Stakeholder Consultation Questionnaire: Exemption No. 3
“Copper alloy containing up to 4% lead by weight”

Industry contribution of ACEA, JAMA, JAPIA, KAMA and CLEPA.

Please find below the answers to the stakeholder contribution concerning exemption 3. Input is based on results of a working group consisting of OEMs and suppliers.

Question 1
Please state whether you either support an extension of the exemption or whether you would like to provide arguments against the extension. In both cases please provide detailed technical argumentation / evidence to support your statement.

The associations involved, ACEA, JAMA, JAPIA, KAMA and CLEPA, claim that the unlimited exemption concerning leaded copper alloys is still required. The maximum lead content must remain at 4%.

The application field of lead-alloyed copper materials goes beyond just automotive uses. Predominantly they are used for example, in the machinery and plumbing. The automotive industry contributes to only 5% of the European market. Therefore general knowledge and research activities specializing in automotive requirements are limited.

The efforts to gain additional knowledge on the usability of lead-free copper alloys have been stepped up by the automotive industry and its suppliers during the last five years (see answer 7). A lot of additional data on alloy characteristics, converting and material use have been compiled, but, compared to the last revision, no fundamentally new findings that might change the argumentation have been identified.

The selection of a certain material for an automotive part[1] is primarily determined by the security and reliability of its function during service life, even under harsh mechanical and environmental conditions. The possibility or ease of production plays a secondary role. So it can be confidently assumed that there are very good reasons that the selection has fallen on a copper alloy. It is also certain that a lead content is never selected higher than necessary for the function – otherwise copper alloys with differing lead contents would not be in use. In contrast to steel or aluminum, copper alloys are neither cheap nor light materials, so will only be used when needed.

Some 95%, by weight of copper and its alloys, used in the automotive industry are lead-free[2]. Thus, on average, less than 20 grams of lead are embodied in the leaded copper alloys of a single vehicle.

Due to the fact that most of the parts made from leaded copper alloys are very small, a large number of parts and components are affected by exemption 3. Since most of these parts are subcomponents of bigger assemblies the field of applications in the automotive sector is broad. The difficulty of providing general statements lies in the fact that the properties of each material have to be assessed under operating conditions of the component produced from the material. Operating conditions can vary and include, for example, the interaction of different materials in contact with gases, lubricants or fluids and electrical power. A failure of a component is not acceptable because of safety aspects. Due to component procurement, virtually every component has to be considered and tested individually. It is not possible to claim that results from proof of principle tests on individual components can be generally read over to other components, as they are, as a rule, subject to different stresses in different environments.

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[1] In this document “part” means a not assembled automotive part made from homogenous material

[2] In this document “lead-free“ means up to 0.1% lead in homogeneous material as defined in the directive

With regards to resource efficiency it should be noted that the majority of leaded copper alloys are made from recycled copper. In order to allow at least a certain fluctuation in composition and impurities from recycling, a material needs to be constant in its characteristic. Tests have indicated that this is not the case when lead content is reduced to about 0.1%. Therefore the recycled content of these alloys may need to be reduced when compared to the leaded copper alloys that are used today.

During the last five years considerable efforts have been made to analyze the areas of application and the requirements thereof. The main application groups “sliding elements”, “mechanical connecting elements” and “electric applications” and their prioritized requirements have been compiled. This knowledge enables the assessment of the capabilities of lead-free copper alloys in automotive applications in general.
The tests show that there are strong technical drawbacks for all of the major application groups in the various material properties. Therefore none of the lead-free copper alloys tested have shown them to be suitable for automotive parts.

The machining and processing of lead-free machining brasses is at an early stage of fundamental research. Public-funded research on basic parameters will continue[3]. As already stated, automotive parts made from leaded copper alloys are usually small. Roughly 75% of these parts have a weight of less than 10 grams and require smooth surfaces and narrow tolerances. Tests on micro-machining prove that the technical requirements are different, i.e. more complex, in this case. Results that have been obtained by conventional machining (e.g. with large parts) are not applicable.

Considerable additional development in production equipment and technology is required for the current lead-free copper alloys. At this time, research activities and other investigations are focused on larger markets such as plumbing applications. These activities do not lend themselves to automotive requirements. The lack of available knowledge is crucial especially for small and medium enterprises that are commonly involved in the field of machining. These enterprises will not be able to offer knowledge and resources for the necessary research work on their own.

Furthermore a review of current literature and research (1) shows that the promising alloy compositions have already been promoted. It is unlikely that new alloy types will be available for advanced research in the coming decade.

A more detailed overview will be given in the following answers and in (2). Due to the facts collected, the joint associations state that the unlimited prolongation of exemption 3 is required and propose a review time of 8 years. This period reflects typical model cycles within the vehicle industry and experiences in material substitution realized within recent years.

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[3] IGF-Forschungsvorhaben Nr. 17953 N: „Entwicklung angepasster Werkzeuge und Bearbeitungsstrategien zur Steigerung der Produktivität und Prozesssicherheit bei der Gewindeherstellung und beim Bohren von schwer zerspanbaren bleifreien Kupferwerkstoffen“

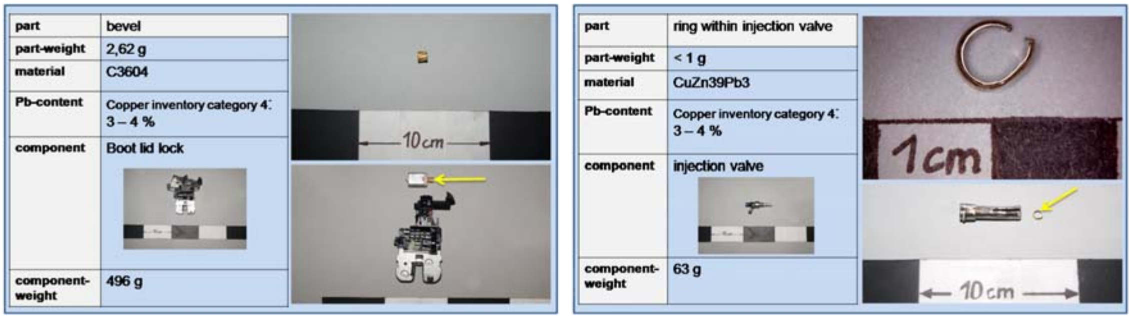
Question 2

Please describe in which applications leaded copper alloys are used in vehicles; and indicate the functionality of lead in these applications (e.g. specific function, performance criteria, etc.). Please make a distinction between applications in which the use of lead is unavoidable (e.g. due to safety reasons) and less important applications.

As already stated the majority of parts affected by exemption 3 are small in size and are usually one single part of a larger automotive component[4]. These small parts are typically developed at sub supplier level further down the supply chain, so they are out of reach for the OEM (usually a contractual relationship only exists with the first tier supplier). Whereas the chemical composition and weight of single parts within a component are known from product management data systems like IMDS and can be allocated to the component, the major functions of these small parts do not have to be recognizable from those of the whole assembled component or application that is in focus at the OEM or the first tier level.

Some examples can be taken from dismantling studies (Figure 1).
In the bill of material, a component is denominated as an “electric boot lid lock”. This title might indicate that the concerned subordinated part, within this component, has something to do with electric applications. In reality the part is a bevel at the end of the drive axle of a small electric motor. Thus its function is like a gear wheel or sliding element.

Another example is a fuel injection valve. From the denomination of the component it might be concluded that the function of the leaded copper alloy part is related to movement or sliding. But dismantling shows that it is a bearing within a mechanical connection. This demonstrates that there is no common standard defining how sub-components are designated.



part	bevel
part-weight	2,62 g
material	C3604
Pb-content	Copper inventory category 4: 3 – 4 %
component	Boot lid lock
component-weight	496 g

part	ring within injection valve
part-weight	< 1 g
material	CuZn39Pb3
Pb-content	Copper inventory category 4: 3 – 4 %
component	injection valve
component-weight	63 g

Figure 1: Examples from dismantling studies – small parts

To further illustrate, a radio system within a car is only one component in the bill of materials or procurement system. A printout of the materials used in the parts of this radio system listed from the IMDS database comprises of more than 50 pages.
In many cases the affected subordinated parts are less than a fiftieth of the weight of the assembled component that is responsible for the main function and the denomination (Nevertheless a failure of the small part will affect the function of the whole component).
It does not make sense to derive the functionality from the denomination at the component or application level within the procurement system or the bill of materials. Beyond that, denominations and functionalities of the components vary greatly amongst suppliers and OEMs.

In summary, it is not feasible to answer this type of question at the application level. Neither is it possible to use the procurement system nor the bill of materials for that purpose. Even if non exhaustive figures are requested, typical requirements of the parts and components used have to be collected manually by means of many interviews, questionnaires and dismantling studies. This has been done since the last

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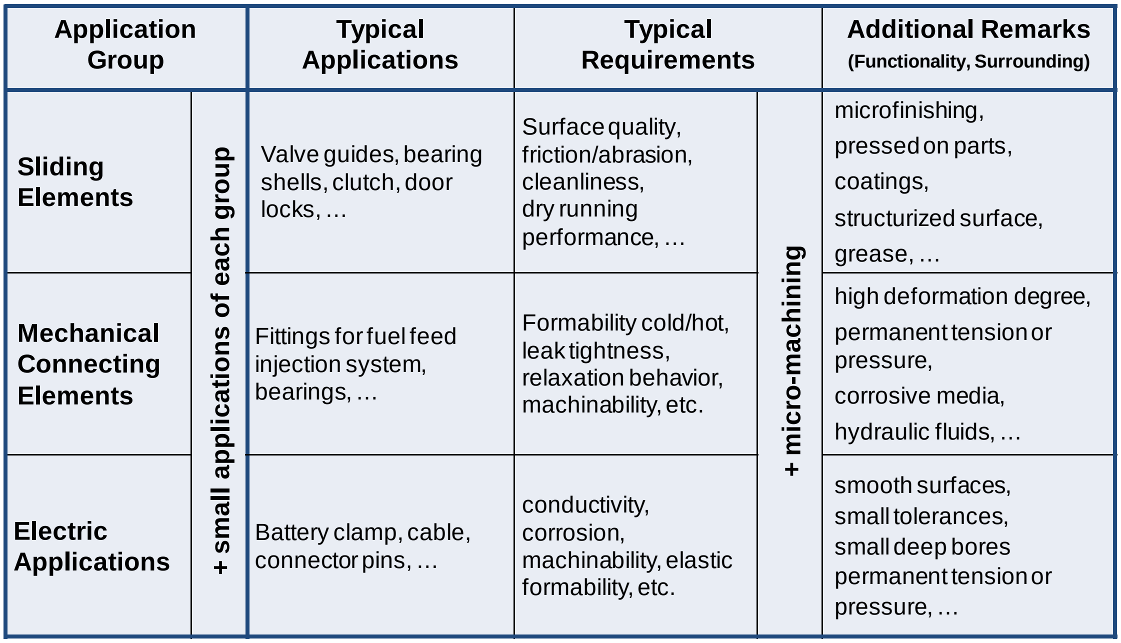
[4] In this document a component is an assembly of parts, that is visible at the OEM or first tier level and in contrast to a part is listed in the bill of materials

revision and three major application groups have been identified from this analysis. These are “sliding elements”, “mechanical connecting elements” and “electric applications”. In addition, the special requirements of small parts have to be addressed. Roughly 75% of automotive parts made from leaded copper alloys are below 10 grams in weight. During analysis it became clear that many applications are linked to electric or electro mechanical devices and are often used in components linked to safety- and environment-related applications. A failure could have consequences resulting in serious accidents and recall campaigns.

Having defined these three major application groups, it was possible to allocate the corresponding processing needs and typical technical requirements to each application group. A sample is given in Figure 2.



Application Group		Typical Applications	Typical Requirements		Additional Remarks (Functionality, Surrounding)
Sliding Elements	+ small applications of each group	Valve guides, bearing shells, clutch, door locks, …	Surface quality, friction/abrasion, cleanliness, dry running performance, …	+ micro-machining	microfinishing, pressed on parts, coatings, structurized surface, grease, …
Mechanical Connecting Elements		Fittings for fuel feed injection system, bearings, …	Formability cold/hot, leak tightness, relaxation behavior, machinability, etc.		high deformation degree, permanent tension or pressure, corrosive media, hydraulic fluids, …
Electric Applications		Battery clamp, cable, connector pins, …	conductivity, corrosion, machinability, elastic formability, etc.		smooth surfaces, small tolerances, small deep bores permanent tension or pressure, …

Figure 2: Main application groups, typical applications and requirements

Examples allocated to these application groups (already stated in 2010):

Materials for door locks can be allocated to “sliding elements”, which need a very high precision for their function and low friction values. In case of an accident, friction must be low enough, so that the closing device may still function in a deformed door to be able to get injured persons out of the car as fast and as easily as possible. Lead in the brass parts ensures the required low coefficient of friction.

Fittings are typical examples of “mechanical connecting elements”. They have to ensure a pressure proof connection between tubes. Therefore, it is necessary to produce functional surfaces with high precision and a high surface quality. Secondly, the material needs a well defined strength and high plasticity to adjust itself to the contour of the mating part. On the other hand it must also be able to withstand the high temperatures and temperature cycles, found in the engine compartment. Leakage of gasoline or oil could lead to a fire. Leakage in the cooling system could result in the total damage of the engine. Leaded brasses have been shown to fulfill these requirements better than any other material and they prevent operating automotive fluids from spilling. Damage from corrosion also has to be avoided.

Battery terminals made from leaded copper alloys have to assure several functions and are allocated to “electric applications”. They must present a good, clean surface to the battery pins. They must be capable of a certain amount of adaptation to the contour of the battery pin. The material must be soft enough to connect the terminals to the battery cable by compression. Contact resistivity and internal resistivity must be low to limit the voltage drop when 1000 amps are applied to start the engine.

New developments have shown that a limited voltage drop plays a pivotal role in the proper function of start-stop-systems.
The use of copper alloys is specific to each single application. A malfunction is not acceptable. The leaded copper alloys are selected, for example, because of properties such as emergency running characteristics (even avoidance of fretting) or thermal and electrical conductivity.

Each part has specific requirements as a result of its function, its partners and their functions and properties in a component and its environment. There may be temperature, friction, wear, mechanical stress, fatigue, current, accelerations, corrosion and vibration behavior against media like salt water, various lubricants, cooling fluid or freezing agents. If one of these conditions is changed nearly all of the rest must be changed also. The function of one part cannot be seen separately from its surroundings. It is not possible to tell without extensive testing which parts or none at all may be changed to lower lead content without disturbing the functions of the component.

Nevertheless, the classification into three major application groups has allowed to focus activities on the main automotive requirements. Based on this knowledge, certain types of alloys can be tested in the future. If there is no positive result, time-consuming component and vehicle tests can be avoided. Of course, these tests have to be conducted for all of the alloys that passed the initial material testing. More details are given in the answers on questions 5 and 6.

Question 3
Please indicate:
- The amount of lead containing copper alloys in vehicles for the above mentioned applications in percentage by weight.
- The total amount contained in those applications per vehicles (in absolute numbers)?

Regrettably it is not feasible to give exhaustive information such as summarized weight at application or at an application group level. The reasons are already explained in detail (see question 2).

A good overview that can be offered is the result of the copper inventory. The inventory on leaded copper alloys was established after the last revision. It enables a good assessment to be provided based on the weight of the parts made from leaded copper alloys for an average “standard” model[5] and an average “fully equipped” model (Figure 3). Furthermore an indication for the most used lead-containing alloy types can be given.

An average standard model contains some 80 parts made from leaded copper alloys. An average fully equipped model, has as many as over 220 parts per car that are affected by exemption 3. The range is widely spread from about 50 parts for one of the reported standard models to more than 500 parts for one of the analyzed fully equipped models. Compared to the actual vehicle weight, the accumulated total weight of the components made from leaded copper alloys per car is very small. On average, it ranges from 1 kg per vehicle for standard models up to 1.7 kg for fully equipped models. The determined average lead content was 1.4% for standard models and 2.1% for fully equipped models. Using these figures, the lead content contained in leaded copper alloys can be calculated. It ranges from 14 grams for an average standard model to 36 grams for an average fully equipped model.

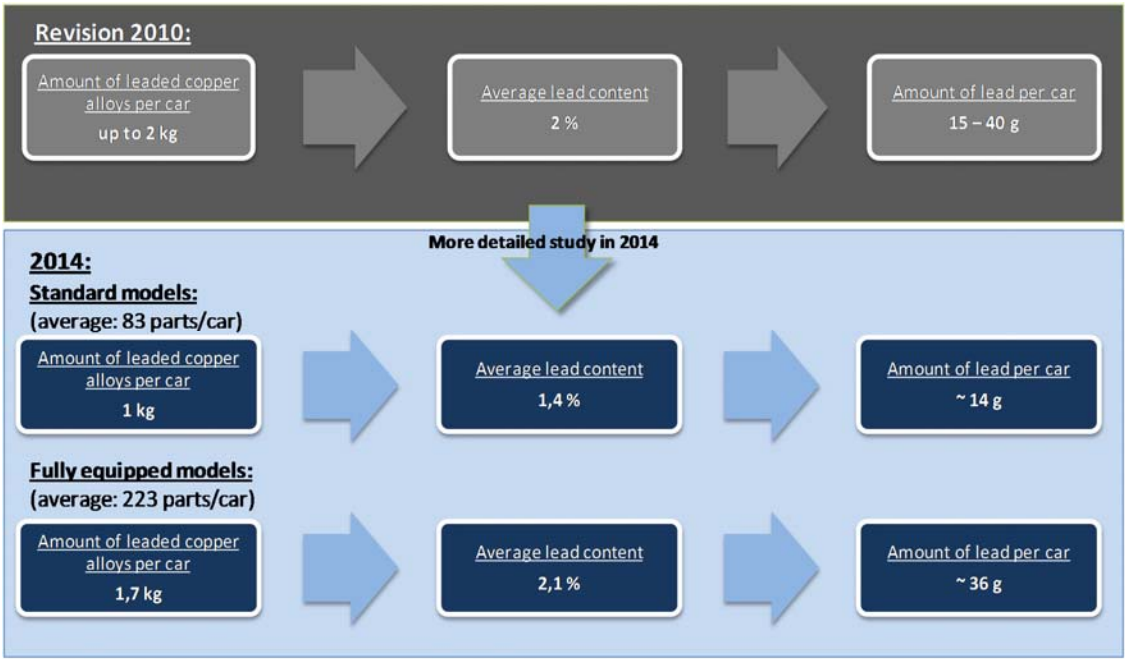


Figure 3: Result of the inventory on leaded copper alloys in cars

Another finding from this study is that more than 75% of the parts made from leaded copper alloys are very small and have a component weight of less than 10 grams.
It has to be emphasized that the average lead content of these small parts is much higher, ranging from 2.5% for standard models up to 2.8% for fully equipped models (Figure 4). This also corresponds with the type of alloys that are used.

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[5] In this document model stands for vehicle model

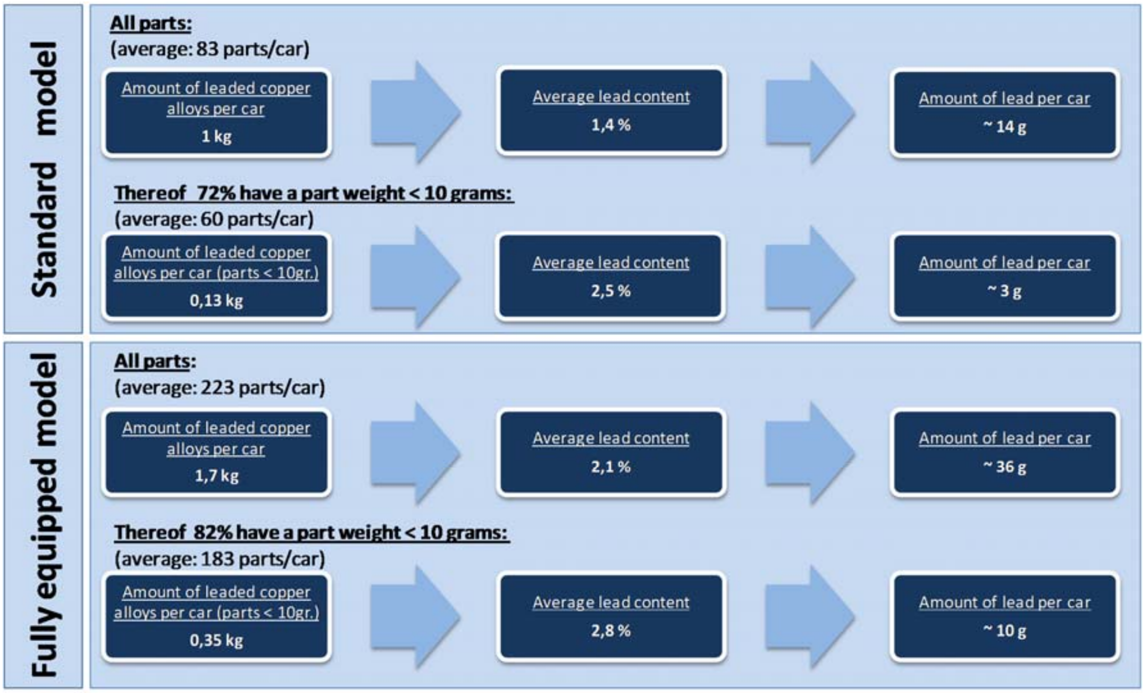


Figure 4: Results of the inventory on leaded copper alloys in cars (small parts)

Question 4
Please provide an estimate of the annual quantities of lead used in these automotive applications in Europe and/or worldwide. If data is not available, please provide estimations.

In 2013, within the EU27+EFTA, 13.3 million new cars and light commercial vehicles were registered. Taking a closer look at the consumer demands by segment, it can be concluded that 80% of that can be linked to standard models and 20% to fully equipped models. Using this mix and the numbers given in the answer of question No.3 in automotive applications roughly 245 tons of lead are used per year within leaded copper alloys. This number, now based on a more detailed analysis, is a little less than the lower limit of the range stated in the last revision (265-710 t/year).

Question 5, 6
What kinds of lead free alternatives are available for which applications (e.g. silicon brass “Ecobrass”)?
Please specify the effects of lead-free substitutions on material characteristics and performance (e.g. appearance, (long-term) reliability, manufacturing yield, safety)?
If no lead free alternatives are available for a specific application, please explain why the substitution of the lead is currently technically or scientifically impossible / impracticable. Please provide sound data/evidence.

Today most automotive copper applications are made from lead-free copper or copper alloys, around 95%. The remaining 5% are machining brasses and some other specialties like machining bronze or nickel silver. For the latter two alloy families no lead-free materials are available; however, some lead-free copper alloys have been promoted by material makers with the claim to be suitable as free machining brass.

According to our findings, more than 100 different lead-alloyed brasses are available on the global market. In contrast to this only a few lead-free qualities are commercially available from a limited number of sources. This number is even smaller on the Asian market, because, to our knowledge, there are fewer restrictions on the use of leaded copper alloys for plumbing applications.

Figure 5 shows the alloy families for brass. Machining brass usually is lead-alloyed. A market review which included material makers and associations has shown that mainly three families of machinable lead-free copper alloys are available. The first family is similar to the lead-free brasses that are not designed for free machining. The difference is that the lead is replaced by higher zinc content as well as some other minor additions. They are added to enhance machinability, which remains poor. In this paper, this alloy family will be denominated as CuZn38-42 alloys. The second family of lead-free copper alloys is silicon-alloyed copper including CuZn21Si3. Ecobrass® is a brand name for one of these alloys. The third family is bismuth-alloyed copper.

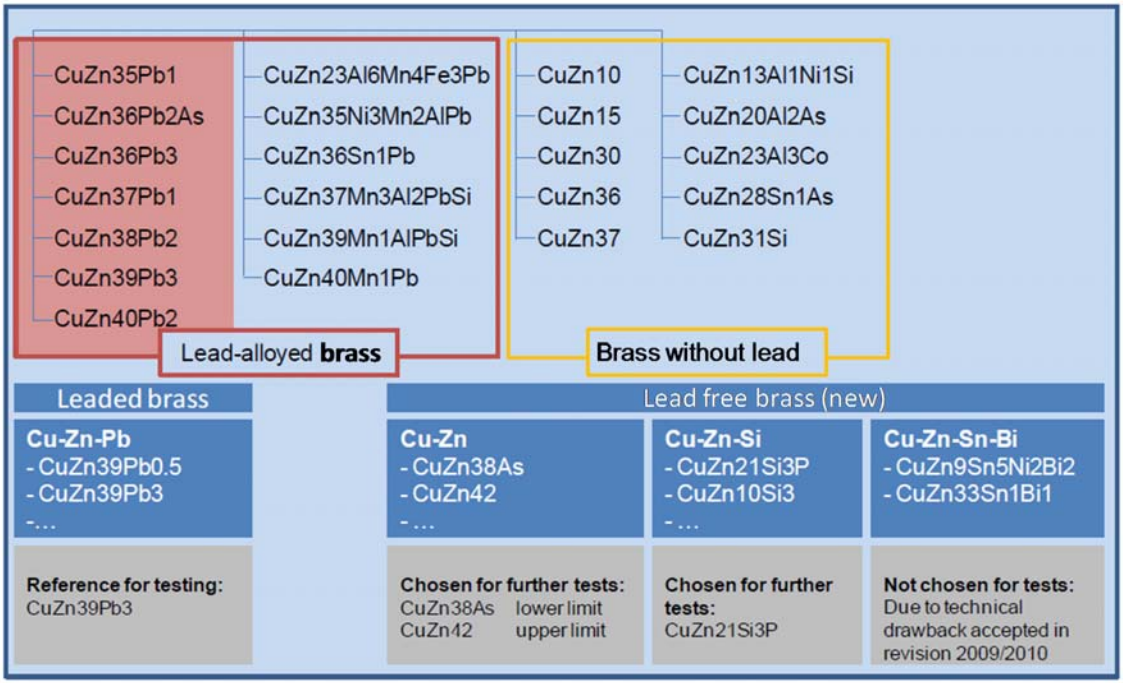


Figure 5: Overview of brass alloy families and materials chosen for further tests

Material research and development is not attracted to the relatively small market of automotive brass applications. Most of the lead-free copper alloys have been developed for plumbing applications. This is not comparable with automotive use. While automotive applications are mainly made from wrought products, plumbing applications in Europe are also produced by the casting route. Therefore the production and material requirements do not necessarily match (2). Silicon-alloyed copper today is more often used to replace parts made from stainless steel (3) than leaded copper alloys.

While the CuZn38-42 family has been promoted by material makers since the last revision, silicon-containing and bismuth-alloyed copper alloys were already addressed in the 2010 report. Regarding these alloy families, two major results that had been accepted in the last revision are still valid:

The first is that due to the low conductivity silicon-alloyed copper is not suitable for "electric applications". The second one is that bismuth-alloyed copper is not a suitable replacement for leaded copper alloys due to mining restrictions (bismuth is a byproduct of lead) and its tendency to stress corrosion cracking and hot embrittlement. This is the reason why the allowed bismuth content in high grade copper is only one tenth of the acceptable lead content. Bismuth alloyed copper should not be used as it may affect automotive copper recycling in general (2; 4; 5).

In mass production, the reliability and repeatability of processes and material properties is essential. Any failure may provoke a severe breakdown or recall. Properties and material characteristic should be independent from batch size or unavoidable deviations in the chemical composition.

During tests on surface machining at the WZL of RWTH Aachen University it became obvious that two delivered CuZn42 alloys showed a fundamentally different machining behavior. This was caused by a slightly different lead content in these two batches (0.07% vs. 0.18%). When machining the material with lower lead content, the chipping behavior changed significantly and a 50 degree higher tool temperature was measured. (6)

One supplier reported insufficient reliability of the same alloy type for different batches delivered. In a sawing process, some batches were processable while others showed unacceptable burrs, so that the material had to be rejected, even if the same parameters and sawing blades were used (7).

Every alloy shows fluctuations in the exact composition. In leaded copper alloys, stability of the material characteristic is guaranteed if the lead content is high enough. In the instance of low lead content, the conditions are less stable. The effect is described in source (2). From testing, it is uncertain if this family of alloys can offer the reliability demanded in terms of usability and processing issues.

In addition to the drawbacks already reported in 2010, it became obvious that there is still a lack of knowledge concerning material properties. The available data mainly refer to standard procedures and material properties (8) that are given in the material manufacturers' somewhat standardized datasheets.

In contrast to prior activities the established main application groups combined with a set of special requirements for each one allowed activities to focus on the major automotive needs involving leaded copper alloys.

The available information from material makers, material datasheets and the available literature did not allow an evaluation of the usability of lead-free copper alloys as an alternative to lead-alloyed machining brass in the automotive industry uses. Standard values on mechanical properties at room temperature, rough processing figures for bigger applications and some basic data on dezincification are not sufficient for evaluating appropriateness for automotive applications.

To gain at least rough indications for their possible use in main automotive application groups material properties such as creep and relaxation, corrosion behavior in contact with different materials or fluids and under stressed conditions have to be analyzed. Tribology data comprising wear, adhesion and friction coefficients are also needed. For electric applications, in addition conductivity specific data for contacting components are required. Furthermore micro-machining is an issue, since most of the lead-alloyed copper parts in the automotive industry are small. (Figure 6)

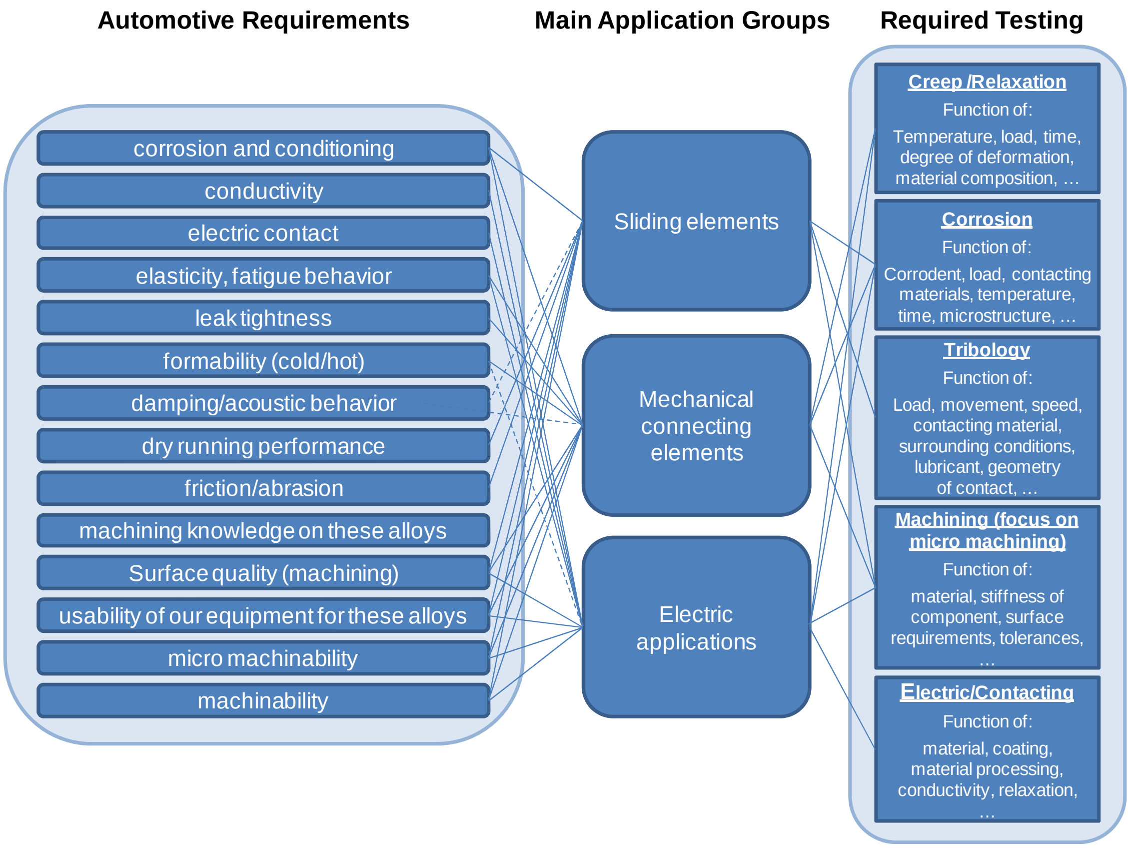


Figure 6: automotive requirements, main application groups, basic tests needed for evaluation

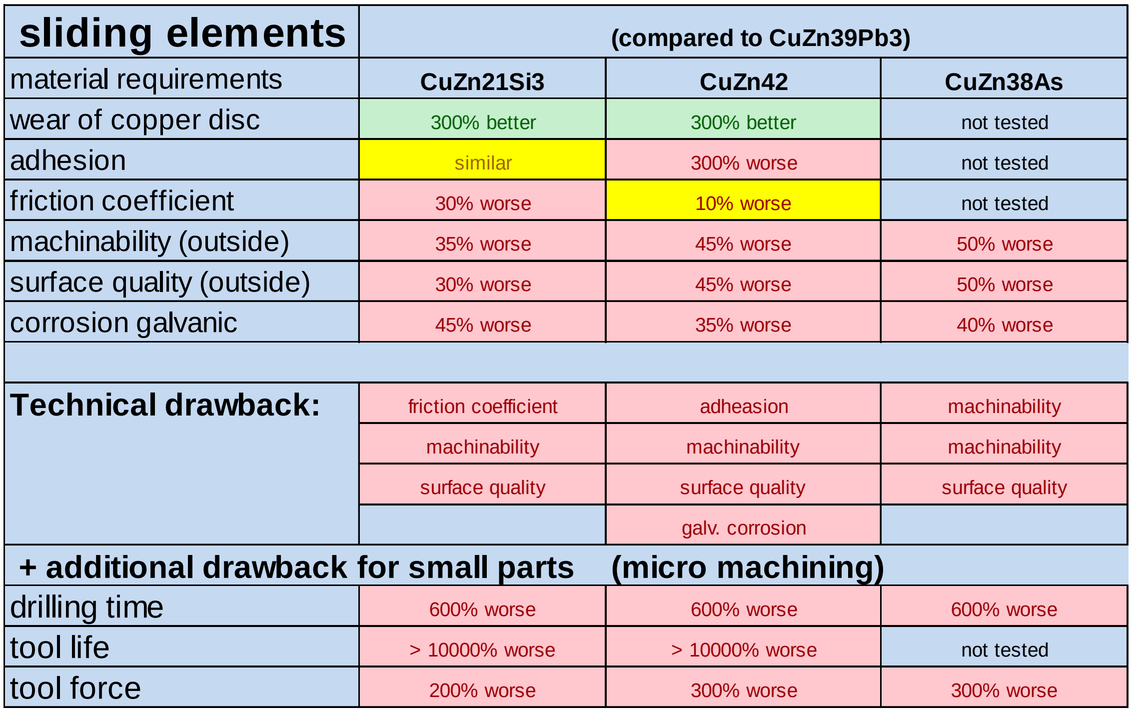
The classification allowed some standard material tests to be defined according to the requirements of each main application group. These were conducted in cooperation with the German Copper Institute (DKI). Based on these tests, further alloys may be tested in future. If there is no positive result, additional time consuming component tests and tests under vehicle conditions can be avoided. These defined more general material tests were conducted at German and French research institutes, labs and universities. The tests concerning these key requirements were complemented by additional applied research at different suppliers and OEMs. It was decided to compare at least one type of the lead-free copper alloys with CuZn39Pb3 or the corresponding lead-containing alloy. For the material tests, typical alloys of the family CuZn38-42 and CuZn21Si3 were selected and compared to CuZn39Pb3 as a reference.

The tribology tests were conducted at the Technische Hochschule Ingolstadt (THI). In pin-on-disk tests during an oscillating movement, the friction coefficient, wear and adhesion behavior were analyzed for different loads and alloys. (9)
The corrosion tests were conducted at the CopperCEEF in France, dealing with the electrochemical behavior in a NaCl environment in contact with aluminum (10) and with stress corrosion cracking behavior in NaCl and Na_2SO_4 environments (11).
To give an indication of micromachining, the drilling of small deep bores was tested at the WZL of RWTH Aachen University (12). The creep behavior was tested at the THI (13). (The detailed test reports are attached to this text as an appendix).
The results from the material tests show that there are strong technical drawbacks for all major application groups, when lead-free copper alloys are used. As even these basic tests cannot be passed, the requirements of the main application groups cannot be fulfilled either. A sample for each application group is given below.

Sliding elements

In Figure 7, material tests concerning the key requirements for sliding elements are shown for some lead-free copper alloys in comparison to results of CuZn39Pb3. Whereas CuZn42 and CuZn38As represent the upper and the lower range of the CuZn38-42 family, the CuZn21Si3 represents the silicon alloy family. Every property that showed a better result (>20% better) for the lead-free copper alloys is shown in green color. Yellow indicates somewhat similar behavior (+/- 20%). Red indicates worse (>20% worse) and is therefore unacceptable behavior for these key requirements.

Concerning tribology, wear of the copper disk, the adhesion of copper on the pin and the friction coefficient were tested. Under these conditions, wear of the leaded copper alloys is much higher. Nevertheless, the contact partner is saved from wear in that case. As regards adhesion, the silicon-alloyed alloys show a behavior similar to CuZn39Pb3, whereas the CuZn42 alloy is much worse. In this case the material from the copper disk was transferred and adhered to its sliding partner to a great extent. While this will interfere with most of the sliding systems, it also indicates potential difficulties in processing these alloys. Showing good correspondence to this result one supplier (7) stated that a lot of copper was transferred to the sawing blades when sawing CuZn42. Due to the resulting burrs some batches were not usable for the tests. In contrast to this, the friction coefficient of the silicon-alloyed alloy is 30% higher (worse) whereas the friction coefficient of the CuZn42 alloy is only 10% higher than CuZn39Pb3. A high friction coefficient clearly indicates that a lot of the energy from movement is undesirably converted into heat and therefore lost. The higher friction coefficients were observed independently of the applied load (9). This clearly indicates that both lead-free copper alloys are not suitable for many tribological systems as the silicon-alloyed copper shows high friction and the CuZn42 type exhibits adhesion.



sliding elements	**(compared to CuZn39Pb3)**		
material requirements	**CuZn21Si3**	**CuZn42**	**CuZn38As**
wear of copper disc	300% better	300% better	not tested
adhesion	similar	300% worse	not tested
friction coefficient	30% worse	10% worse	not tested
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
corrosion galvanic	45% worse	35% worse	40% worse
Technical drawback:	friction coefficient	adheasion	machinability
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
		galv. corrosion	
+ additional drawback for small parts	**(micro machining)**		
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse

Figure 7: application group sliding elements – compilation of examples of test results

For sliding elements, galvanic corrosion is also an issue. One important property is the ability to maintain stable conditions under different electrical potentials, contact materials or surrounding conditions. In this case the silicon-alloyed copper and both of the CuZn38-42 family alloys were much worse than the leaded copper alloys when the whole range of electrochemical potentials was taken as a basis (10). In reality this is an essential requirement because there will be different potentials for each application and usage case. Next to the materials used the surrounding media involved are important. It is known since several years that bio-fuels like bio-ethanol trigger intergranular corrosion in several alloys. Actual tests done on bearings within the fuel feeding system show, that this is also the case for lead free copper. The corrosion speed raised by about 60% when using a lead free alloy (30).

For sliding elements, a good surface quality must be achieved during machining. As a first indication, test results from the research project (6) were analyzed. In this case the indication is given by different weighted evaluations of the single elements of the machining index test. The possibility to generate different correct results as a machining index figure already indicates that the machining index is an unsuitable tool for comparison purposes. If the parameters are not clearly defined for different approaches, this will end up with different results.

Within the research project (WZL at RWTH Aachen University) however, all test series and alloys were analyzed under the same conditions. The tests showed that the results are much worse for both of the lead-free alloy types. This was independent from analyzing machining in general or focusing on surface finishing only. In addition it has to be understood that these tests are only referring to outside machining, giving maximum potential in the variation of tools, lubrication and cooling. This allowed to somehow compensate an even bigger non-linear relationship between chipping quality and cutting depth and feed rate that occurred only in the case of lead-free copper alloys. To enhance the inferior results academic measures like cryogenic cooling were also used. But results still remain inferior (14).

As already stated, micro-machining is an issue for the majority of automotive brass parts. An example is the drilling of small deep bores. Similar geometries to those chosen for testing can be found in automotive crimping applications (2). To ensure comparable conditions to the tests on outside machining, the tests were conducted at the same research institute (WZL at RWTH Aachen university). The results clearly show the higher material requirements in that case. It has to be pointed out that as to micro-machining, the drilling of small deep bores for example, none of the tested alternative alloys showed an acceptable behavior. Even if much more time consuming drilling strategies were applied, i.e. extracting the drill from the hole every drilled millimeter to support chip removal, it was not possible to drill 1000 holes with one tool when using lead-free CuZn42 or CuZn21Si3 alloys. (12)
One supplier (7) reported similar results for the production of electric contacts. The tool life for the drilling operation was reduced to below 1% when the lead-free alloy (CuZn42) was used instead of the lead-alloyed series production alloy. Within these drilling tests, a tripling of the tool forces was observed when using a lead-free alloy. This is also in accordance with the tests conducted in the research project (6).

Component tests give additional evidence concerning the difficulties in using lead-free coppers for the main application group “sliding elements”.

New tests have been conducted in 2013 by (15) on small electric motor pinions (comparable to the bevel in figure 1). In this case the copper pinion is driving a gear wheel made from DELRIN100 (plastic). The study was conducted at the University of Erlangen and analyzed the wear and the evolution of heat within this tribological system in an endurance test. Compared to the results achieved with CuZn39Pb3, the lead-free alloy caused unacceptable wear of the contact partner, the DELRIN plastic gear wheel.

Shift forks made from lead-free material were tested by one OEM in an endurance rig test with a serial production gearbox. Even if material tests at the supplier had been positive, the component endurance tests had to be stopped before the required runtime was achieved due to extensive wear of the shift fork. This failure could cause a disastrous breakdown of the gearbox under customer conditions. (16)

Further test results have already been reported during the last revision such as the variation of the lead content for valve guides (17). One problem that was also reported from these tests was the lack of feasibility for serial production. Due to the required surface quality, the tool life was reduced dramatically when using a lead-free alloy. Under these conditions, in some cases only one engine per tool could have been machined. In addition, unacceptable wear was reported from corresponding rig tests on engines. Activities in using alternative metals instead of copper alloys also failed (2).

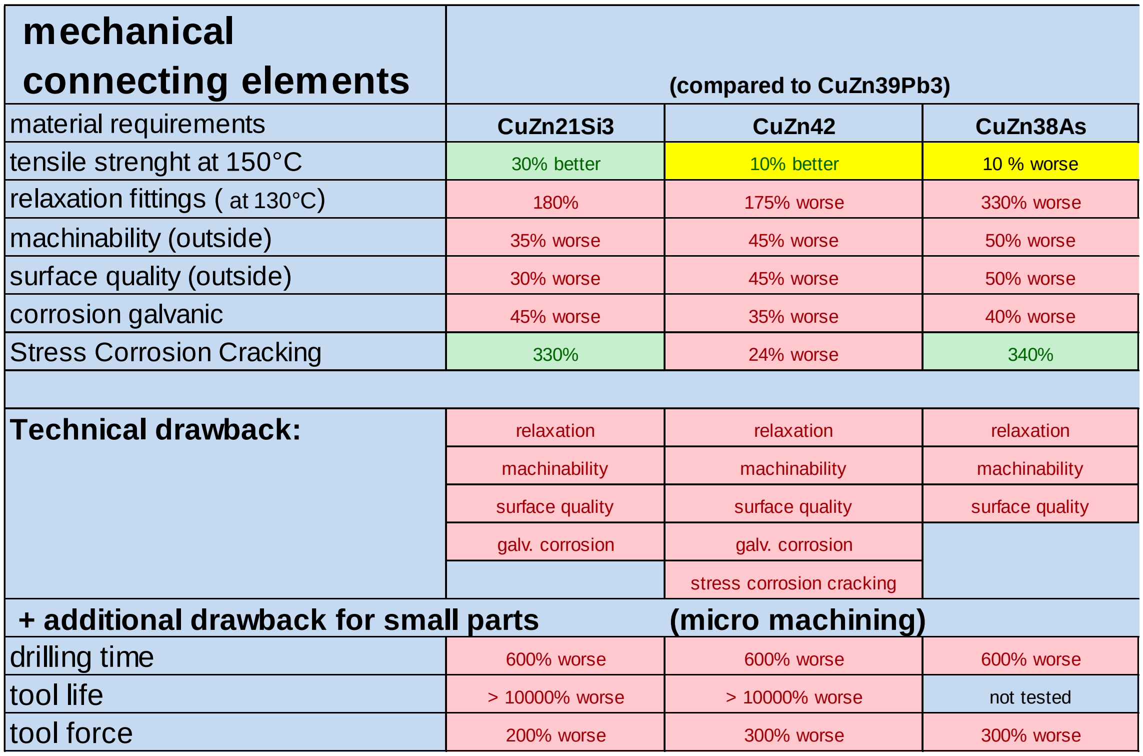
It is obvious that at this time lead-free copper alloys cannot be used for the application group “sliding elements”. In addition to substantial tribological and other functional drawbacks the tests on materials and components show that it is highly uncertain that an acceptable solution concerning micro and inside machining for lead-free copper alloys can be found in future.

Mechanical connecting elements

Another main application group is “mechanical connecting elements”. The main requirements concerning that area of application were tested in material and component tests (Figure 8).
For connecting elements, the material behavior at elevated temperatures, the machinability, the surface quality, galvanic corrosion and stress corrosion cracking are important. For smooth operations and small parts, micro machinability is also an important characteristic.

The tensile strength of CuZn38-42 family alloys at 150°C is similar to that of CuZn39Pb3. For the silicon-alloyed copper higher strength at room temperature and 150°C is observed. (13)
Loosening that might result in leakage cannot be accepted in mechanical connecting elements. Mechanical relaxation of the connection force or torque is an important issue. Tests show that even under static loading, CuZn38-42 family alloys and silicon-containing lead-free alloys show significant higher degree of loosening of the mounting torque when compared to the leaded copper alloys (18). Further tests on fittings under internal pressure and alternating temperatures were conducted on silicon-alloyed copper in 2010. In this test the lead-free silicon-alloyed copper failed before the lead-alloyed copper by a long way (19).

The results for machinability and surface quality have already been discussed in the sector “sliding elements”. Regarding fittings, it has to be added that functionalities such as leak tightness and low relaxation values are connected with smooth surfaces and small production tolerances and thus to micro machining.



mechanical connecting elements	**(compared to CuZn39Pb3)**		
material requirements	**CuZn21Si3**	**CuZn42**	**CuZn38As**
tensile strenght at 150°C	30% better	10% better	10 % worse
relaxation fittings (at 130°C)	180%	175% worse	330% worse
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
corrosion galvanic	45% worse	35% worse	40% worse
Stress Corrosion Cracking	330%	24% worse	340%
Technical drawback:	relaxation	relaxation	relaxation
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
	galv. corrosion	galv. corrosion	
		stress corrosion cracking	
+ additional drawback for small parts		**(micro machining)**	
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse

Figure 8: Application group connecting elements – compilation of examples of test results

Galvanic corrosion is a major issue for connecting elements, for typically different materials come into contact when different parts are connected. The negative results for lead-free copper alloys regarding this aspect have also been discussed.

In addition, stress corrosion cracking is a topic for connecting elements, for these parts are usually permanently stressed. Different temperatures, humidity and surrounding conditions caused, by chemical influences from salt (winter service) or sulfur (exhaust emissions) will increase the risk of stress corrosion cracking. Therefore solutions containing NaCl and H_2SO_4 were used for the material tests involving stress corrosion cracking. It has to be clarified that these generic corrosion tests cover typical ambient conditions, but of course not all conditions occurring in practice (e.g. different PH-values, different environmental loads). Therefore case-specific testing is appropriate in any case. It was found that the silicon-containing alloy behaves much better than the leaded copper alloys. Concerning the CuZn38-42 family, the CuZn42 alloy failed this test whereas the corrosion-stabilized CuZn38As gave similar results to the silicon-alloyed copper alloy. (11)

Further component tests have been conducted on tire valves by a supplier (20). These tests showed that the interconnection between the rubber and the tire valve failed under corrosive surroundings, when lead-free copper alloys were used. The result was negative for all three lead-free alloy families (CuZn38-42, silicon-alloyed, bismuth-alloyed families). Similarly, a test program using aluminum instead of copper for tire valves failed several years ago (2).

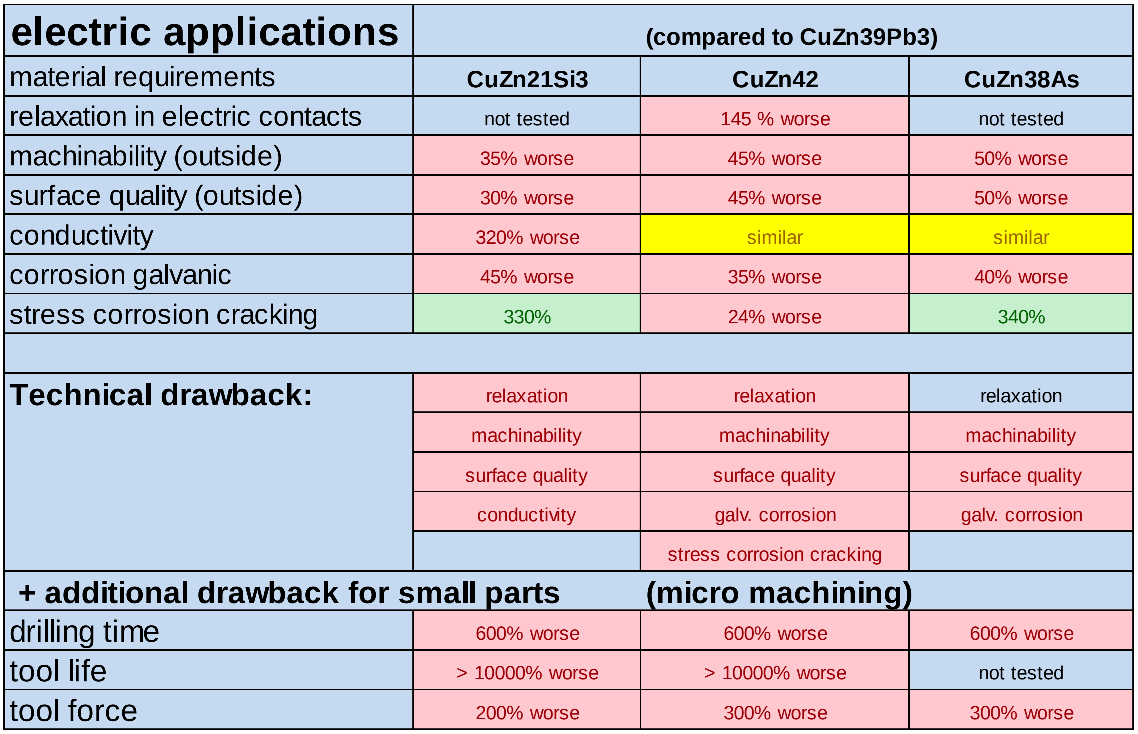
Summing up it can be said that, as regards mechanical connecting elements in automotive applications, no suitable lead-free copper alloys are currently available.

Electric applications

For the third main application group, the electric applications, the most important property is conductivity. Relaxation is also an important issue in electric contacts, since a fall in contacting force will cause a higher interface electric resistance. More heat is produced and might result in a fire. Corrosion in an electric contact leads to higher electric resistance and might result in the same effects as relaxation. Even more critical is the topic of stress corrosion cracking. If a breakage of the electric contact occurs the functionality of the component will fail and the risk of a short circuit arises that may result in a fire.

The comparison of the results for electric applications is shown in Figure 9. As already stated, weak conductivity is the major technical drawback for the silicon-containing alloys in this application group. The CuZn38-42 family has a similar conductivity as the leaded copper alloys.
In accordance to the tests conducted on connecting elements, the mechanical relaxation occurring in electric applications made from CuZn42 is much higher than for leaded copper alloys. The resulting value obtained is below the acceptable limit for electric contacts. (21)

The results for machinability, surface quality and corrosion have already been addressed.
Additional tests were conducted on crimping applications at different suppliers. Automotive crimp connections usually have to be in accordance to the USCAR 21 standard (22). The requirements, especially the respective ambient conditions, are much higher than the corresponding EN/DIN standard. Tests have shown that low lead or lead-free copper alloys cannot be used for this type of electric application. The micro drilling of small bores (typically less than 1mm in diameter and a length to diameter ratio of 10:1) does not achieve the narrow tolerances and high surface quality needed within the borehole for a reliable connection between the cable and the crimp. Furthermore, good relaxation resistance is important. If the connecting force drops, this will cause higher contact resistance and heat. Finally a breakdown of the connection or even a fire might occur as a result.



electric applications	**(compared to CuZn39Pb3)**		
material requirements	**CuZn21Si3**	**CuZn42**	**CuZn38As**
relaxation in electric contacts	not tested	145 % worse	not tested
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
conductivity	320% worse	similar	similar
corrosion galvanic	45% worse	35% worse	40% worse
stress corrosion cracking	330%	24% worse	340%
Technical drawback:	relaxation	relaxation	relaxation
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
	conductivity	galv. corrosion	galv. corrosion
		stress corrosion cracking	
+ additional drawback for small parts		**(micro machining)**	
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse

Figure 9: Application group electric applications – compilation of examples of test results

Using lead-free brass such as CuZn42, unacceptable relaxation values were obtained. Similar results were stated from two suppliers that conducted independent test series. A detailed description is given in (21; 23). Even tests with different coatings used in special cases, nowadays did not help to solve this problem (23).

Tests, conducted on battery terminals in 2010 using a silicon-alloyed copper were repeated in 2014 using the alloy CuZn42. Even if the recommendations on processing from the research program done at WZL at RWTH Aachen University were taken into account, as far as possible, the supplier was not able to produce the battery terminals in the required quality that would have allowed further testing (24; 25).

All this confirms that for the third major application group “electric applications” also, the known lead-free copper alloys cannot be used.

Question 7

Please indicate which research has been done during the last years to find substitutes and/or to develop alternatives? Please provide specific documents/evidence supporting the search for substitutes (e.g. roadmap)

The claim that lead-free copper alloys fail to meet the specification requirements triggered further detailed analysis on the function of lead in these alloys. Since the last consultation in 2010, significant work has been conducted to gain comprehensive material knowledge on lead-free copper alloys and corresponding process technologies. An overview is given in Figure 10. New results make up a comprehensive inventory on the type of alloys used and an analysis of material properties and manufacturing processes needed for the main application groups.

Studies have been conducted to collect available knowledge. These have been accompanied by industry-driven tests on materials and components. Further input was gained from public-funded research programs, some of which are still continuing. Material producers, component and car manufacturers were integrated into this process and were supported by research laboratories and universities.

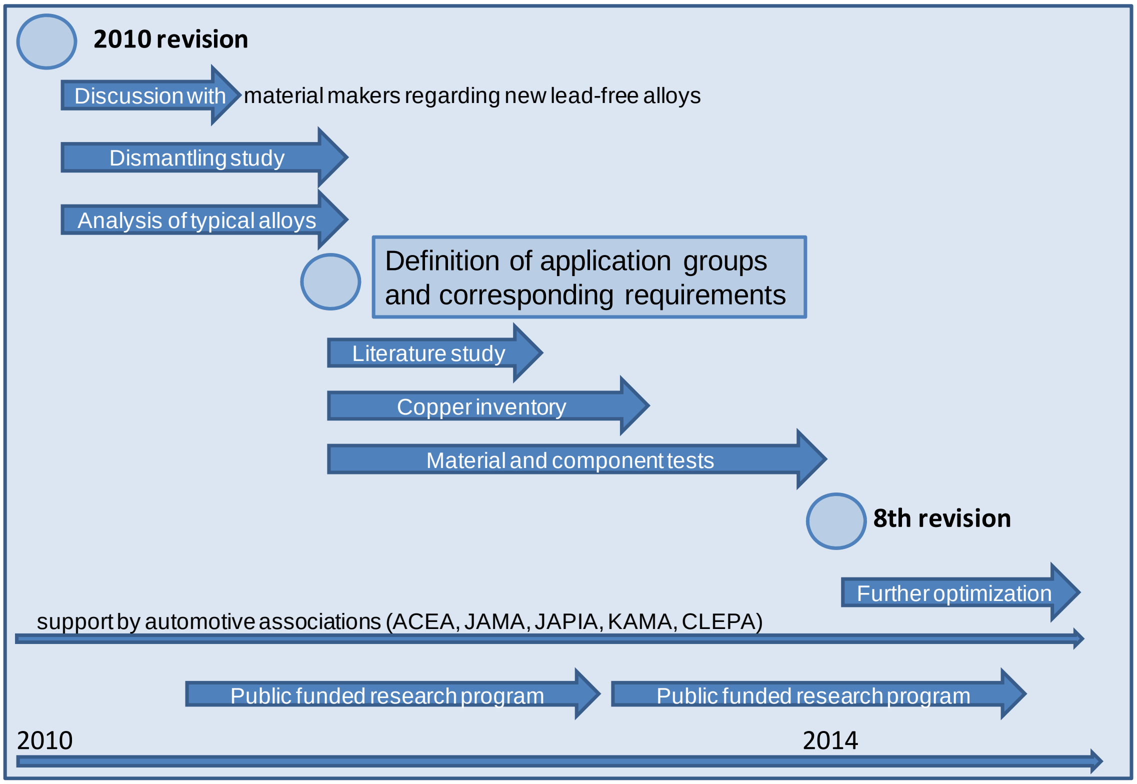


Figure 10: Roadmap of activities since the last revision

Since 2010 the inventory of the use of leaded copper alloys in cars was optimized. The range of applications where these materials are used is widely spread. It is obvious that many applications are linked to electric or electro mechanic devices. In many cases, these applications are also linked to safety- and economics- related considerations. To verify findings on applications by screening OEM and tier 1 product information, such as drawings, a dismantling study was conducted on examples of components in order to scrutinize and understand the requirements of these parts.

Many of the parts are very small. The integration of these parts into an assembly is in many cases on a sub-sub supplier level. As to their function, they usually have the same material requirements as the heavier parts, but additionally have challenging requirements in terms of micro machining. Nevertheless the function of the part might vary from that of the component in which it is used.

It was decided to allocate the applications into three major application groups: these are “sliding elements”; “mechanical connecting elements” and “electric applications”. This classification has allowed activities to focus on material testing. For the first time some basic standard material tests have been defined for each application group. Based on this knowledge, certain types of alloys can be tested in future. If there is no positive result, time-consuming component and vehicle tests can be avoided. Nevertheless these tests have to be conducted for all alloys that passed the initial material testing.

Gaining of additional material knowledge:

The updated literature study is showing that despite all efforts no new lead-free copper alloys have been developed since 2010 that show potential for future industrial use (1). The alloys already known were developed initially for drinking water applications which pose totally different requirements. Reports on usage and processes deal with the requirements of this application group. This was confirmed by major European brass manufacturers.

Whereas knowledge of basic properties (such as strength and fracture elongation at room temperature) of semi-finished goods were available, only little knowledge of the material data needed in the automotive industry and converting data was available. Without these data, there is no chance to assess the material behavior for the main automotive application groups.

Concerning the three main application groups “sliding elements”; “mechanical connecting elements” and “electric devices” the required material properties are resistance to creep and relaxation, corrosion behavior in contact with different materials, fluids and under stress, tribology, vibrations, contacting and other electrical requirements.

For these topics some basic testing procedures were defined to analyze differences between the materials in general. The studies were mainly coordinated by the German Copper Institute and have been conducted at research laboratories and at universities.

The tests were conducted on lead-free copper alloys using CuZn39Pb3 as a reference. Special focus was on alloy types promoted after 2010 such as CuZn42 and CuZn38As. From the family of silicon-containing alloys, CuZn21Si3 was chosen for further testing. Bi-alloyed copper was not investigated. The problems of recycling and mining showing that this alloy is an unsuitable alternative were discussed and accepted already in the 2010 revision.

The results from material testing, also confirmed by similar test done by JAMA (26), show that there are strong technical drawbacks for lead free copper alloys in all major application groups. Since basic tests cannot even be passed, nor can the requirements of the main application groups be fulfilled.

Nevertheless component tests were done to give evidence to the results in material testing. The results from component tests strengthen the scientific findings from the material tests. The universal properties of leaded copper alloys cannot be met by lead-free copper alloys. Therefore these cannot be used as an alternative and there is little hope since all of the obvious alternative alloying elements have been analyzed. Material research efforts on less promising solutions cannot be addressed by the automotive industry to a greater extent due to the small market share of automotive brass (~5%).

Gaining of additional processing knowledge:

Processing and machining are the most important topics for this family of alloys.
Material producers and material processing enterprises have conducted a comprehensive, public-funded research program on macro machining of these alloys that was finished in the autumn of last year.

Tests completed within this program show that working forces are up to 3 times higher and working temperatures rise significantly (200-300°C higher) when machining tests are conducted with lead-free copper alloys. Higher working forces may result in losing accuracy in component geometry, and higher temperatures can damage tools and parts.

Furthermore, the process window is much smaller for these alloys, leading to more rejects and quality problems. One factor contributing to this is the chip breaking quality. In contrast to leaded copper alloys, it is not independent from feed and cutting depth. This is even more critical when considering that chip breaking quality of the lead-free copper alloys is already much worse under ideal working conditions. Academic measures like cryogenic or high pressure cooling were needed to complete the tests. Heavy lubrication is also needed (6). The advantages of dry machining for health and environment will be lost (27). This is in contrast to research activities to enable a more universal use of dry machining. These programs were also supported by the EU commission in recent years (28).

Reduced tool life and problems in chip breakage are general problems for series production. Processes might be interrupted and in many cases manual processes will be needed to proceed.

It is obvious that if under optimized conditions and during surface machining on standard sized parts (where the most changes for tools an process parameters are possible), only 50% of the machining index of leaded copper alloys can be reached, the difficulties will multiply when machining of small parts and/or internal machining is required.

Due to their size, most parts in the automotive industry do not deal with conventional machining but with micro machining. Therefore it was decided to analyze the drilling of small bores as one example of micro machining at the same institute that did the tests for the research project. The results show that processing time, tool life and drilling strategy for the lead-free copper alloys are far from what could be considered acceptable for series production.

Even with the most advanced drilling strategy two out of three lead-free copper alloys tested failed to finalize the 1000 bores of the test program. For leaded copper alloys, tool life is expected to be a factor of 100 to 1000 times higher.

Furthermore the machining tests showed that, for the lead-free copper alloys, even small changes in lead content will cause drastic changes in the required processing. This is also an alarming obstacle for series production and has to be addressed in further tests and material specifications.

Meanwhile material producers and processing companies have initiated a further public-funded research program on internal machining that will be completed by the end of 2015. Therefore basic, public-funded research work is still going on. It can be concluded that the general knowledge on special machining strategies, suitable tools and lubricants is still in an early research stage - otherwise governments would not fund related research projects. Further efforts have to be made before series production processes can be derived from these test results.

Due to different processes in series production using turntable machines instead of turning centers, many of the adopted suggestions that might be developed in research and might be helpful for processing lead reduced alloys are not easy to integrate into the machinery in operation. Changes would require further substantial financial investments (7).

A reduction of the lead content in general is not possible too, for micromachining that is needed for most of the parts is an unsolved problem.

Recycling:

There are absolutely no obstacles to recycle leaded copper alloys. Well established material recycling loops exist. Even copper alloy-based scrap is a desired product. Leaded copper alloys mainly enter the material cycles for brass-based scrap. All copper from automotive applications goes into common recycling loops for copper and brass. To our knowledge, Si-containing lead-free machinable copper alloys require specific recycling procedures and should not be mixed with conventional lead-containing brass scrap fractions.

Further limitations to lead content would run the risk of cannibalizing or damaging existing well established recycling loops. This would be a conflict with other ELV directive targets such as the increased use of secondary (raw) materials. It has to be noted, that today scrap in the form of chips and shavings is the basis for producing new lead-alloyed brass.

Question 8

Are there technical developments that allow a further reduction of lead? Can the limit of 4% be minimized? If not, please explain why this is currently technically or scientifically impossible / impracticable.

We understand the intention of this question, but as can be seen from Figure 6, vehicle component-specific assessment is needed because of the big variety in demands. Over the last five years significant work has been undertaken to assess technical development that could lead to reduction in lead. However the knowledge gained through this work is not sufficient yet to give a clear answer in such a broad field. Due to the complexity of the use of these alloys, further research and development work is needed by whole supply chain to assess any technical development that potentially could result in further reduction in lead.

As already described, leaded copper alloys with up to 4% lead are used for all major application groups. The most used machining brass alloys of the type CuZnXXPb3 usually embody a lead content according to worldwide standards ranging from 2.5 to 3.7 %. For other alloys containing up to 4% lead that are used in automotive applications, no substitutes are offered by the material producers.

Furthermore most of the parts used are linked to micro machining. At present it is completely open if available machining methods will allow a general reduction in lead in any case. An indication of the challenge regarding this point is given by the failed results involving lead-free machining brasses.

The micro machining, tests reported by JAMA show that, in this case, even a reduction from an alloy containing 3.1% lead to an alloy containing 2.3% lead content caused unacceptable failures due to burrs, chatter marks and wear of the tool used. Tool life was reduced from 25,000 pieces to only 400 pieces (29). This result is in good correspondence with the tests done on valve guides in 2010 (17).

Since the last revision, the total lead content in machining brass in a car is on average somewhat stable or slightly decreasing. Nevertheless, due to new environmental and emission controlling measures and additional safety-related features, the number of small parts is rising slightly. As outlined, a lead content of 4% is extremely important for micro machining and essential for complex micro machining. As already mentioned, the procurement systems are not able to analyze this topic in detail.

The process of reducing the leaded copper alloys will continue in future. But it is already clear now that the lead-free copper alloys – as delivered today – cannot offer a technologically acceptable solution. Due to this lack of usability, it is not expected that an elimination of leaded copper alloys will be possible based on these alloys.
Nevertheless, activities to reduce the lead content will go on, but that might be limited to alloys that already have a low lead content today. Due to these reasons, it is not possible to reduce the maximum lead content of 4% in copper alloys.

Further information is given in the attached documents.

Conclusion:

The joint associations are stating that the unlimited prolongation of exemption 3 is required. The maximum lead content must remain at 4%. Due to the lack of new materials in research, and typical model cycles within the automotive industry, the joint associations propose a review time of 8 years.

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