essential.

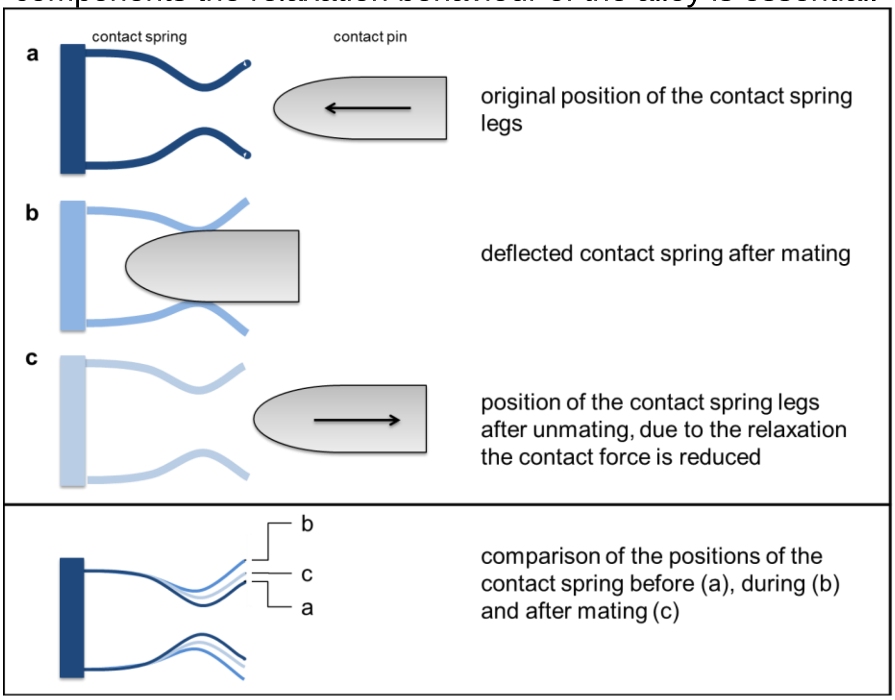

Figure 2: Reduction of the contact force due to relaxation.

Relaxation means the decrease over time of a tension under outside force. The rate of decline in tension increases with increasing temperature (Fig. 2). At constant deformation a drop in the force applied by the contact spring occurs with time. This process is known as relaxation. A phenomenon of relaxation is the slackening of springs, wherein a contact force drop occurs.
A safe contacting is ensured if the pressure $\sigma = F_N/A$ in the contact point is not below the minimum value which is given by the design. Thus under dry friction conditions (i.e. without lubricant) an impurity layer is certainly broken through. The precious metal plating and the geometry of the contacting system are given by the application and cannot be changed (examples for reasons: standards, environment, voltage, temperature, current…). In consequence the time depending variable on the contact pressure is the normal force. Thus the reliability depends on the relaxation of the spring contact over the time. Because of the relaxation caused lower contact forces F_N the constriction electrical resistance R_E of the connection increases. According to Greenwood and Williamson the dependence of the constriction resistance on the normal force is given as[8]:

$$R_E \sim F_N^{-0,9}$$

In the following figure this dependence is shown graphically (fig. 3):

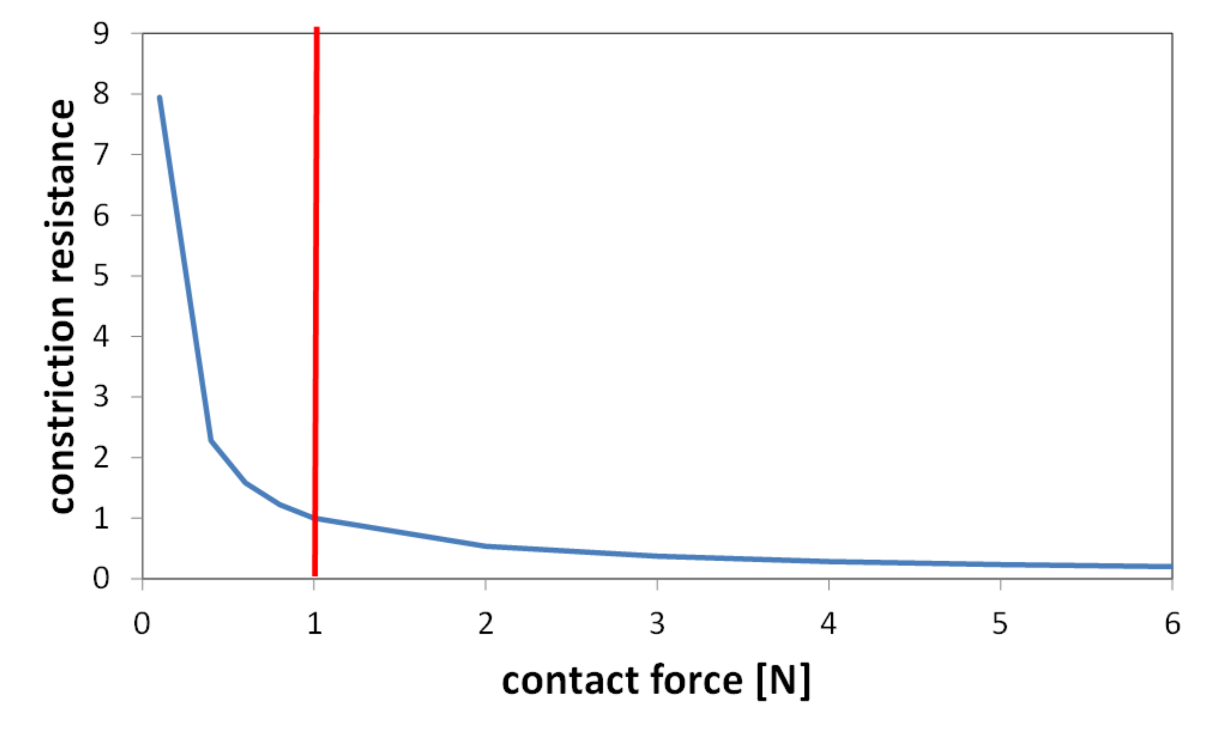

Figure 3: Constriction resistance in dependence on the contact force.

In case of decreasing contact force due to relaxation the constriction resistance of the connection increases and the current-carrying capacity is reduced. If the contact

[8] Vinaricky, E.: *Elektrische Kontakte, Werkstoffe und Anwendungen* 2. Auflage Berlin : Springer-Verlag, 2002, S. 16.

force is lower than 1 N the constriction resistance increases very fast. Because of the strongly increased electrical resistance, the connection point will be heated up (heat = current x resistance[2]). A consequence is overheating, failure and potentially fire and thus harm for people, equipment, etc.
Therefore the relaxation of new materials has to be examined very carefully. According to IEC 60512-11-9 turned standard contacts have been stored mated at elevated temperature. The spring forces have been measured before and after the temperature treatment using a contact force measuring instrument.
In a laboratory test the sample parts are stored at different temperatures and the normal force of a standard spring contact over the storage time is measured (fig. 4). According to the market requirement turned contacts must be usable at temperatures up to 125 °C. Standard contacts made from the original material CuZn39Pb3 fullfil this requirement over the complete life time (>> 5000h). The normal force of the lead-free alloy CuZn42 has already after just 100 hours storage time at 125 °C fallen below the required minimum value of 1N (red line in Fig. 4). Thus a safe contacting is not given.

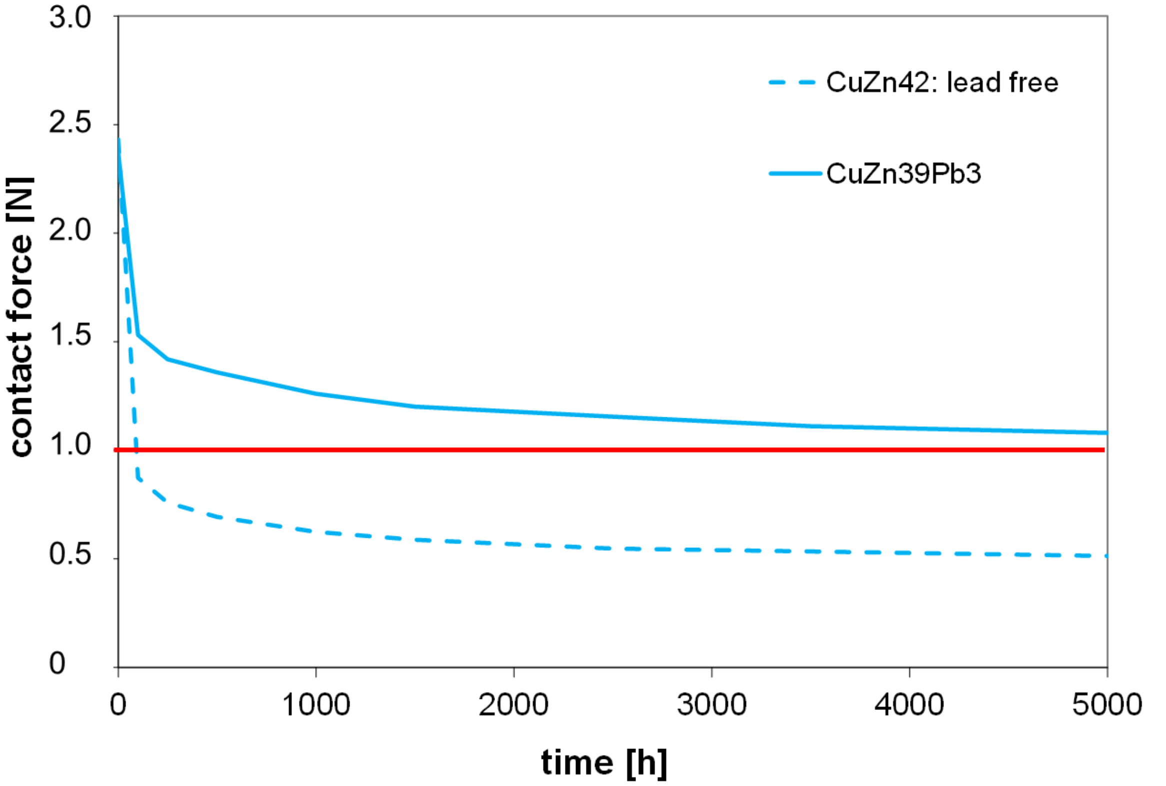

Figure 4: Contact force in relation to time at 125 °C.

4.2 Intrinsic Characteristics of the alloys – CRIMPING

Crimping is a preferred technique for the connection of a cable with a contact. This technique connects a cable with a contacting element. A stripped cable is put into a connection bore of the contact (for investigations on drilling see 3.2). The contact is then squeezed with the cable using a crimping tool. Thus the cable is connected to

the contact in a form-closed and gas tight manner. This connection has to provide a high electrical and mechanical safety over the whole lifetime.
For a permanently safe connection no cracks are allowed. A crack permits the penetration of any corrosive substances which may be present. As a consequence the resistance increases and the contact point is heated up. Thus the risk of fire or unreliability exists.
Such cracks have negative consequences on the mechanical stress of the connection too. The presence of a crack reduces the required mechanical pressure exerted on the cable. Thus the cable is more loosely held than intended. The pull-out force is below the required value as given in standards. The cable is pulled out of the contact and the connection is broken. The pulled out cable can apply power to touchable parts and thus a hazard for people is the potential consequence. Also due to the broken connection equipment, for example a motor, would fail. So a full production line can fail.

For crimp contacts, alloys with a moderate strength but with high elongation are required to avoid cracks arising during crimping. These requirements are so far not achievable with lead-free alloys owing to their inferior ductility.

Example:
A crimp contact was made from the alloy CuZn42. During the usual crimping process continuous cracks were observed (fig. 5).

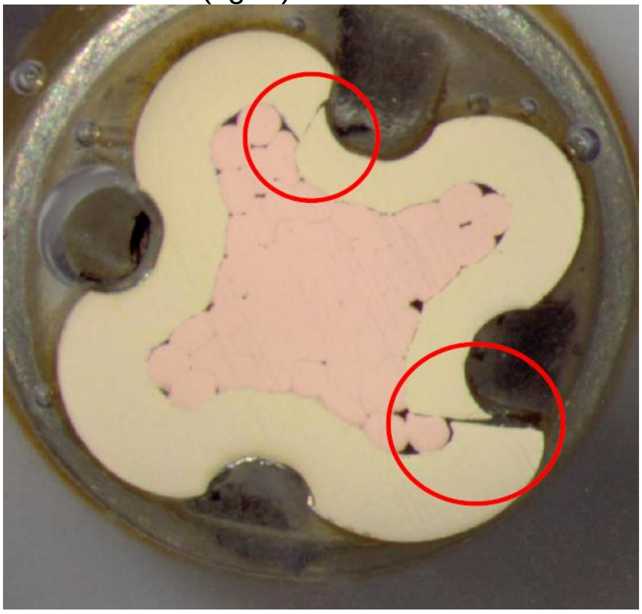

Figure 5: Crimp contact made from CuZn42 with cracks.

The pull-out force was measured as 254N. This is below the market requirement and the status of technique. For 2.5 mm^2 cable diameter the minimum required pull-out force is 310N (IEC 60352-2).

4.3 Mechanical contact between parts

In EEE, mechanical contact between parts is common for different purposes and functions. These parts may be made from the same materials (e.g. copper materials vs. copper or other metallic materials) but also from completely different materials (copper material vs. plastics). In both cases any relative movement between these parts is subject to adhesion or abrasion phenomenon and therefore to wear. In some electrical and electronic systems there is no space for fluid lubrication. Therefore to prevent unpredictable failures the system needs to be self lubricating and this is provided by lead containing copper materials. One example are small electro motors. Here a gear pinion made from brass is mechanically connected to a gear pinion made from plastic (POM). These two elements are part of the gear box. The original material of the copper gear pinion is CuZn39Pb3. It was replaced by the special brass CuZn31Mn2Si1Al1. A wear test of both combinations was conducted. With the original material the wear of the POM gear wheel is very small thus giving a high reliability of the connection. In case of the lead-free brass a much higher wear of the POM gear wheel was observed (picture 1). A SEM-screening shows a higher wear (dark deposits) on the lead-free brass pinion. This could cause a premature failure of the POM gear wheel. Thus according to the definition of 2011/65/EU the reliability of the substitute is not ensured.

Picture 1: Gear pinions made from leaded brass CuZn39Pb3 (left) and lead-free brass CuZn31Mn2Si1Al1 (right) after wear test in combination with gear wheels made from POM.

4.4 Lead-free copper alloys for use in bearings and bushings

Alternatives to lead for bearings and bushings have been thoroughly researched by individual members as well as by the bearing suppliers. Lead-free bearing and bushing technology has been developed and used for automotive and other on-road applications. However, the lead-free technology is limited in its ability to handle debris ingestion.

Engines are expected to be serviced and rebuilt to extend useful service life. Existing automotive derived lead-free bearing technology does not adequately handle debris and variations in service procedure characteristic of field service.

Industry is actively pursuing alternative lead free technologies. Work is underway to validate technologies, and where appropriate, implement solutions. This is a 3 step process. First is demonstration of suitable technology, second is application of that technology to member engine platforms and third is full validation including field testing. The last two steps, application and validation, can easily take 4-5 years for main and connecting rod bearings. If suitable technology existed today, it would be possible to have a viable alternative for 2019, however, such technology does not exist yet for engines. Without available technology today to start the multi-year development and validation process, development of reliable lead-free replacements by July 2019 seems not to be possible.

4.5 Reliability of the characteristics in case of small batches and low lead content

For the usability of materials it is essential that they have stable parameters that are independent of the specific batch and of the batch size.
For the tests at RWTH Aachen two CuZn42 alloys with 0.07% lead and 0.18% lead, respectively, were used. It was shown that this very small change in the lead content had severe effects on the characteristics of the alloys. As an example the tool temperature in case of the test with the lower leaded alloy was more than 50 °C higher than in case of the higher leaded alloy. Lead-free and low leaded alloys show (as all alloys) fluctuations in the exact composition so also in the lead content. For the original alloys this is not problematic as the relatively high lead content causes stable parameters of the alloy. In case of a very low lead content such fluctuations will have consequences on the usability and processability of the alloys. Obtaining materials with well define characteristics is critical to maintaining quality in production and high variability between batches of lead-free alloy would be problematic. Thus the reliability of the lead-free alloys is not certainly given.

The tests of one company serve to illustrate the problems experienced by industry in general. They observed a strong dependence of the parameters of the alloy on the batch size. An amount of 10 tons was ordered. Within this batch fluctuations in the strength were observed which led to wide variations in machining behaviour as show in Figure 6:

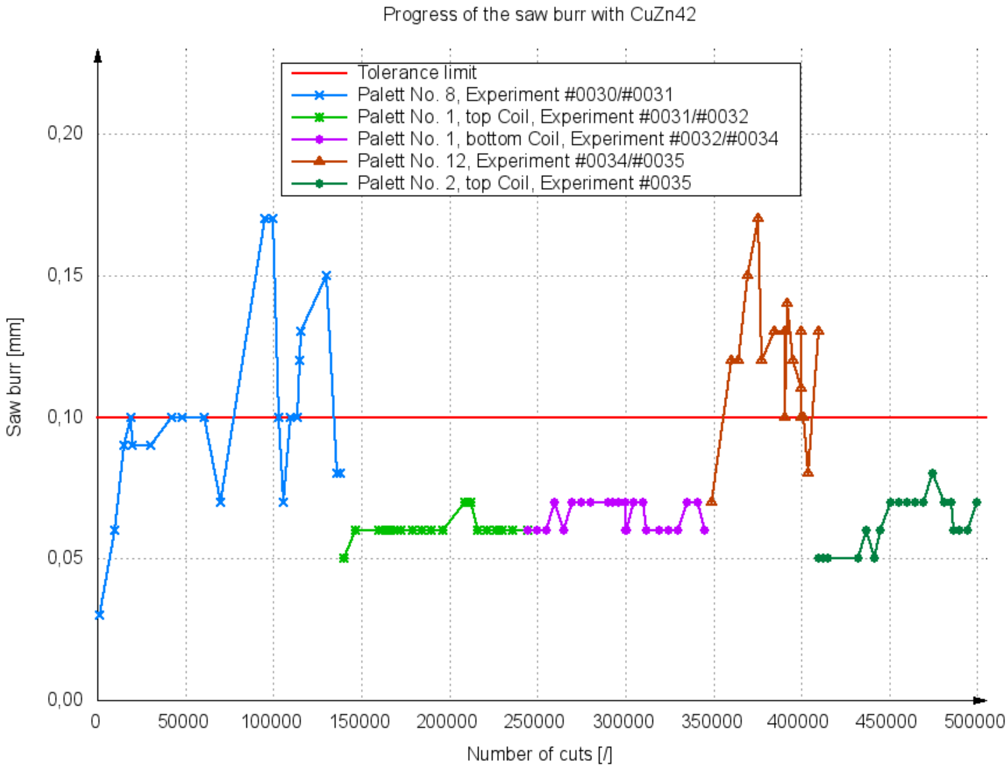

Figure 6: Different burrs for one batch of the alloy CuZn42.

In figure 6 the burr of different parts of a batch of CuZn42 is shown over the cycle number of one saw blade. For all tests the same saw blade was used. Thus the results are independent of eventual wear of the blade. It is obvious the different parts of the batch show different burrs. Manufacturing experience is that all alloys which cause burrs above 0.1 mm will not provide usable end product and so are waste. Due to the fluctuation in the material quality the processing gets unstable.

5 Results for the third indent: impacts

Are the total negative environmental, health and consumer safety impacts caused by substitution likely to outweigh the total environmental, health and consumer safety benefits thereof?

Copper and its alloys are a valuable raw material for the electro- and electronics industry. Due to the excellent electric and thermal conductivity and the relatively high corrosion resistance copper cannot be replaced for many application. Especially in countries that are not rich in raw materials like many European countries (e.g. Germany) it is essential to keep this valuable resource available. There have been rumours that copper stocks will be exhausted in 40 years. Although this is not correct[9], this fear shows the enormous importance of copper for all industries and in particular for the electro- and electronics industry. Also the copper price shows the demand of this high-tech industry. Thus the price for one ton of copper increased from 2000€ in 2002 up to more than 5000€ in 2014. In addition to the production using primary copper from ores and concentrates, production using secondary copper from waste equipment and scrap is very important. Copper completely conserves its characteristics during recycling and thus copper can be recycled an unlimited number of times. The enormous importance of recycling is also shown through legal policy in the RoHS- and WEEE- directives. Also from an economical view complete reuse of copper is the target. A copper ore with a copper content of less than one percent is seen to be profitably minable. The copper content in waste equipment and scrap is normally much higher.[10] Moreover for the production of semi-finished goods from recycled copper only 20% of the energy that is required to produce primary copper is used. Thus not only for lead-free but also for leaded copper alloys a closed loop was formed. Semi-finished goods of leaded brass are to nearly 100% made from recycled material.[11] So here lead is further applied to a very valuable use although in case the reused material was originally used for another application, e.g. drinking water or buildings.
The addition of three to four percent lead to copper alloys makes it much easier to process. One of the most prominent characteristics often named is the machinability. Thus leaded copper alloys can in several cases, e.g. components of watches, be dry machined while for lead-free alloys always a lubricant is required. The enhanced machinability also has the consequence that small impurities of the material (like other metals or non-metals) can be accepted. Thus a highly energy demanding

[9] http://www.maschinenmarkt.vogel.de/themenkanaele/konstruktion/werkstoffe/articles/451384/

[10] „Recycling von Kupferwerkstoffen“, Deutsches Kupferinsitut, Düsseldorf.

[11] http://www.kupferinstitut.de/de/werkstoffe/system/recycling-kupfer.html

purification of secondary copper would be required if it was to be used in lead-free alloys. To produce very pure copper electrolytic refining is required. Regarding the energy consumption during copper production the electrolytic process is the most significant step.[12]

There is no ecologically or economically feasible process to selectively remove lead from brass while brass is the mostly used leaded copper alloy. An high energy process of reductive and oxidative melting as well as electrolytic purification would be required. It has to be mentioned that lead cannot be removed below <0.1% by using only metallurgic processes. In addition lead would not be detoxified by removing and it will not be obtained in pure form but will be contained in the slags or it will be condensed in the filters of the plant. In case of brass not only lead but also zinc would be removed by such a process. Thus about 40% of the weight of the alloy would have to undergo a complex and highly energy demanding process for it´s reuse.

Arguments have been given that in case of deletion of exemption 6c the leaded alloys will just be sold outside the EU are completely incorrect. This is for example given due to the complexity of the supply chains. No company will accept losing the EU as biggest sales market in the world.

All together it is shown that in case of deletion of exemption 6c the copper alloys required in electric- and electronics industry will not be made from reused copper in the way as today. Thus an increase in the demand of raw materials and energy will result.

On the other hand there is a closed loop management for copper alloys from electro- and electronic equipment. As shown above during production of the equipment no lead will be released to the environment. This is also the situation during the use phase of the equipment:

Copper components in EEE are protected against contact with their surrounding environment. For example connecting elements normally show a high grade of protection like IP65 or IP67 according to IEC 60529. Also other components of EEE are protected against this contact by hoods and housings or similar technical measures. In general it is obvious that current-carrying components may not have contact with any fluid. The electric- and electronic equipment is very safe and does not cause any danger or harm to the environment.

6 Conclusions and Outlook

Intensive studies on lead-free alloys have been performed over the last years. Especially for lead- and silicon-free material not very detailed data have been available during the last consultation on 2002/95/EC in 2010. In the companies and in a public founded project at RWTH Aachen several new or adjusted concepts have been thought up and assessed.

So far no lead-free material exists that is according to the considered characteristics suitable to replace the leaded materials. Furthermore there is no approach known that had found a promising substitute for lead and no new ideas for replacing lead in copper alloys are available.

[12] “BAT Reference Document for the Non-Ferrous Metals Industries”, Joint Research Centre, 2014, p. 221.

The studies also show that the alloys have to be checked very exactly on an eventual usability for the specific applications. The usability cannot be derived from general data given in a data sheet. This is shown in chapters 3 and 4.
Also the usability of reused copper is not given for lead-free alloys.
It is not possible to limit exemption 6c to specific applications or to reduce the allowed maximum lead content below 4%.
In the next decades it cannot be expected that the leaded materials currently used can be replaceable by lead-free materials. But these years can be used for further studies on new processing techniques and concepts. Several of them are suggested by RWTH Aachen and other public founded research. Of course there are also ongoing investigations in the companies.
Thus exemption 6c is required with the current wording and is likely to be needed for longer than the maximum validity period of further five years.