Exemption Request Form - Exemption #6(c)

Date of submission: _____

1. Name and contact details

1) Name and contact details of applicant:

Company: Rosenberger Hochfrequenztechnik GmbH & Co. KG
Name: Dr. Michael Müller
Function: Manager Product Compliance
Tel.: +49 8684 18-2662
E-Mail: michael.mueller@rosenberger.com
Address: Hauptstraße 1, 83413 Fridolfing, Germany

Company: PHOENIX CONTACT GmbH & Co. KG
Name: Karina Klaes
Function: Product Compliance
Tel.: +49 5235 3-41581
E-Mail: kklaes@phoenixcontact.com
Address: Flachsmarktstraße 8,
32825 Blomberg, Germany

On behalf of the Company/Business organisations/Business associations listed below participants in the **RoHS Umbrella Industry Project ("the Umbrella Project"):**

We will be inserting in this table endorsing Associations: (i) names, (ii) EU Transparency Register IDs (where applicable) and (iii) Logos.			

2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

☒ Request for extension of existing exemption in

☐ Request for deletion of existing exemption in:

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

☒ 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: We apply for renewal of this exemption for the categories marked in section 4 further below for the respective maximum validity periods foreseen in the RoHS2 Directive, as amended. For these categories, the validity of this exemption may be required beyond those timeframes. With regard to Category 11, we request that this application is not processed earlier than the applicable latest application date foreseen in RoHS2, as amended (i.e. 18 months before the respective maximum validity periods foreseen in RoHS2).

☐ Other: _____

3. Summary of the exemption request / revocation request

Renewal of RoHS exemption 6c was last reviewed starting in 2015 resulting in Commission Delegated Directive (EU) 2018/741 that renewed the exemption until 21 July 2021. In its 2015 exemption request, the Umbrella Project explained that it expects the exemption to be required for more than five years.

After the last renewal request was sent in 2015 and still ongoing, massive research on lead free alternatives was conducted by many stakeholders including public funded research. The result of this research is that it is still mostly not possible to substitute leaded copper alloys.

Lead is by far most used in leaded copper-zinc alloys (brass). For these alloys, still two main kinds of lead-free alternatives are available: silicon-brass as CuZn21Si3P and brass with higher zinc content and without chip breaker as CuZn42, CuZn40 and CuZn37. No new type of lead-free brass became available in the last five years. In this document the findings of 2015 are checked if still valid and complemented with new findings. Results from different industries are shown.

It is shown that the available lead-free brass alloys are mostly not yet applicable for the uses of leaded brass. However, first improvements for the use of lead-free brass can be reported. Other leaded copper alloys (e.g. leaded bronze, leaded copper beryllium, leaded nickel silver) are used in smaller amounts than brass. For them no lead-free alternative could be identified.

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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)

☒ 1
☒ 2
☒ 3
☒ 4
☒ 5
☒ 6
☒ 7
☒ 8
☒ 9
☒ 10
☒ 11

b. Please specify if application is in use in other categories to which the exemption request does not refer: With regard to Category 11, we request that this application is not processed earlier than the applicable latest application date foreseen in RoHS2, as amended (i.e. 18 months before the respective maximum validity periods foreseen in RoHS2).

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)

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

3. Function of the substance: To aid machining and technical performance of parts. A non-exhaustive list of attributes which lead provides: 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. For details please refer to annex, chapter 9.
   Please supply information and calculations to support stated figure.

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 annex.

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

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
☐ 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

Available lead-free materials are CuZn21Si3P and CuZn37, CuZn40, CuZn42. Both alloy types are further discussed in the annex.

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

Please refer to the annex.

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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.

Please refer to the annex.

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

Please refer to the annex.

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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

☐ Registration

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

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. The requested exemption is therefore justified as other criteria of Art. 5(1)(a) apply.

(B) Elimination/substitution:

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

☐ Yes. Consequences? _____

☒ No. Justification: see annex.

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

☐ Yes.

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

☒ No.

Justification: see annex.

3. Give details on the reliability of substitutes (technical data + information): see annex.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to See annex
   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:

a) Describe supply sources for substitutes: _____
b) Have you encountered problems with the availability? Describe: _____
c) Do you consider the price of the substitute to be a problem for the availability?
☐ Yes ☐ No
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: _____

⇨ 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

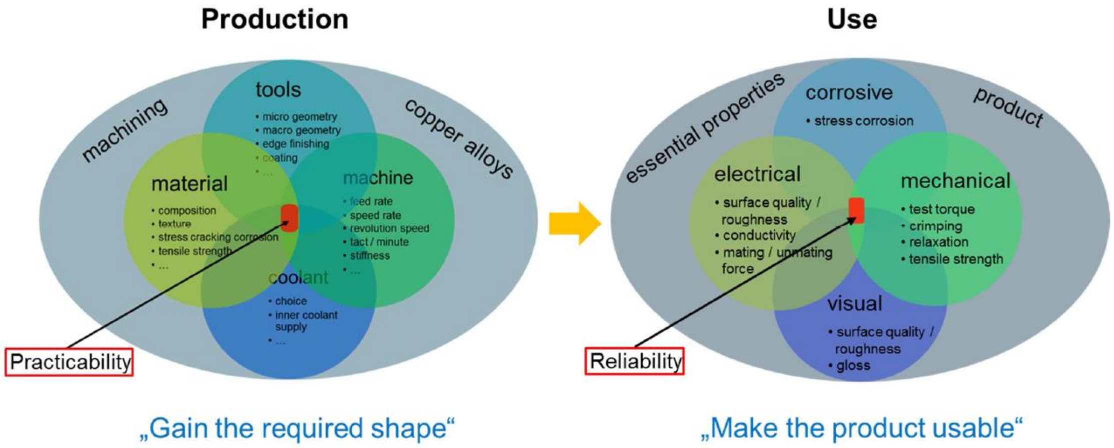
Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

None of the information is proprietary. _____

Annex

1 Introduction

Copper alloys are neither cheap nor light materials, so will only be used when needed. This short claim gives a first idea about the uses of leaded copper alloys in electrical and electronic equipment (EEE). It can be assumed that in EEE copper alloys will never be used for decorative functions but for specified uses that are often safety relevant. An overview of the different requirements is given in picture 1.



Picture 1: Requirements for copper alloys in the electrical and electronic industry.

The requirements for copper alloys can be divided into two general situations. At first, in the production step the required shape of the equipment or component must be obtained. In the further steps of the equipment´s or component´s life cycle the so produced part has to fulfil the requirements that are defined by its use.

The first situation of production refers to the first indent in RoHS Article 5(1)(a): “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 second situation of usability refers to the second indent in RoHS Article 5(1)(a): “the reliability of substitutes is not ensured”.

The third indent of RoHS Article 5(1)a (“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”) will be discussed in a separate chapter of this exemption request as it is independent of the specific use of the alloys.

Picture 1 shows the many different parameters that have to fit together to make the production of the part practicable and obtain a usable product. Some of these parameters can be influenced by the manufacturer of the part (e.g. tool, machine or lubricant) and others are defined by the use situation of the part (e.g. conductivity, relaxation, corrosion, lubricity). Some of the influenceable parameters can be changed by the manufacturer (e.g. machine settings like turning speed) while for others it is more complex as manufacturers are dependent on the portfolio of suppliers (e.g. coolant and tools). It is harder still to change the material as although this too is dependent on suppliers, there is a much narrower portfolio of possible materials and a much smaller number of possible suppliers exist. Of course, the development and production of new coolants and tools is much easier and faster than in case of copper alloys.

In the following chapters we will discuss the current technical and scientific situation of lead free copper alloys in the electrical and electronic industry. Leaded brass is the by far most used leaded copper alloy. This document will therefore focus on brass. Chapter 2 will give an overview of available lead free brass. In chapters 3 and 4 these alloys will be discussed from a more general technical and scientific point of view. Chapter 5 shows detailed results for lead-free brass without chip breaker and higher zinc content: CuZn37, CuZn40, CuZn42. In chapter 6 detailed results for lead-free silicon brass are discussed. Chapter 7 gives an overview over other leaded copper alloys. The lubricating effect of lead in copper alloys is discussed in chapter 8. Environmental impacts as well as a socio-economic analysis are subject of chapters 9 and 10. The specific situation of small and medium enterprises (SME) is examined in chapter 11. Chapter 12 shows the results of a survey taken to identify examples for successful substitutions of leaded copper alloys. In chapter 13 the findings are summarized.

2 Currently Available Lead-Free[1] Copper Alloys

The by far most used leaded copper alloy is leaded brass. Other leaded copper alloys are leaded nickel silver, leaded bronze and special alloys (see chapter 7). For leaded brass a standards survey was performed to obtain an overview of available lead free alloys.

In Europe four standards define the composition of copper alloys:

EN 12163:2016 - Copper and copper alloys - Rod for general purposes

EN 12164:2016 - Copper and copper alloys - Rod for free machining purposes

EN 12165:2016 - Copper and copper alloys - Wrought and unwrought forging stock

EN 1982:2017 - Copper and copper alloys - Ingots and castings

Tables 1-1 to 1-8 summarize the brass types defined in the four standards. Outside of Europe, alloys with other names or numbers are used which are not always identical in composition to the EN standard alloys. While the overall picture is the same in Europe and outside Europe, deviations in the chemical composition exist. Thus, the following tables give a comprehensive overview about available alloys in general. No additional families of lead free brass with completely different alloys components from outside Europe are known to us. In case an application allows only a very small deviation in the properties the regional differences in the alloys can be a hindrance.

EN 12163:2016

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
Copper-Zinc alloys	CuZn10, CuZn15, etc.				not machinable
	CuZn40	CW509L	min. max.	- 0.2	commercially available also with a lead content below 0.1% w/w
	CuZn42	CW510L	min. max.	- 0.2	
	CuZn38As	CW511L	min. max.	- 0.2	

Table 1-1: Copper-Zinc alloys according to EN 12163:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

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[1] In this document the term „lead-free“ means that the material has a lead content less or equal to 0.1% w/w and fulfils the substance requirements of RoHS Article 4 without application of an exemption.

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
complex Copper-Zinc alloys	CuZn23Al6Mn4Fe3Pb	CW704R	min. max.	0.2 0.8	
	CuZn31Si1	CW708R	min. max.	- 0.8	
	CuZn35Ni3Mn2AlPb	CW710R	min. max.	0.2 0.8	
	CuZn36Sn1Pb	CW712R	min. max.	0.2 0.6	
	Cu39Sn1	CW719R	min. max.	- 0.2	
	CuZn21Si3P	CW724R	min. max.	- 0.10	

Table 1-2: Copper-Zinc-Lead alloys according to EN 12163:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

EN 12163:2016 standardises different copper alloys (only brass is shown in tables 1-1 and 1-2). Only one of the standardised brass, CuZn21Si3P, is defined with a lead content ≤ 0.1% w/w. In addition the three alloys CuZn40, CuZn42 and CuZn38As are commercially available with a lead content ≤ 0.1% w/w.

EN 12164:2016

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
Copper-Zinc alloys	CuZn40	CW509L	min. max.	- 0.2	commercially available also with a lead content below 0.1% w/w
	CuZn42	CW510L	min. max.	- 0.2	
	CuZn38As	CW511L	min. max.	- 0.2	

Table 1-3: Copper-Zinc alloys according to EN 12164:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
Copper-Zinc-Lead alloys	CuZn36Pb3	CW603N	min. max.	2.5 3.5	
	CuZn39Pb3	CW614N	min. max.	2.5 3.5	
	CuZn40Pb2	CW617N	min. max.	1.6 2.5	
	CuZn37Pb2	CW606N	min. max.	1.6 2.5	
	CuZn38Pb2	CW608N	min. max.	1.6 2.5	
	CuZn39Pb2	CW612N	min. max.	1.6 2.5	
	CuZn35Pb1	CW600N	min. max.	0.8 1.6	
	CuZn35Pb2	CW601N	min. max.	1.6 2.5	
	CuZn37Pb1	CW605N	min. max.	0.8 1.6	
	CuZn38Pb1	CW607N	min. max.	0.8 1.6	
	CuZn39Pb0,5	CW610N	min. max.	0.2 0.8	
	CuZn39Pb1	CW611N	min. max.	0.8 1.6	
	CuZn36Pb2As	CW602N	min. max.	1.7 2.8	
	CuZn35Pb1,5AlAs	CW625N	min. max.	1.2 1.6	
	CuZn33Pb1,5AlAs	CW626N	min. max.	1.2 1.7	

Table 1-4: Copper-Zinc-Lead alloys according to EN 12164:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
complex Copper-Zinc alloys	CuZn32Pb2AsFeSi	CW709R	min.	1.5	
			max.	2.2	
	CuZn37Mn3Al2PbSi	CW713R	min.	0.2	
			max.	0.8	
	CuZn40Mn1Pb1	CW720R	min.	1.0	
			max.	2.0	
	CuZn40Mn1Pb1AlFeSn	CW721R	min.	0.8	
			max.	1.6	
	CuZn40Mn1Pb1FeSn	CW722R	min.	0.8	
			max.	1.6	
	CuZn21Si3P	CW724R	min.	-	
			max.	0.10	
	CuZn33Pb1AlSiAs	CW725R	min.	0.4	
			max.	0.9	

Table 1-5: Complex Copper-Zinc alloys according to EN 12164:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

The situation in EN 12164 is the same as in EN 12163. The only lead-free brasses are CuZn21Si3P and the alloys CuZn40, CuZn42 and CuZn38As that are commercially available also with a lead content ≤ 0.1% w/w (even though this standard permits up to 0.2% w/w).

EN 12165:2016

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
Copper-Zinc alloys	CuZn37	CW508L	min.	-	
			max.	0.1	
	CuZn40	CW509L	min.	-	commercially available also with a lead content below 0.1% w/w
			max.	0.2	
	CuZn42	CW510L	min.	-	
			max.	0.2	
	CuZn38As	CW511L	min.	-	
			max.	0.2	

Table 1-6: Copper-Zinc alloys according to EN 12165:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

	Material designation		% (mass fraction)		Remark
	Symbol	Number	Element	Pb	
Copper-Zinc-Lead alloys	CuZn36Pb2As	CW602N	min.	1.7	
			max.	2.8	
	CuZn38Pb1	CW607N	min.	0.8	
			max.	1.6	
	CuZn38Pb2	CW608N	min.	1.6	
			max.	2.5	
	CuZn39Pb0,5	CW610N	min.	0.2	
			max.	0.8	
	CuZn39Pb1	CW611N	min.	0.8	
			max.	1.6	
	CuZn39Pb2	CW612N	min.	1.6	
			max.	2.5	
	CuZn39Pb2Sn	CW613N	min.	1.6	
			max.	2.5	
	CuZn39Pb3	CW614N	min.	2.5	
			max.	3.5	
	CuZn40Pb1Al	CW616N	min.	1.0	
			max.	2.0	
	CuZn40Pb2	CW617N	min.	1.6	
			max.	2.5	
	CuZn35Pb1,5AlAs	CW625N	min.	1.2	
			max.	1.6	
	CuZn33Pb1,5AlAs	CW626N	min.	1.2	
			max.	1.7	

Table 1-7: Copper-Zinc-Lead alloys according to EN 12165:2016. Alloys with lead content ≤ 0.1% w/w are marked in green, alloys with lead content > 0.1% w/w are marked in red.

The lead-free alloys defined in EN 12165:2016 are copper, low alloyed copper, copper-nickel alloys (not shown in tables 1-7 and 1-8) and CuZn37. Copper and low alloyed copper alloys as well as copper-nickel alloys have completely different properties than brass and cannot be a promising alternative. The alloys CuZn40, CuZn42 and CuZn38As are standardised with a maximum lead content of 0.2% w/w but commercially available also with less than 0.1% of lead w/w.

EN 1982:2017

Type	Pb max. [% w/w]
CuZn15As-B (CB760S) and CuZn15As-C (CC760S)	0.5
CuZn36AlAsSb-B (CB771S) and CuZn36AlAsSb-C (CC771S)	0.2
CuZn37Al1-B (CB766S) and CuZn37Al1-C (CC766S)	0.50
CuZn38Al-B (CB767S) and CuZn38Al-C (CC767S)	0.1
CuZn42Al-B (CB773S) and CuZn42Al-C (CC773S)	0.1
CuZn33Pb2-B (CB750S) and CuZn33Pb2-C (CC750S)	3.0
CuZn33Pb2Si-B (CB751S) and CuZn33Pb2Si-C (CC751S)	2.2
CuZn35Pb2Al-B (CB752S) and CuZn35Pb2Al-C (CC752S)	2.2
CuZn36Pb-B (CB770S) and CuZn36Pb-C (CC770S)	1.6
CuZn37Pb2Ni1AlFe-B (CB753S) and CuZn37Pb2Ni1AlFe-C (CC753S)	2.50
CuZn39Pb1Al-B (CB754S) and CuZn39Pb1Al-C (CC754S)	2.5
CuZn39Pb1AlB-B (CB755S) and CuZn39Pb1AlB-C (CC755S)	1.7
CuZn39Pb1Al-B (CB757S) and CuZn39Pb1Al-C (CC757S)	1.5
CuZn36Pb1AlAsSb-B (CB772S) and CuZn36Pb1AlAsSb-C (CC772S)	1.1
CuZn16Si4-B (CB761S) and CuZn16Si4-C (CC761S)	0.8
CuZn21Si3P-B (CB768S) and CuZn21Si3P-C (CC768S)	0.1
CuZn25Al5Mn4Fe3-B (CB762S) and CuZn25Al5Mn4Fe3-C (CC762S)	0.2
CuZn32Al2Mn2Fe1-B (CB763S) and CuZn32Al2Mn2Fe1-C (CC763S)	1.5
CuZn34Mn3Al2Fe1-B (CB764) and CuZn34Mn3Al2Fe1-C (CC764)	0.3
CuZn35Mn2Al1Fe1-B (CB765S) and CuZn35Mn2Al1Fe1-B (CC765S)	0.5

Table 1-8: Maximum lead content of brasses according to EN 1982:2017.

EN 1982 identifies the same three lead-free brass alloys as the other three standards. The report from the last revision of exemption 6c from 2016[2] mainly discusses CuZn21Si3P. The applicants also showed test results for the alloy CuZn42. Both alloys are already named in the standards survey above.

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[2] Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restriction in Electrical and Electronic Equipment, Oeko Institut, 2016.

Alloys with high copper content

During the last revision of exemption 6c the alloy C18625 with 99.4% w/w copper was discussed. Also the standards survey showed several existing lead-free alloys with high copper content. Such materials have of course very positive properties but they are not a possible substitute for leaded-brass. Such nearly pure copper alloys are much softer than brass. Thus they do not show the strength required for the applications of leaded brass. In addition such alloys can usually not be machined as they would form too long chips.

Bismuth containing alloys

In the past also bismuth containing lead-free alloys were discussed. The results showed that bismuth alloyed brass is not a suitable substitute for leaded brass.[3] Also a recent publication of the German Copper Institute confirmed these findings.[4]

Not-standardised alloys

Besides the standardised alloys, several non-standardised alloys or variants of standardised alloys exist. The most prominent examples are the brasses CuZn37, CuZn40 and CuZn42, available with a lead content of less than 0.1% w/w.

Such alloys can of course show promising properties. So, while the use of not-standardised alloys is common, it makes the development of tools and machines and even more of products made from these alloys very slow. This is caused by the fact that no comparability between the alloy being tested and alloys of different manufacturers exists. High deviations in the macroscopic properties between the alloys of different manufacturers exist. As often such alloys are produced in small batches, also deviations between different batches from the same alloy manufacturer were observed. In addition a single-source situation, so when a material is available only from one supplier, is usually very problematic for a manufacturer as delivery problems or a force majeure situation could cause the collapse of a whole supply chain.

Tools and coolants are usually developed according to the properties of the material that is to be processed with and also the part that is to be produced. Thus, for non-standardised materials also no standardised tools and coolants exist. Every part manufacturer will purchase individually manufactured tools from its suppliers. The number of possible combinations of non-standardised material plus non-standardised tools and lubricants is very high making the development very slow.

Summary of Chapter 2 - Currently Available Lead-Free Copper Alloys

A standards survey on existing lead-free copper alloys with focus on lead-free brass was performed. The result is consistent with the findings in previous reviews of RoHS exemption 6c. The only standardised lead-free brass is the silicon alloyed brass CuZn21Si3P (discussed in chapters 4 and 6 of this document).

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[3] Adaption to scientific and technical progress under Directive 2002/95/EC, Oeko Institut, 2009.

[4] https://www.kupferinstitut.de/fileadmin/user_upload/kupferinstitut.de/de/Documents/Arbeitsmittel/Factsheet_Bismut_als_Bleiersatz_English.pdf

The alloys CuZn37, CuZn40 and CuZn42 are standardised with a lead content of up to 0.2% w/w. These alloys are also available with a lead content of ≤ 0.1% w/w. They are discussed in chapters 3 and 5 of this document. For all three alloys, variants with slightly different composition and technical properties exist. If recommended by material manufacturers also these alloys have been tested, mainly without significant changes in the results.

Alloys with high copper content, nearly pure copper, are not suitable substitutes for leaded brass and also bismuth containing alloys cannot be used. The development of uses of not-standardised alloys is very slow.

3 Overview: Lead-Free Brass without Chip Breaker CuZn37, CuZn40 and CuZn42

Lead-free brass of the type CuZnX (X= 37-42) is a family of alloys consisting of copper and zinc. To these alloys no additional chip breaker such as lead or silicon is added. For one alloy, CuZn38As, Arsenic is added to hinder the de-zincification of the alloy, which occurs when immersed in water. These alloys are well known and are applied in several drinking water applications. Due to very different requirements in electrical and electronic equipment, so far no use of this alloy type as substitute of leaded brass has been reported. De-zincification is usually not relevant for the electric and electronic industry. CuZn38As is not further discussed in this document as the use of highly toxic arsenic without its need would not make sense in electrical and electronic equipment.

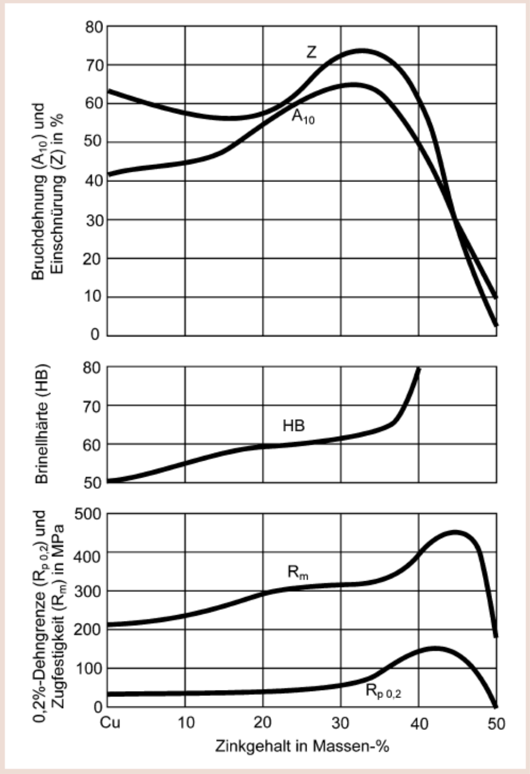
As shown in chapter 2 the three standardised alloys of this class are CuZn37, CuZn40 and CuZn42 with a lead content up to 0.2% w/w each. All three are available in variants with a lead content of less than 0.1% w/w which deviates from the maximum amount stated in the standards. General findings for these alloys are shown in this chapter and results from specific application tests can be found in chapter 5.

This alloy class does not show the low electrical conductivity of silicon alloyed brass (see chapter 4).

Brass is a mixture of copper and zinc. With increasing proportion of zinc, several properties of brass change. The colour of the alloy changes from golden red for CuZn5 until yellow for CuZn37. Until approx. 37% w/w of zinc the alloy consists of α-mixed crystals. Alloys with higher zinc content then show besides α-mixed crystals also β-mixed crystals. In the α-mixed crystals copper and zinc atoms are arranged in a face-centered cubic unit cell while β-mixed crystals form a body-centered cubic unit cell.

The β-mixed crystals cause alloys that are harder and more brittle which makes them more easily machinable. Therefore, lead- and silicon-free brass that is discussed as assumedly possible substitute of leaded brass always belongs to the brasses with high zinc content. The most prominent and usually recommended alloy is CuZn42.

The high zinc content causes several changes to the mechanical behaviour of the alloys. Picture 2 shows the elongation and hardness of brass depending on the zinc content.



Picture 2: Mechanical coefficients of copper-zinc alloys of rods in annealed condition (source: DKI[5]).

The elongation at break ("Bruchdehnung" in picture 2) describes the capacity for deformation of a material. Picture 2 (above) shows that for copper-zinc alloys, the elongation at break has its maximum at approx. 30% w/w Zn and will then strongly decrease. The hardness ("Brinellhärte" in picture 2) of the material strongly increases when a zinc content of 40% w/w is reached. Also the tensile strength ("Zugfestigkeit" in picture 2) of the material increases with the increased zinc content until a bit more than 42% w/w.

These characteristics make the material a promising candidate as possible lead free alternative but they already show the problems that can be expected:

- The higher hardness of the material causes a higher wear of tools and can cause a break of the tools (see chapter 5).
- The lower cold forming ability makes the material not suitable for crimping (chapter 5).

Further general characteristics of the alloy have been analysed by RWTH Aachen and also by ACEA[6,7].

Picture 3 shows results of a research project of RWTH[7]. The formation of short chips is essential for the machining step as long chips will damage the formed part and cause a non-stable process. The dots in the lines of the respective alloys show a combination of feed rate ("Vorschub") and cutting depth ("Schnitttiefe") at which short chips were formed. It can be observed that also for the lead free alloys it is possible to find combinations of feed rate and cutting depth that cause the formation of the desired

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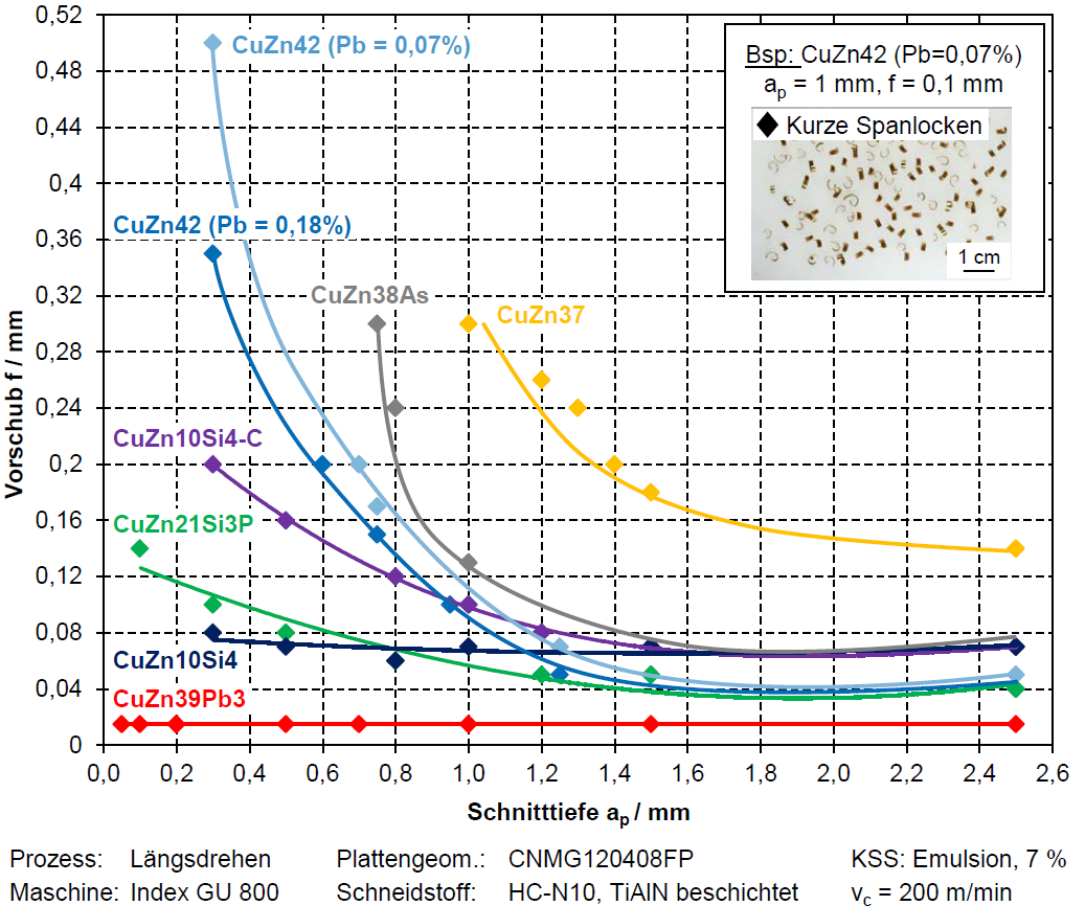
[5] Kupfer-Zink-Legierungen, Informationsdruck i.5, Deutsches Kupferinstitut, **2007**.

[6] 8th Adaptation of ELV Annex II, Submission of ACEA, CLEPA, JAMA, KAMA et al. to the stakeholder consultation, **2014**. And complementing documents. Available at: https://elv.exemptions.oeko.info/index.php?id=60

[7] Schlussbericht zum geförderten Vorhaben IGF 16867 N, **2013**.

short chips, but the comparison with CuZn39Pb3 shows that the situation is much more complex and unstable for the lead-free and silicon-free alloys. While for CuZn39Pb3 with a low feed rate for different, also low cutting depths, short chips are formed, this is not the case for CuZn42. Here either very high feed rates or high cutting depths have to be chosen. Chapter 5 shows that it was not yet possible to find a tool (cutting insert) that is able to withstand these conditions. For CuZn21Si3P (see chapters 4 and 6) the possible combinations of feed rate and cutting depth are more similar to CuZn39Pb3 but the problems with tool wear and tool breakage are even more severe (see chapters 4 and 6).

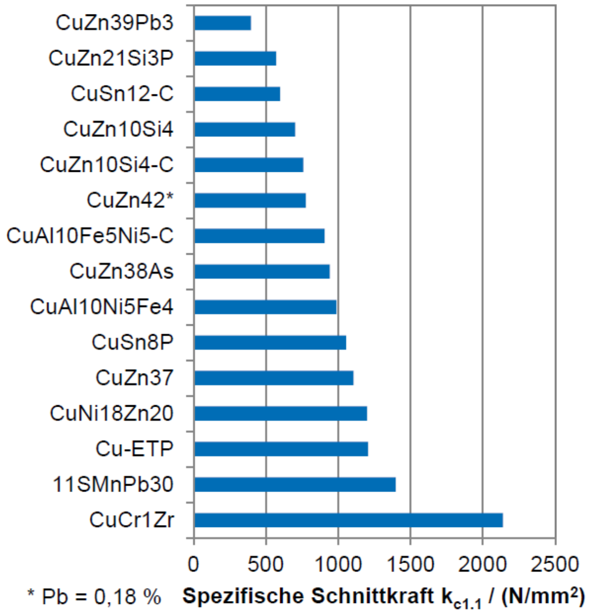


Picture 3: Chip formation when turning brass (source: RWTH Aachen[7]).

It has to be noted that these findings are valid only for the combination of one specific tool (cutting insert) and coolant. The small difference in the lead amount of the two different CuZn42 alloys (0.07% w/w vs. 0.18% w/w) causes a quite different behaviour.

It is observed that four parameters work together to find a combination that forms short chips: feed rate, cutting depth, cutting insert and coolant. Actually, for the cutting insert its geometry, basic material and surface plating are relevant. This shows that a high number of possible combinations exist that have to be checked by a part manufacturer on its own (as discussed in chapter 2).

The research of RWTH Aachen[7] gives data about the specific cutting forces of CuZn39Pb3 compared to lead free alloys. The specific cutting force $k_{c1.1}$ is the force that is required to cut out a chip with a width and depth of 1 mm each. Picture 4 shows the results for the different alloys. It can be observed that for CuZn42 nearly the double cutting force is required compared to CuZn39Pb3.



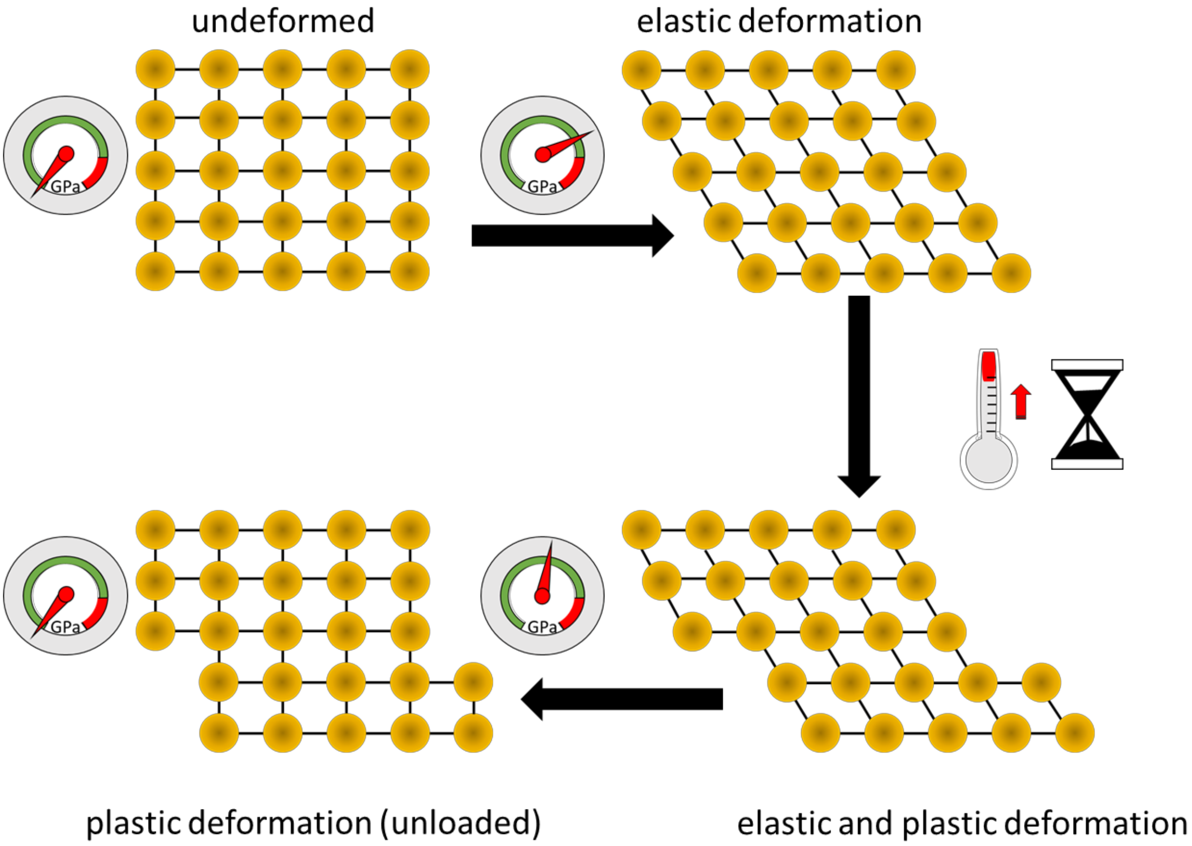
Picture 4: Specific cutting for of different copper alloys (source: RWTH Aachen[7]).

It has to be noted that only the CuZn42 batch with 0.18% w/w lead was tested that would not fulfil the substance requirements of RoHS. For CuZn42 with a lead content < 0.1% w/w an even higher cutting force can be expected.

The machinability index is given in the data sheets as 50 – 70 % depending on the lead content (Table 3 on page 26). This corresponds to the findings above.

In the 2015 renewal application we reported about the stress relaxation of CuZn42. Picture 5 illustrates the process. Stress relaxation means the drop of stress of an elastically loaded material depending on time and temperature. Over time, the elastic deformation is turned into a plastic deformation of the same order. The reason for relaxation is that the system will reach its thermodynamic and mechanical equilibrium. After an external load the material will relieve the newly formed internal tension via the moving of dislocations and the diffusion of atoms.

The magnitude of relaxation is determined by the external load and the thermodynamic disequilibrium of the sample and its environment. If a sample is considered independently of the test device the initially introduced load will always partially result in plastic elongation.



Picture 5: Stress relaxation results in plastic deformation.

While some basics of stress relaxation are understood as shown above, so far it is unfortunately not possible to quantitatively predict the magnitude of stress relaxation for different materials. Further details of findings are given in chapter 5.

Summary of Chapter 3

Brass is an alloy of copper and zinc. With increased zinc content above 37% w/w besides the α-phase also a β-phase is formed. This makes the material harder and more brittle and thus enhances the machinability. The disadvantages of this material are more complex machining requirements and less favourable cold forming behaviour. The stress relaxation of CuZn42 is caused by the transformation of elastic deformation into plastic deformation.

4 Overview: Lead-Free Silicon-Brass CuZn21Si3P

Under RoHS exemption 6c the most discussed lead-free alloy is CuZn21SiP3, so called Ecobrass. The last report of the consultant from the review of the exemption in 2016[2] discusses nearly exclusively this alloy as possible lead free alternative. Indeed, CuZn21Si3P has very promising properties, but usually it is seen as alternative to stainless steel instead of leaded brass[8]. Even though this alloy is also made

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[8] J.-M. Welter: Leaded copper alloys for automotive applications: a scrutiny, p. 21.

of copper and zinc and can thus be considered as brass, it has quite different properties to leaded free machining brass. Table 2 compares the electrical and thermal conductivity of CuZn39Pb3 and CuZn21Si3P.

	CuZn39Pb3	**CuZn21Si3P**	**CuZn39Pb3 : CuZn21Si3P**
Electrical conductivity	15 MS/m	4.5 MS/m	3.3 : 1
Thermal conductivity	123 W/(m•K)	35 W/(m•K)	3.5 : 1

Table 2: Comparison of the electrical and thermal conductivity of CuZn39Pb3 and CuZn21Si3P.

The electrical and thermal conductivity of CuZn21Si3P are much lower than of CuZn39Pb3 and these two parameters are too low for applications that are electrical or thermal conductors. In electrical and electronic equipment these are the majority of applications of leaded copper alloys.

One obvious example for these is welding equipment whose welding output circuit has to conduct hundreds of amperes, but also for all electrical and electronic connectors (power, data and signal connectors) the electrical and thermal conductivity would be too low (see chapter 6.2 for detailed findings).

While for brass without lead and silicon as discussed in chapters 3 and 5 a mixing of chips with other brass types, e.g. leaded brass, is usually possible, this is not the case for silicon brass. The presence of silicon in the alloy causes the formation of a silicon rich κ-phase as well as an intermetallic γ-phase. Next to this iron and manganese silicides are formed. While the formation of such hard particles is beneficial for the properties of silicon brass it causes the situation that the silicon containing chips may not be mixed with other chips as for other alloys this behaviour of silicon would be problematic. Thus, in case silicon brass is used by a company it has to setup up a second chip circle for silicon brass chips and ensure that no mixture of them with silicon-free chips occurs to enable both alloys to be recycled. As a mixture they would be landfilled. Further details are explained in chapter 9.

The machinability of CuZn21Si3P is named by Mitsubishi Shindoh as 70 – 75% calculated from the reciprocal cutting force[9]. For CuZn42 the machinability is given as 50 – 70 % depending on the lead content[10]. Table 3 compares the machinability indices of the materials:

	Pb [% w/w]	**Machinability [%]**
CuZn39Pb3	2.5 – 3.5	100
CuZn21Si3P	< 0.09	70 – 75
CuZn42	0.2	70
CuZn42	max. 0.1	60
CuZn42	max. 0.009	50

Table 3: Machinability of CuZn21Si3P compared to CuZn39Pb3 and different types of CuZn42.

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[9] https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Exemption_6c__2015-10-mitsubishi-shindoh-rohs.pdf

[10] https://www.wieland-smh.de/files/shared_com/media/de/datenblaetter/datenblaetter_z/m57.pdf

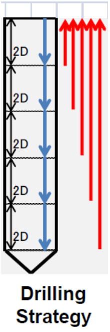
https://www.wieland.com/files/downloads/media/de/datenblaetter/datenblaetter_z/m58.pdf

https://www.wieland.com/files/downloads/media/de/datenblaetter/datenblaetter_z/m59.pdf

In the renewal application of 2015 we already explained that the machinability index is more of a kind of fingerprint than a fixed material constant[11]. The machinability index depends on four criteria and depending on the weighting of these criteria (which depends on the application) different values are obtained. The report of RWTH Aachen[7] calculated a machinability index of CuZn21Si3P as 60 – 69 %. Taking this into account it can be followed that the machinability of CuZn21Si3P should be slightly favourable compared to CuZn42 (max. 0.1% w/w Pb) but both are far from the machinability of leaded brass CuZn39Pb3.

Drilling

Mitsubishi Shindoh reports about the drilling of CuZn21Si3P[9]. A 1.0 x 10 mm bore was to be drilled. This is a common requirement for electrical and electronic equipment that is not linked to the size of the part as also big parts can require small bores. A five steps drilling strategy was applied (picture 6) which means that the hole is not formed in one step but a fifth of the bore is formed then the drill is lifted and this action is repeated five times. With a drill with internal cooling it was possible to drill 1000 bores in a one-step procedure.



Picture 6: Five- steps drilling (Source: Mitsubishi-Shindoh[9]).

We do not think that a 5 steps drilling is a practicable strategy as already explained in the RWTH Aachen report about drilling[12]. As explained in this report, the requirement is a one step drilling with 1.000.000 bores before the drill has to be changed. The Aachen report gives several good results and hints for improving the drilling of CuZn21Si3P. This report only reports a maximum number of 25.000 bores for one drill. After this the experiment was stopped. Although only low wear of the bore was observed after the experiment, as the numbers of required bores (1.000.000) and experimentally achieved bores (25.000) differs so much, it is not possible to conclude from it. All together the findings of Mitsubishi Shindoh and RWTH Aachen are promising but they do not yet show a possibility of drilling CuZn21Si3P as required.

Pressure equipment and Pipelines

Directive 2014/68/EU defines basic requirements for pressure equipment. The German “Rohrfernleitungsverordnung” defines requirements for pipelines. In Germany for both the “AD 2000-

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[11] https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Phoenix/6c_RoHS_Exemption_6c_Renewal_Dossier_16_JAN_2015.pdf

[12] Schlussbericht zu dem IGF-Vorhaben 17953 N, Aachen, 2016.

Merkblatt W6/2" applies. It defines copper alloys that may be used in such applications. Several alloys are allowed for such use. Besides the leaded brass CuZn39Pb3 also the low-lead brass CuZn40 is listed. But CuZn21Si3P is not contained in this "Merkblatt" and also no other silicon-brass alloys are named there. Therefore, these alloys may not be used in applications for which the "AD 2000-Merkblatt W6/2" applies.

Summary of chapter 4

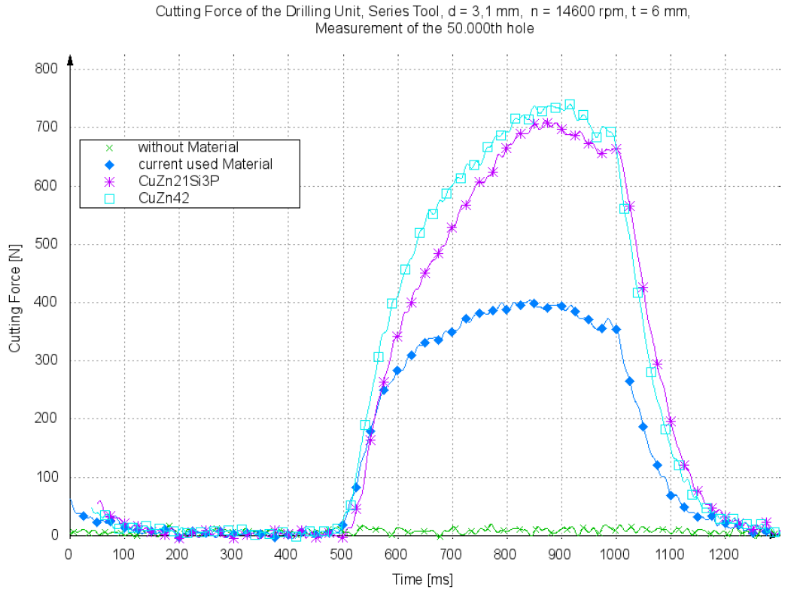
CuZn21Si3P is the mostly discussed lead-free brass under RoHS exemption 6c. Its thermal and electrical conductivity is approx. 1/3 of that of leaded brass making the material not suitable for electrical and thermal conductors. For drilling of small bores a practicable solution has not yet been found. For different applications covered by Directive 2014/68/EU (pressure equipment) CuZn21Si3P may not be used in Germany.

5 Technical Results: Lead-Free Brass without Chip Breaker: CuZn37, CuZn40 and CuZn42

5.1 Practicability of the Substitution of Leaded Copper Alloys by CuZn42

5.1.1 Results reported in 2015

The alloy CuZn42 was already discussed in the last review 2015-2018. Drilling tests by one manufacturer showed that with the standard equipment only 3% of the required tool life time were achieved. A thread cutting test showed even worse results with only 0.6% of the required tool life. The findings can be explained by the much higher cutting forces of CuZn42 and CuZn21Si3P compared to CuZn39Pb3 ("current used Material" in picture 7). Both findings are consistent with the overview of the materials given in chapters 3 and 4.



Picture 7: Cutting forces of CuZn39Pb3 (= "current used Material") compared to CuZn42 and CuZn21Si3P.

5.1.2 Results obtained since 2015

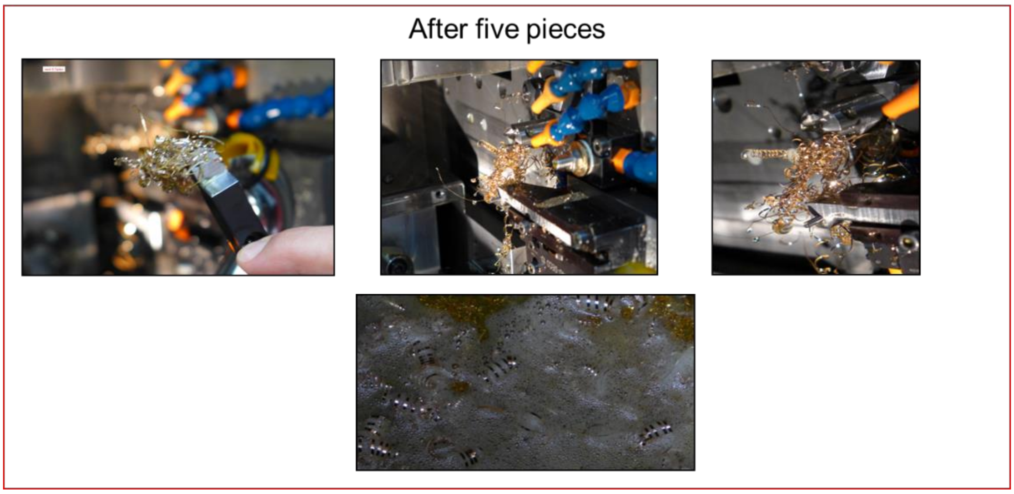
Machining tests of one manufacturer show the behaviour of CuZn42 when it is machined with standard equipment. This means a standard cutting insert that is also used for the machining of leaded brass was first tested and also the standard machine parameters were applied. Picture 7 shows the results of this approach. Already after the first piece long chips were formed. After only five pieces a ball of long chips was formed that winded around the tool and the produced part (picture 8). No further investigation with these parameters was performed as a success could not be expected. These findings are in line with those from RWTH Aachen that were reported in chapter 3.

After one piece

After five pieces

Picture 8: Machining of CuZn42 with standard geometries and machine parameters.

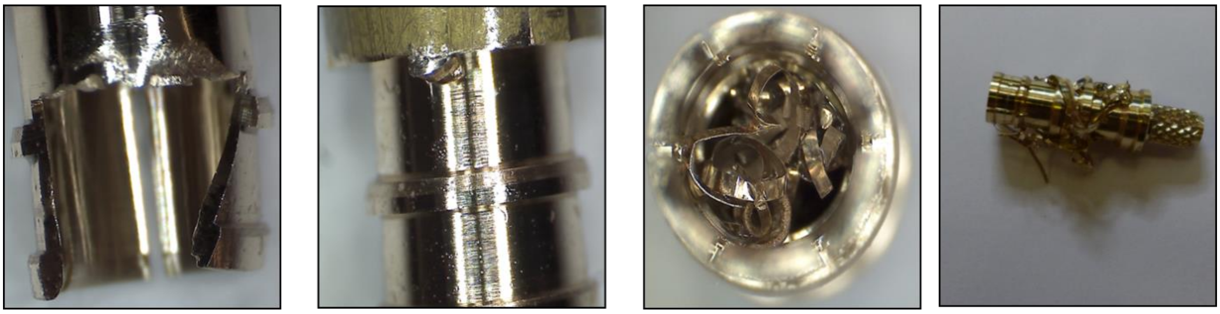
To improve the results, the rotation speed was reduced and the feed rate was increased. The result was a better breaking of the chips but even this is far away from enabling process reliability (picture 9). A further increase in the feed rate is not possible with the existing machine/tool combination of this manufacturer. This result shows that an increase in the feed rate improves the chip form. It was unfortunately not possible to reproduce the results of RWTH Aachen as the present machine/tool combination does not allow the very high feed rates. While we think the results of RWTH Aachen are correct, they could not be put into practice by the manufacturer. This will be the same situation with the equipment available to other manufacturers.



Picture 9: Machining of CuZn42 with improved machine parameters.

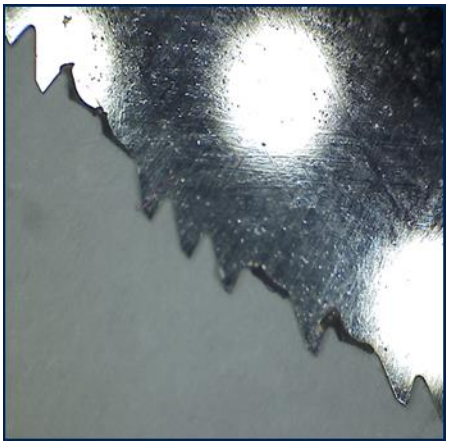
Furthermore after 50 pieces and after 500 pieces the tool broke. This result is in line with the findings of 2015 that reported a very short tool life in case of drilling and thread cutting.

Picture 10 shows examples of failure parts made from CuZn42 with standard tools and machining parameters as well as with improved parameters. The two pictures on the left of picture 10 show a crack and a damage of the part. The much higher cutting forces compared to CuZn39Pb3 are a possible reason for this. The two pictures on the right show the situation that chips were moved either in the cavity of the part (second from right) or turned around the part. Both situations lead to failures as the parts will undergo different further steps after turning, e.g. electroplating, and there is no chance to remove the chips from the serially produced parts.



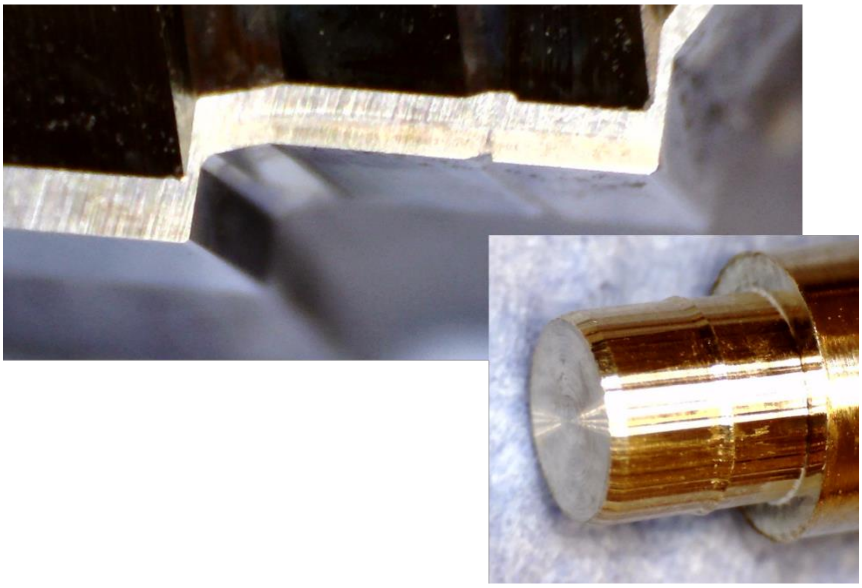
Picture 10: Examples for failure parts made from CuZn42.

Picture 11 shows a saw blade that was used to produce 1000 parts from CuZn42. It can be seen that already after this very low number of pieces the blade cannot be used anymore as some teeth broke.



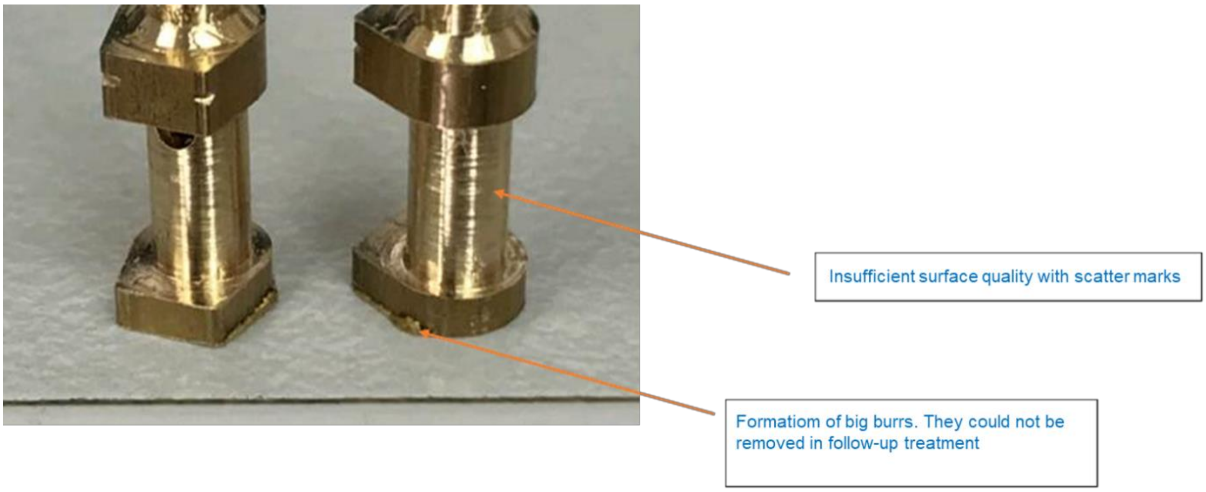
Picture 11: A saw blade with broken teeth after producing 1000 parts from CuZn42.

As it was clear that with the standard tools it is not possible to produce parts from CuZn42, special tools were obtained via a cooperation between the tool manufacturer and the part manufacturer. By using tools with chip breaker a more positive chip forming behaviour could be achieved but unacceptable chatter marks occurred (picture 12). So far no solution has been found to avoid the formation of chatter marks.



Picture 12: The use of special tools with chip breaker caused the formation of chatter marks.

This result was also reported by another manufacturer (Picture 13): with standard tools a not acceptable chip-form was obtained. With special tools more favourable chip-forms were obtained but chatter marks were formed. Also big burrs were formed and it was not possible to remove them in the follow-up treatment.



Insufficient surface quality with scatter marks

Formatiom of big burrs. They could not be removed in follow-up treatment

Picture 13: Two parts made from CuZn42 with special tools: chatter marks and big burrs formed.

Regarding manufacturer specific tools the situation is the same as for non-standardised alloys described in chapter 2. While it is of course worth and necessary to do research on manufacturer specific tools, it should be kept in mind that such development is extremely slow as every manufacturer does research completely on its own and cannot derive information from generally available knowledge as standardisation, public founded or academic research.

As can be seen in the pictures above the respective part that was tested also contains a knurl (picture 14). When pressing the knurl it was shown that a very poor quality with big edges was derived that would cut the finger of a user. Even more severe is the formation of very thin parts that can break fast. Such risk cannot be accepted in electrical and electronic equipment as the loose parts can get into other parts of the EEE and can cause damages, e.g. by short-circuits. So far no possibility was found to press this knurl in sufficient quality.

Picture 14: A knurl made from CuZn42 with sharp edges and broken material.

5.2 Reliability of the Substitution of Leaded Copper Alloys by CuZn42

5.2.1 Results reported in 2015

Stress Relaxation

During the last review of exemption 6c the stress relaxation behaviour of the material CuZn42 was discussed[11]. As this is a material constant there are no changes in the findings. CuZn42 can therefore still not be used for applications that require low relaxation of the material. These are all applications where a part has to press over a long time on another with a minimum force, especially at increased temperature. Examples are different kinds of electrical connections like contact sockets, spring contacts, etc..

Crimping

In 2015 it was reported that CuZn42 cracked during crimping at one manufacturer[11]. The crimping technology was explained as follows:

"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 […]. 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 an electric shock hazard for people is the potential consequence. Also due to the broken connection equipment, for example a motor, would fail, so that a full production line, for example, can fail."

5.2.2 Results obtained after 2015

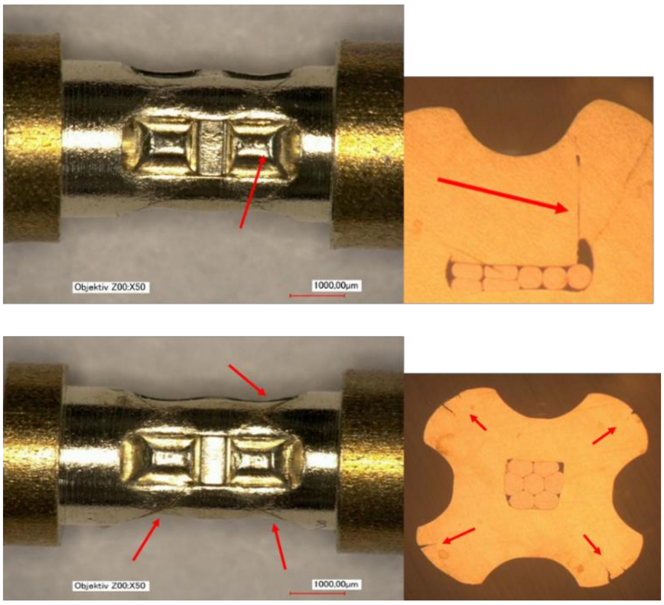
Stress Relaxation

As shown in chapters 3 and 5.2.1 the relaxation behaviour under stress is a material constant. It is not possible to overcome this by technical measures. Thus, it is not possible to use this material for applications where stress relaxation may not be too high.

Crimping

As crimping is a widely applied technology, tests with CuZn42 were performed by several manufacturers. All manufacturers that reported results of crimping tests of CuZn42 reported that they got the same result that the material cracked while crimping. Already in chapter 3 it was explained that the formation of β-mixed crystals due to the higher zinc content is advantageous for the machining of the material but disadvantageous for the cold forming behaviour. Picture 15 illustrates the situation. Upper images: A crimp connection shows cracks from the conductor until the edge of the connection;

lower images: in addition also at the outside surface cracks exist at all four edges. As explained, this result cannot be accepted.



Picture 15: A crimp connection of CuZn42 with cracks.

Summary of chapter 5

It was reported in 2015 that no solution for drilling small bores in CuZn42 was found. Several research regarding turning of the material was performed in the last years. With standard tools it was not possible to turn the material. The use of special tools allowed a better chip formation but caused unacceptable chatter marks.

The findings of 2015 regarding stress relaxation remain valid and make CuZn42 not usable for applications that require low relaxation. It is still not possible to crimp contacts made of CuZn42.

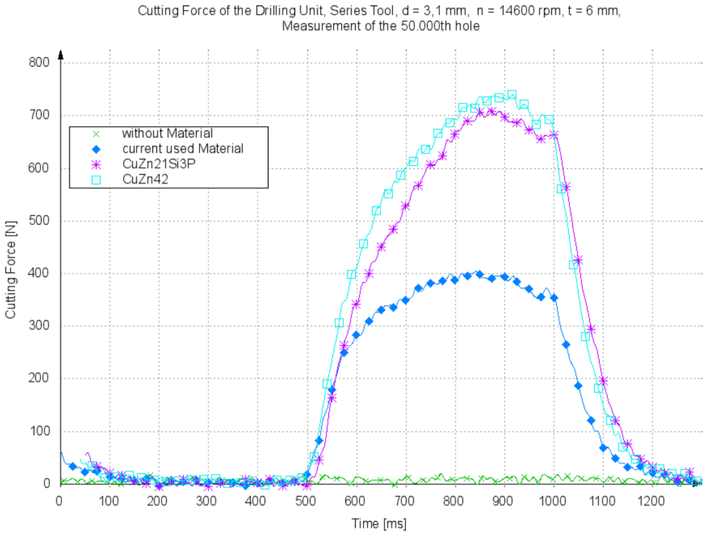
6 Technical Results: Lead-Free Silicon-Brass CuZn21Si3P

The electrical and thermal conductivity of Si-alloyed brass is much lower than in case of leaded brass. For example the electrical conductivity of the most prominent Si-brass CuZnXSiY (Ecobrass®) is only one third of the electrical conductivity of standard leaded brass CuZn39Pb3. Si-brass is therefore not a possible substitute for applications that require thermal or electrical conductivity. Due to this behaviour Si-brass is usually seen as substitute of stainless steel but is not a common substitute of leaded brass.

6.1 Practicability of the Substitution of Leaded Copper Alloys by CuZnXSiY (e.g. CuZn21Si3P, so called Ecobrass®)

6.1.1 Results reported in 2015

The alloy CuZn42 was already discussed in the last review 2015-2018. Drilling tests by one manufacturer showed that with the standard equipment only 3% of the required tool life time were achieved. Thread cutting test showed even worse results with only 0.6% of the required tool life. The findings can be explained by the much higher cutting forces of CuZn42 and CuZn21Si3P compared to CuZn39Pb3 (“current used Material” in picture 7). Both findings are consistent with the overview of the materials given in chapters 3 and 4.

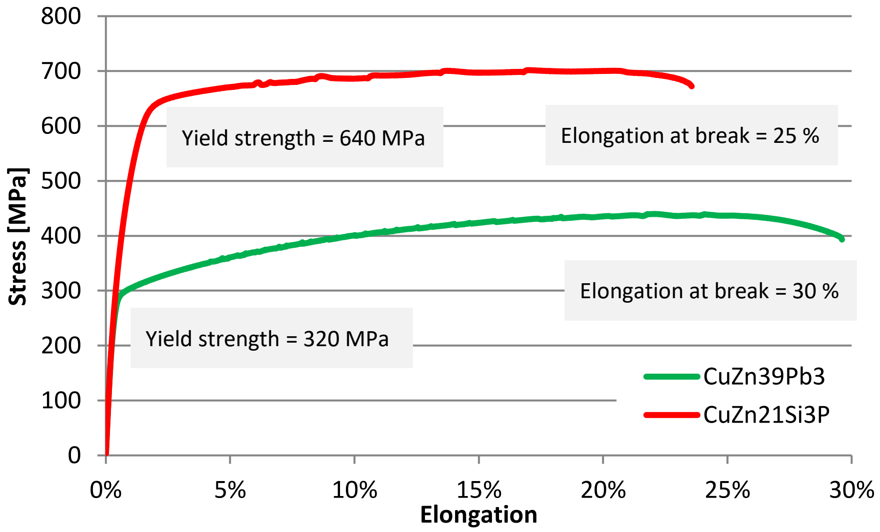


Picture 7: Cutting forces of CuZn39Pb3 (= “current used Material”) compared to CuZn42 and CuZn21Si3P.

6.1.2 Results obtained since 2015

Mechanical Properties

Like its electrical properties, the mechanical properties of CuZn21Si3P are more similar to stainless steel than to leaded brasses like CuZn39Pb. Especially, yield strength and elongation at break are significantly different when comparing CuZn21Si3P to leaded brass (picture 16).



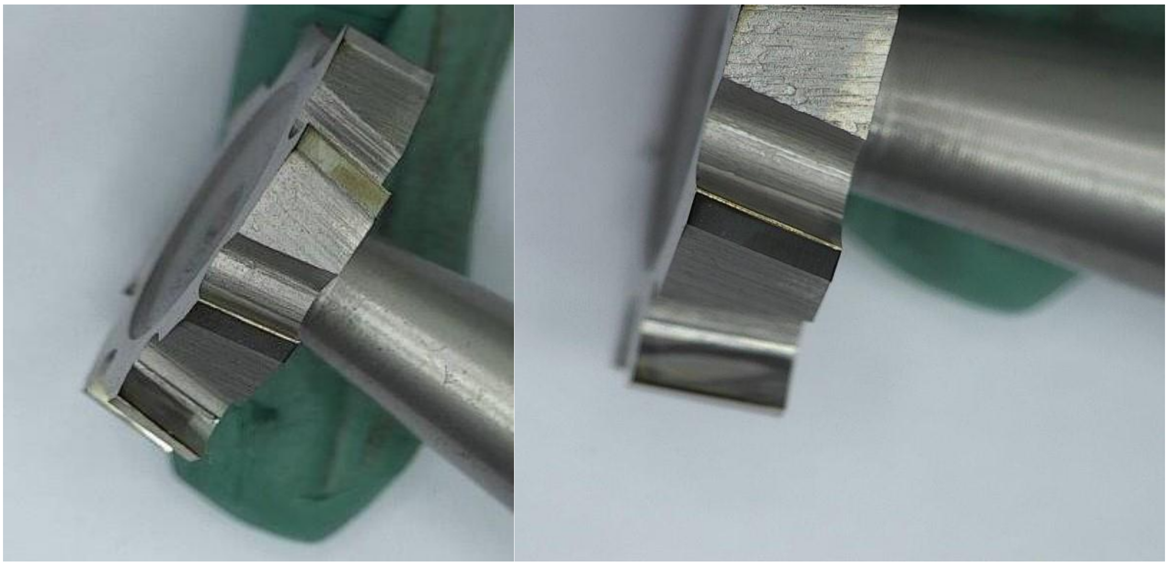
Picture 16: Stress vs. strain diagram obtained by tensile testing of rods with 15 mm diameter.

The yield point is the point on a stress versus strain curve that indicates the limit of elastic behaviour and the beginning of plastic behaviour. Yield strength is the material property defined as the stress at which a material begins to deform plastically. It is the fundamental material property for all chip-less forming techniques such as rolling, pressing, bending or knurling. High yield strength, as shown by CuZn21Si3P, is inherently coupled with difficult cold forming and increased tool wear. Hence, cold forming techniques like knurling lead to similar extremely rough and unusable surfaces as occur with CuZn42, as shown above and below (see pictures 14 and 18). Also other important cold forming techniques like crimping are usually not possible with this material due to the silicon rich κ-phase, which causes brittleness in the microstructure.

Elongation at break measures how much bending and shaping a material can withstand without breaking. The measured elongation at break value is an indication of the material's ductility. CuZn2Si3P shows typically 5 to 15 % less elongation compared to CuZn39Pb3, meaning it withstands less deformation and breaks earlier. This behaviour increases the risk of unnoticed cracks in chip-less formed parts and may compromise product safety.

The inferior elongation at break makes certain geometries impossible to form with CuZn21Si3P as the material doesn't deform enough before it cracks. Subsequently, this renders a substitution of leaded brass impossible for parts which are bended or crimped.

As explained in chapter 4 CuZn21Si3P is much harder than CuZn39Pb3. As expected this causes a much higher wear of the tools. Picture 17 shows the abrasion on a slitting cutter after machining CuZn21Si3P. Wear tests have shown an approx. twice as high wear and thus a halved service life in comparison to leaded machining brass (e.g. CuZn39Pb3). In addition, high temperatures develop during machining CuZn21Si3P, which in turn prevent precise machining.



Picture 17: Abrasion of a slitting cutter after machining CuZn21Si3P alloy.

6.2 Reliability of the Substitution of Leaded Copper Alloys by CuZnXSiY (e.g. CuZn21Si3P, so called Ecobrass®)

Knurl

Pressing of a knurl was tested with CuZn21Si3P compared to CuZn39Pb3. As explained in chapters 4 and 6.1.1. the applicability of cold forming techniques to CuZn21Si3P is reduced compared to CuZn39Pb3. The knurls formed in CuZn21Si3P could not be accepted (picture 18). Besides sharp edges, loose and easy to break particle were formed. As explained in chapter 5.1.2 this cannot be accepted as loose particles are a safety risk, they can cause short-circuits. This finding was also reported by other manufacturers.

Picture 18: A knurl pressed from CuZn39Pb3 (left) and two knurls pressed in CuZn21Si3P with loose particles (right).

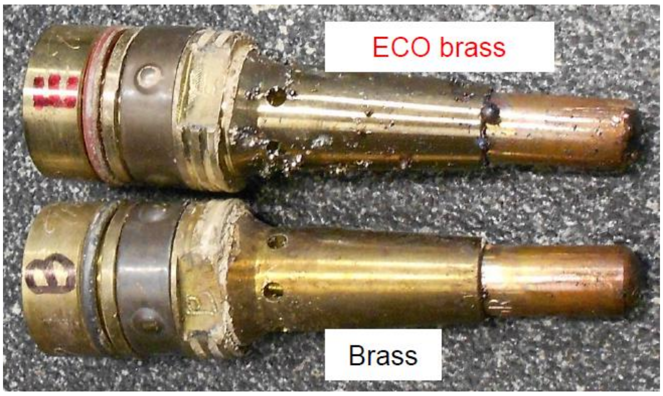
Electro-Welding (Consequences of low electrical and thermal conductivity)

A manufacturer of electro-welding equipment compared gas nozzles and retaining heads made from C36000 (equivalent to CuZn36Pb3) to such made from C69300 (equivalent to CuZn21Si3P). The gas nozzle directs the shielding gas to the welding arc. Due to the lower thermal conductivity the gas nozzle made from C69300 overheated (picture 19). The spatter adhesion to C69300 nozzle was stronger than that to the C36000 nozzle. The front-end temperature of the C69300 nozzle was higher than that of the C36000 nozzle. At the same lab setup welding conditions, the front end of C69300 nozzles melted, while the C36000 nozzles survived.

Picture 19: Gas nozzles made from leaded brass (B1and B2) compared to such made from silicon brass (E1 and E2). The front end of C69300 nozzles (E1 and E2) melted during the test.

The retaining head carries the contact tip that is usually made from lead-free material in a chip-less process. The poor thermal and electric conductivity of C69300 retaining head encourage the high temperature of the contact tip. This caused high feeding friction of electrode wire and unstable arc, especially in high heat welding applications. In both CV and Pulse setups in this report, the contact tip life was shortened by 1/3 to 1/2 when switching the C36000 brass retaining head to C69300 brass retaining head.

After test, no spatter was left on the C36000 retaining head, while spatter was present on the C69300 retaining head (picture 20). The spatter was so strongly adhered to the retaining head that it could not be removed by hand. Reaming may remove surface spatter, but spatter in the gas holes would retain and accumulate.



Picture 20: A retaining head made from silicon brass (up) compared to one made from leaded brass (down). After the test spatter adhered to the head made from silicon brass.

6.3 Costs of substitution

A recent publication of Schultheiss et. al. gives a good overview over the differences in machining CuZn21Si3P compared to CuZn39Pb3[13].

The publication calculates the cost increase when CuZn39Pb3 would be substituted by CuZn21Si3P based on findings at a Swedish SME. If the material costs are considered the price of one part would increase by 77%. If the material price would be ignored (which is not possible in reality) the relative increase in production costs would still be 72%. The socio-economic impacts of substitution is under RoHS not seen as criteria justifying the renewal of an exemption by itself but as additional parameter. But due to the extreme value calculated we see these findings rather as technical (criteria) than as purely socio-economic. As remark one should consider the completely different price situation in industry compared to private consumer. While private consumers are used to inflation, meaning a yearly increase in prices, in industry the opposite is the case. Every industry customer wants the suppliers to lower the prices, usually by 3-5% per year, for the same products. Thus, a price increase by 77% will only be accepted in very specific cases.

Even more important are two variables the Schultheiss group identified: Scrap rate and Downtime rate. Both are increased by a factor of 10 when CuZn39Pb3 is to be substituted by CuZn21Si3P. The scrap rate observed for CuZn39Pb3 was 0.2% and for CuZn21Si3P it is 2.2%. With this much higher rate we think it is not yet possible to speak from a technically practicable substitution. This would mean 10 times more scrap with the corresponding loss of money and material that has to be recycled. Even more such an increase in the scrap rate would interfere with the existing processes requiring additional steps of sorting out bad parts and additional quality control.

7 Other Leaded Copper Alloys

Besides brass, other leaded copper alloys exist that are used in much smaller quantities and for specific applications. Three main types can be identified:

- Leaded Bronze: Copper-Tin-Lead Alloys
- Leaded Nickel Silver: Copper-Nickel-Zinc-Lead Alloys
- Leaded Copper Beryllium: Copper-Beryllium-Lead Alloys

Due to the higher copper content or specific alloying elements the alloys are much more expensive than leaded brass. They are used when their specific properties are required and not instead of each other or of brass.

Leaded Bronze

A prominent example is turning bronze CuZn4Sn4Pb4. It is used for spring contacts. No lead free substitute material for leaded bronze was recommended by the material manufacturers.

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[13] The International Journal of Advanced Manufacturing Technology (2018) 99:2101–2110.

Leaded Nickel Silver

For nickel silver a very high nickel content is characteristic. This gives the material a very high corrosion resistance enabling the manufacturer to use this material without a further surface plating. Leaded nickel silver is for example used for optical contacts that require a very tight dimensional tolerance. No lead free substitute material for leaded nickel silver was recommended by the material manufacturers. RWTH Aachen examined the lead free nickel silver CuNi18Zn20. Turning tests of the material showed a very high cutting force and tool temperature.[7]

Leaded Copper Beryllium

Copper beryllium alloys have unique properties. The combination of high tensile strength, low Young´s modulus and low relaxation is not found at any other material. Copper beryllium alloys mainly consist of copper thus they have a high electrical conductivity but without lead it is not possible to machine these alloys (see chapter 2 on alloys with high copper content). The requirements of different standards can currently only be achieved by using leaded copper beryllium. These standards are:

a. MIL-STD-348B
b. IEC 61169-1 Radio-frequency connectors, part 1: generic specification
c. IEEE Std 287-2007 IEEE Standard for Precision Coaxial Connectors (DC to 110 GHz)

Further following standards stipulate the use of copper beryllium in connectors:

a. MIL-PRF-39012F
b. ESCC (3402/001) RF Coaxial Connectors Type SMA 50 Ohms (Male Contact)
c. ESCC (3402/002) RF Coaxial Connectors, Type SMA, 50 Ohms (Female Contact)
d. ESCC (3402/003) RF Coaxial Connectors Type SMA 50 Ohms Adaptors and Connecting Pieces
e. ESCC (3402/004) RF Coaxial Connectors Type SSMA (Male Contact)
f. ESCC (3402/005) RF Coaxial Connectors Type SSMA (Female Contact)
g. ESCC (3402/006) RF Coaxial Connectors Type SSMA Adaptors and Connecting Pieces
h. ESCC (3402/009) RF Coaxial Connectors Type TNC 50 Ohms (Female Contact)
i. ESCC (3402/021) RF Coaxial Connectors, Type SMA 2.9, 50 Ohms (Male Contact)
j. ESCC (3402/022) RF Coaxial Connectors, Type SMA 2.9, 50 Ohms (Female Contact)
k. ESCC (3402/022) RF Coaxial Connectors, Type SMA 2.9, 50 Ohms (Female Contact)
l. ESCC (3402/023) RF Coaxial Adaptors and Connecting Pieces, Type SMA 2.9, 50 Ohms
m. ESCC (3402/025) RF Coaxial Connectors, Type SMP, 50 Ohms (female contact)
n. ESCC (3402/026) RF Coaxial Connectors, Type SMP, 50 Ohms (adaptors and connecting pieces)
o. ESCC (3402/027) RF coaxial connectors, TNC, very high power, 50 Ohms (female interface) based on Type TNC-VHP
p. ESCC (3402/028) RF coaxial connectors, TNC, very high power, 50 Ohms, Adaptors based on Type TNC-VHP
q. ESCC (3401/017) Contacts Electrical Crimp Wire-Wrap Solder and Saver for 3401/016 Connectors

r. ESCC (3401/020) Connector Savers Electrical Rectangular Miniature Removable Contacts, based on type D*BMA

s. ESCC (3401/044) Connectors Electrical Circular Bayonet Coupling Removable Crimp Contacts, based on MIL-C-38999 SeriesII

t. ESCC (3403/005) Attenuator, RF Coaxial, Type SMA, DC-22GHz

The mostly used leaded copper beryllium alloy is CuBe2Pb. The lead free version, CuBe2, has only 20-30% of the machinability of the leaded version.

Aside from the presence of lead in leaded copper beryllium alloys, it is worth mentioning that beryllium itself was recently assessed for a potential restriction under the RoHS Directive[14]. The Oeko-Institut concluded that “although some substitute materials are available, they do not match with the technical requirements in all respective application areas of beryllium”. For this reason and considering the high technological importance of beryllium for the European EEE sector, as well as all possible end-application areas of EEE products, the Oeko-Institut recommended not to include beryllium in the Annex II of the RoHS Directive. In the specific case of leaded copper beryllium alloys, a non-renewal of the RoHS exemption 6c for lead in copper alloys would de facto mean a ban of CuBe2Pb, without available substitutes in many highly technological sectors.

8 In Service Use of lead containing components – Self-Lubrication

Applications that are exposed to ionising radiation cannot use grease or oil lubricants as these substances will decompose/denaturate. For such applications, e.g. bearings, the self-lubricating effect of lead is very important. It allows the use of such bearings without an additional lubricant. So far no other basic material or basic material and lubricant combination was found to replace leaded copper alloys for such applications.

9 Environmental Impacts

The boiling point of lead is 1744°C and the boiling point of zinc is 907°C. Thus, it is not possible to selectively remove lead from leaded brass via distillation (as zinc will evaporate first). Also no other economically or ecologically feasible process to selectively remove lead from brass exists. This had to be done by metallurgical processes followed by electrolytic purification that would split the alloy into the constituent elements. This process requires much more energy than the recycling of leaded copper alloys.

For leaded copper alloys a closed loop exists. Semi-finished goods of leaded brass are to nearly 100% made from recycled material.[15] This is even more supported by the high price of copper that allows economically feasible recycling since very long time.

A sudden restriction of leaded brass would therefore cause an adverse effect as the required material could not be made by direct recycling anymore. An energy intensive removing of lead from scrap or the

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[14] RoHS Annex II Dossier for Beryllium and its compounds, Restriction proposal for substances in electrical and electronic equipment under RoHS, Report No. 5, version 2, Oeko-Institut e.V., 25.09.2019.

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

use of virgin material (and disposal of scrap as waste) would be the consequence. Even more it should be considered that in Europe no primary copper production exists but the Urban Stock is the available European copper source. In addition leaded brass allows higher impurities of other elements than lead-free brass. So less purification of the scrap that is used to produce the semi-finished good is required resulting in less waste by-products.

10 Socio-Economic Analysis

When producing brass products by machining operations often a large proportion of the semi-finished product will not become part of the product but will be machined to form metal chips. For example when a contact is turned out of a brass rod, depending on the shape of the contact, even more than half of the material can be turned into chips. Picture 21 illustrates the situation for turned contacts. Another example, when turning housings made of brass rods, a chip content of more than 80 % may even occur.

Picture 21: Chips resulting from turning contacts.

It is very important to recycle the chips produced in the machining operation. This is the aim of the EU's circular economy policy. Without recycling, production would become uneconomic as even more resources would be consumed resulting in very poor resource efficiency.

Chips of leaded brass and silicon brass may not be mixed. This means if a batch of leaded brass chips is contaminated with chips of silicon brass or vice versa, it becomes de facto worthless. For both ways the accepted tolerances are very small.

Silicon brass is used for drinking water applications and for some special application where it is used instead of stainless steel. At the moment most of the brass chips in machining shops will contain lead. A well-established cycle for recycling of leaded brass chips exists. As the majority of the chips are leaded brass, cross contamination with silicon brass is less likely at the moment, but cases of mix-up of both due to confusion of workers have been reported. If the share of silicon brass used increases, it is expected that the number of mix-up cases and thus worthless chips batches will increase. It is hard to quantify this as it depends on the human factor.

Even more severe is the situation for the machines. In case a partial substitution with silicon brass was possible (which is mainly not yet the case) it has to be expected that for several years both materials, leaded brass and silicon brass, would be used in parallel. If both materials had to be machined with the same machine it would have to be cleaned very well when changing the material. This is a quite time consuming process that would strongly increase the setup time of the machine. The alternative would be to buy a number of new machines which would mean a big investment for the companies.

11 Situation of Small and Medium Enterprises

In general the same technical and socio-economic challenges apply to small and medium sized enterprises (SME) as for all others. But for them these challenges can have more severe consequences than for bigger companies. This is also considered in recital (8) of RoHS.

To estimate the consequences for SME we worked closely with partnering associations of the Umbrella Project that represent SME. Mainly three challenges were identified: investments in new machines, additional manual work and additional chips cycles.

All technical findings show a lower machinability of lead-free brasses (both types) compared to the currently used leaded brass. So, even if the technical challenges explained above could be overcome always a longer production time or less parts produced per time are expected. A possibility to compensate this is the purchase of additional machines. Here a disadvantage for SME has to be expected as they will usually not be able to carry the investments as bigger companies can.

A similar situation exists for additional manual work. Due to the lower machinability of the lead-free brasses also the chip formation is negative compared to leaded brass and a higher scrap rate occurs. So for lead-free brass it is not expected that a process as stable as for leaded brass could be achieved. This requires additional manual work to remove and collect chips. As explained in chapter 9 a mixing of leaded and lead-free chips may not happen. Due to this in case of parallel production with leaded and lead-free material and even more with leaded and silicon-material automatic chip processing is not possible anymore as a mixing of the chips could not be avoided. Required additional manual work is especially problematic for regions with high salaries.

12 Examples for Successful Substitution

We understand as successful substitution the situation when a market-ready product exists that was made before from a leaded copper alloy and is now made from a material without hazardous substances. A successful substitution would also exist if a new market-ready product is made from such a material for which leaded copper alloys would have been considered or similar products are made from leaded copper alloys. It has to be a market-ready product, so not something that is made only on a lab scale. The substitution has to go from leaded copper alloys to materials without hazardous substances, not from others than copper alloys to lead-free copper alloys.

We think that the existence or absence of examples for successful substitution give a very good finger print about the current technical situation toward substitution of leaded copper alloys.

In the last review of the exemption, it was not possible to identify examples for a successful substitution of products covered by RoHS. The company Mitsubishi Shindoh reported about uses of CuZn21Si3P (so called ECOBRASS) in drinking water applications[9]. For these applications different requirements than for electrical and electronic equipment exist.

We made a survey asking all 50+ partnering associations of the Umbrella Project to check with their members which examples of a successful substitution are known to them. In this survey we clearly stated that identifying successful substitutions would show the willingness of industry to reduce the use of lead. Even more it shows the functioning of RoHS which is accepted by all stakeholders as very valuable piece of legislation. In addition, already in the last round we explained that a company that is able to substitute leaded copper alloys will not hide this. Therefore we think that the feedback we got represents the current knowledge of the associations and their members. The survey run for five weeks from 26th of August 2019 until 30th of September 2019 with weekly reminders.

The results of this survey are consistent with the findings of the earlier chapters of this document:

The electrical and electronic manufacturers' associations reported that no examples of successful substitutions could be identified. Such associations represent the manufacturers of more classical electrical and electronic equipment that usually requires electrically conductive material. For them brass with higher zinc content will usually be the most promising material. But as shown in chapters 3 and 5 this material still shows several drawbacks for which no solution was found so far.

Associations and companies with more mechanical orientation as for example mechanical engineering reported of improvements. Below are the statements obtained in the survey (some have been translated to English).

Statements received from electrical and electronic manufacturers' associations:

“We are working with our suppliers concerning the substitution of leaded copper alloys. Unfortunately, we did not have any successful substitutions at this moment and we will not be ready to show a detailed explanation of the different works”

“Member companies will normally use leaded brass as a conductive part (fixed and moving contact bars, terminal parts etc.) within switchgear, variable speed drives, relays, PLCs, etc.. Companies have researched the use of alternative materials but no substitutes have been found which offer the combination of machinability and conductivity which their products require. As an example, the alloy CuZn21Si3P has been tested and demonstrates good machinability (between 70…75%), but conductivity is 7.8% according to the International Annealed Copper Standard (IACS – an accepted standard for the conductivity of commercially available copper). Free-cutting brass (such as CuZn36Pb3 – which has 100% machinability) has an IACS conductivity of 26%; almost four-times better. Adoption of the substitute material would therefore greatly increase overall material usage and weight as well as reducing the life of tooling etc.”

“We have not identified a successful substitution from leaded copper alloy materials to materials without hazardous substances”

“Unfortunately we have no specific or valuable information about examples of successful substitutions of leaded copper alloys available. This topic should be better addressed directly to the members of metal industry associations and component manufacturers within the Umbrella project.”

“We use electronic components and circuit board components from third parties. We support the activities of these producers to further use exemptions and apply for an extension of the validity periods as long as no alternatives for the materials exist. In addition a substitution of leaded copper alloys was so far not possible due to the lack of alternative materials that show the required technical properties. We are in close exchange with our suppliers and we observe the further developments very exactly."

Statements received from mechanical engineering associations:

"We already process low leaded copper alloys (Pb max. 0.2% w/w) for specific customers. The change to low leaded alloys requires longer process times and a shorter tool life. For castings in the field of vision (chromed parts) the surface quality is often only achievable with higher rejection rate (costs!). All together we would not call this a successful substitution."

"At the moment we only have experience with low leaded alloys but not with lead free alloys".

"We are dealing with the topic of "lead-free brass" since long time and we were already able to gather some experience with the material. Our products are not yet completely changed to lead-free brass but we already produce some components in such a way and others are to follow. For this we use lead-free brass from our own foundry and we also process components from lead-free brass from suppliers. According to our experience the material is 15-20% more expensive than common brass with approx. 1.6% lead and it shows some challenges in machining. In addition we work with a higher wall thickness and thus the material demand is enhanced which has negative influence on the production costs. The tools and processes have to be adjusted to the new material to obtain the required surface quality. These adjustments are workable but they are time and cost intensive for the specific products in regards to preliminary investigations. Also the process time is increased. We think it is possible to change our whole product portfolio but it requires several years of time to apply this to series production. Therefore, a renewal of exemption 6c is desirable for us."

"We already introduced lead-free materials in many of our product groups and we mainly substituted the leaded materials. With appropriate preparation and today´s experience this can be done without problems if the higher prices are not considered. We are in the lucky position that our sector accepts acceptable additional costs for the predicate "lead-free"."

"At the moment we do not use lead-free or low-leaded copper alloys. We consider the use of lead-free or low-leaded brass as possible in principle and workable. But this expectation only bases on trials that have been done with small amounts of semi-finished goods/raw materials. Also statements and experience of suppliers (raw materials, tools and machines) contributed to this expectation as also research results, e.g. from RWTH Aachen. At the moment our machines would not allow us to completely work without conventional brass. We think that required invests and the time required for purchasing new machines, tools and technologies justify the application for renewal of exemption 6c. […]"

These feedbacks show very well the diversity of the situation. Some companies represented by mechanical engineering associations were able to substitute most of their leaded copper alloys while for others it was a smaller share and for others it was not possible at all. To better understand this and connect it to the findings above it has to be noticed that machinery manufacturers usually only produce customer-specific machines in very small quantities. These machines as well as their components are usually not products one could order from a catalogue but they are developed by the machinery manufacturer according to the requirements of the customer. Due to this extremely high diversity differences in the possibility to substitute leaded copper alloys result. This situation is very good explained by the following results, reported by a manufacturer of automation technology (translated to English):

A threaded ring is currently made from leaded brass and was to be made from Si-brass. When this ring is tested in low pressure applications (0 to 300 bar) it worked well. But when the ring is tested in high pressure applications (0 to 1000 bar) a plastic deformation of the ring made from Si-brass occurred. This finding was not expected considering the strength properties of the materials. It rather seems to be a kind of creepage caused by the high pressure shocks of the test. Here lead seems to stabilize the microstructure of the material.

13 Summary

Copper alloys are widely used in electrical and electronic equipment when their specific properties are required. For machining purposes up to 4% w/w of lead are added to the alloys. Lead has different functions in the alloys, for example as a chip breaker and internal lubricant. Further investigations of the alloys in the strive to substitution identified additional functions of lead that are partially not yet fully understood as for example the influence on the stress relaxation behaviour or mechanical deformation.

The by far mostly used kind of leaded copper alloys is leaded brass. For this material two main families of possible lead-free alternatives exist: brass without chip breaker (e.g. CuZn42, CuZn40, etc.) and silicon alloyed brass (e.g. CuZn21Si3P).

For electrical and electronic applications, e.g. all kinds of connections for the transfer of data, signal or power, the discussed brass types without chip breaker (e.g. CuZn42) seems at the moment to be the most promising material to substitute leaded copper alloys. But still several challenges exist for which so far no solution could be found. Due to the lower machinability it is not possible to process the material with standard tools. Also the use of adapted tools was not successful. Other properties as insufficient stress relaxation and crimp ability are material constants. They are often safety relevant (see chapter 5.2) so it is questionable if ever a solution can be found.

In addition, leaded brass is used widely for specifically designed mechanical parts with small scale features like e.g. cable glands, housing parts, filigree formed accessory parts, etc.

The electrical and thermal conductivity of CuZn21Si3P is approx. 1/3 of that of leaded brass. It is therefore not considered as possible substitute for electrical and electronic applications. CuZn21Si3P is mainly seen as substitute for stainless steel.

A survey with all 50+ associations of the Umbrella Project on examples of a successful substitution identified first improvements. Several companies from the mechanical engineering sector reported that they were able to fully or partially substitute leaded brass. But, the overall situation is very divers so it is not yet possible to derive groups of applications for which substitution is possible or may be possible in the near future. For example, the detailed assessment of a threaded ring made from CuZn21Si3P also identified an unexpected behaviour of the material, highlighting that in depth testing has to be done for every substitution.

Public funded research showed that a change from CuZn39Pb3 to CuZn21Si3P would cause a cost increase of 77%. This would not be accepted for mass products but only for special products that are usually produced in small numbers.

For small and medium sized enterprises, the necessary investments in new machines would be problematic and additionally required manual work in the production process is especially problematic for companies in regions with high salaries.

Further leaded alloys in use are leaded bronze, leaded nickel silver and leaded copper beryllium. For them no promising alternatives could be identified.

From the findings above we have the opinion that RoHS is working very well. All stakeholders working on this renewal application agree that the use of lead in copper alloys shall be reduced as far as technically possible (RoHS article 5). First successes in the substitution of leaded copper alloys in the mechanical sector show that industry applies high efforts for the substitution and that even higher prices are accepted if this is possible. The technical findings on the alloys show how much efforts companies had to invest to reach these successes.

In conclusion we have the opinion that the renewal of RoHS exemption 6c with the current wording “Copper alloy containing up to 4 % lead by weight” is justified for another five years or seven years respectively, depending on the category. The extremely high diversity of technical requirements of the applications of leaded copper alloys makes it impossible to already identify applications that could be excluded from the exemption. Even more the first successes show that industry already applies sufficient efforts for the substitution of leaded copper alloys and changes of the exemption would only consume resources, required for research, but would not give relevant benefit to human health and the environment.