Exemption Request Form

Date of submission: 20 January 2023

1. Name and contact details

1) Name and contact details of applicant:

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2) Name and contact details of responsible person for this application (if different from above):

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Function: Material compliance WG chair

Address: As above

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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 Annex III

☐ 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: 7(c)-I

Proposed or existing wording:

7(c)-I: Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezo-electronic devices, or in a glass or ceramic matrix compound used in engines, engine components and ancillary components and in end-products

Duration where applicable: 5 years

☐ Other:

3. Summary of the exemption request / revocation request

Lead in glass and ceramic materials are widely used in all types of Electrical and Electronic Equipment, including in EUROMOT member applications. Lead is used for its unique properties including high precision sensors, hermetic sealing properties and material stability in a wide range of conditions.

EUROMOT applications have to withstand temperature cycling in the range of -40°C to +150°C, harsh environmental conditions with high humidity and exhaustion fumes in addition to mechanical strain due to the high vibrations. Those operation conditions require the high reliability that is characteristic of the of leaded glass and ceramic materials such as low-melting point, excellent wettability with different materials, weather and corrosion resistance, low susceptibility to dielectric breakdown under high electric loads and high mechanical strength and crack resistance. Those properties make leaded glasses and ceramics components reliable over a life cycle of over 10 years.

Industry has investigated the substitution of lead in glass, ceramic and matrix compounds for the last 20 years with the aim of the developing reliable technical solutions on an industrial scale. Despite this extensive research, substitution technology has not been found up to the present day for many critical applications and there are no prospects of finding substitutes with comparable characteristics of performances and reliability in the near future. Once a viable alternative has been developed, EUROMOT members will need to undertake systems level testing, reliability assessments and approvals for some component changes.

EUROMOT recognises that there is the recommendation to change the current wording of the exemption and sub-divide the scope listing into specific uses. EUROMOT members, as end equipment suppliers does not have the necessary technical information to be able to determine if all of the uses of lead in a glass or ceramic are listed. However, EUROMOT members have engaged extensively with their supply chain and, although information is scarce it has been made apparent that lead-free alternatives for EUROMOT applications are not available from the manufacturers and therefore a timeline for assessing the transition to a lead-free alternative is difficult to predict. Moreover EUROMOT members are of the opinion that the proposed scope is too restrictive and will likely prevent the use of lead in a glass or ceramic in applications that are not listed and this would prevent engines and the corresponding end-products from being sold in the EU. In the meantime it is essential that the original scope of the exemption remain valid for EUROMOT members uses such that there is sufficient time to allow for these activities to be undertaken.

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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: Internal combustion engines, associated components and end-products in which these are used.

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

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

b. Please specify if application is in use in other categories to which the exemption request does not refer: Yes, in category 1 to 10

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:

Lead is used to obtain the appropriate physical characteristics in glass and/or ceramic for each specific end-use. Characteristics include, but are not limited to, low melting point, wettability, chemical stability, small thermal expansion and less susceptibility to dielectric breakdown.

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

Up to 93% by weight of homogeneous material

5. Amount of substance entering the EU market annually through application for which the exemption is requested. Please supply information and calculations to support stated figure.

Two EUROMOT members provided data for 7cI.

Manufacturer A estimated for 7cI that the total quantity of lead in parts using exemption 7cI is 11.5kg, based on their estimated use and market share.

Manufacturer B estimated for 7cI that the total quantity of lead in parts using exemption 7cI is 1.5kg based on their estimated use and market share.

As such the quantity of lead used in engines in scope of RoHS for exemption 7cI is expected to be between 1.5 and 11.5 kg per year in EU excluding the UK. It should be noted that this is not reflective of all Category 11 uses which is not able to be calculated by EUROMOT.

6. Name of material/component:

Lead in a glass or ceramic materials, other than dielectric ceramic in discrete capacitor components, used in electronic components.

7. Environmental Assessment:

The independently researched Life Cycle Assessment (LCA) of lead-free piezoelectrics[1] was referenced in the Umbrella projects exemption renewal. The LCA compares laboratory scale lead-free alternatives (potassium sodium niobate (KNN) and sodium bismuth titanate (NBT)) to the mass production of lead zirconate titanate (PZT), due to a lack of lack of established industrial-scale processes in lead-free alternatives. The LCA uses the following five indicators: greenhouse gas emissions (GHG emission), material use, land use, toxicity (5 variants) and pollution. Therefore considering aspects from the sourcing and production stages, energy consumption and life expectancy.

Overall the lead-free alternatives assessed have a greater total negative environmental impact. This is based on the consideration that KNN has higher primary energy consumption and ECO indicator 99 than PZT. It is recognised that NBT during synthesis has a lower overall environmental profile compared to PZT. However, 90–95% of bismuth and its oxide are derived as a by-product of lead smelting roughly, which is also a concern as to how it could be up-scaled. Comparison between NBT and PZT indicates that the environmental profile of bismuth oxide surpasses that of lead oxide across several key indicators, especially climate change, due to additional processing and refining steps which pose extra challenges in metallurgical recovery. Furthermore, bismuth compares unfavourably with lead due to its higher energy cost of recycling. Full details of the LCA can be found in the Umbrella Project's exemption 7cI renewal request[5].

LCA: ☐ Yes
☒ No

[1] Ibn-Mohammed et al., University of Sheffield, as part of the research programme Substitution and Sustainability in Functional Materials and Devices referenced in the application of the exemption request form RoHS 7(c)-I Umbrella Industry Project, 19 December 2019 https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_22/Exemptions/7c_I/Application_UP_7_c_-I_Exemption_Request_31Jan2020_final.pdf

(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?

Description of the supply chain, product sectors and uses of lead

EUROMOT members manufacture engines used in a wide variety of end-applications including heavy goods vehicles, excavators, emergency generators, compressors, pumps, and tools (portable and stationary[2]). The majority of these engines have end-uses that are excluded from the scope of RoHS as they are forms of transport or non-road mobile machinery as defined by the RoHS Directive. As a result, only a small proportion of engines and their glass or ceramic materials that are used by EUROMOT members need to comply with RoHS[3].

Lead is used in a wide variety of Electric and Electronic Components that are incorporated into Electrical and Electronic Equipment (EEE). EUROMOT members use similar components to the wider electrical industry sector which is described in the Umbrella Project in its exemption 7(c)-I renewal request and its answers to clarification questions[4].

In addition to the general use of 7(c)-I components, there are also engine-specific components such as sensors and actuators which rely upon 7(c)-I. The following is an illustrative list of uses of components and their end uses utilising exemption 7(c)-I obtained from EUROMOT members and other sources of information.

Indicative components used:

- Actuators,
- Dielectric converter,
- Diodes,
- Glass electrical contact, and
- Integrated Component (IC).

Equipment uses:

- Actuation module
- After-treatment control unit
- Alternating current generator
- Antenna Printed Circuit Board (PCB) components
- Belt drive
- Carburettor
- Charging device

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[2] Many types of professional tools that use combustion engines are excluded from RoHS as Non-Road Mobile Machinery (as defined by RoHS), but the status of some types is unclear, and some are "semi-mobile" machinery which is probably in scope.

[3] These engines are also not used in road vehicles in scope of the EU End of Life Vehicle (ELV) Directive.

[4] https://rohs.exemptions.oeko.info/exemption-consultations/2020-consultation-2/aiii-ex-7c-i

- Common rail fuel injection systems
- Control unit or supply modules for Diesel Exhaustion Fluid
- Control unit components
- Differential pressure or vacuum switch
- Engine control unit
- Emissions device
- Electrical throttle
- Engine control components
- Fuel pump control components
- Fuel shut off valve
- Fuel filter assembly
- Ignition coil
- Motor power distribution unit
- Negative Temperature Coefficient Surface (NTC) Thermistors Regulator rectifier
- Oil mist separator
- Resistors, including metal film resistors and electrodes
- Sensors: such as pressure, differential pressure, level, temperature, temperature manifold absolute pressure, air, oil, NO_x and CO
- Positive Temperature Coefficient (PTC) thermistors
- Transient voltage suppressor
- Throttle actuators
- Turbocharger

The above illustrative examples can experience severe operating conditions of temperature, vibration and corrosion and must be reliable for at least several decades. With exact service conditions and lifetime are end-product dependent.

Piezoelectric materials are used due to their accuracy and sensitivity, in components such as actuators, resistors and IC's. In addition, lead containing piezoelectric materials have a high curie temperature (Tc) and depolarisation stability of material properties under changing temperature conditions. This is particularly important due to the operating temperatures of engines in which components can reach +150°C or higher in some applications. Piezoelectric materials are used in general applications, such as actuators for high precision positioning of tools with an accuracy in the order of µm. Another indicative use is as heat-sensitive sensors whose resistance increases with temperature, and can be used in almost all areas where a digital temperature measurement is required, for example in motor protection.

Lead is also used in sealing and bonding glass, in applications such as a glaze overlay on chip components, to prevent corrosion of internal parts. Leaded glass is also used as an hermetically sealing material for diodes, IC's and other components. The glass is characterised by particular resistance to high humidity environments and operating/storage temperatures varying between -55°C to +175°C. Moreover it provides mechanical protection of components surfaces, electrical insulation, including dielectric breakdown resistance.

EUROMOT's members use many 100s and probably 1000s of components that rely on this exemption. The manufacturer of each component specifies the function and characteristics of each component and everyone will be different. EUROMOT members needs these components such that their engines operate correctly and meet emissions limits required by EU legislation. If there are significant changes in a component's characteristics (for example, if an IC is replaced by one with a different design), it may not be possible to supply these engines in the EU until re-design, testing and recertification are completed, which will take many years. In addition for EUROMOT's members, the components need to operate under harsh environmental conditions and all components must operate as specified for many decades.

EUROMOT recognises that from the Umbrella project that there is the proposal to limit the exemption scope to sub-divided scope listing out specific uses. EUROMOT members, as end equipment suppliers, have not been able to obtain the necessary technical information from suppliers to be able to determine if all of the lead in a glass or ceramic uses are listed. However, EUROMOT members are of the opinion that this scope would be too restrictive and will likely exclude some essential technical use of lead in a glass or ceramic in applications that are not listed. Engagement with EUROMOT members supply chain is on-going to identify if any specific uses are not included. In the meantime it is essential that the original scope of this exemption remain valid such that there is sufficient time to allow for these activities to be undertaken.

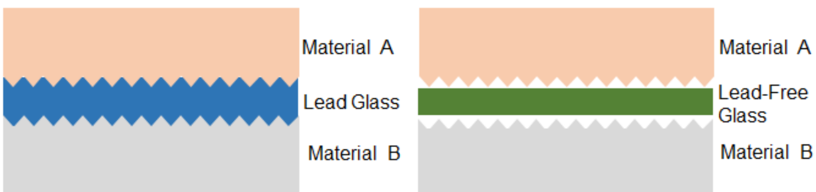
(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

Engines made by EUROMOT's members are used in a wide variety of environments and under many different use conditions. Each type of engine needs to be suitable for all conditions that it is likely to be used in and so are designed to be reliable under the most severe conditions. In order to ensure the essential properties, such as thermal characteristics and resistive value stability it is necessary to add lead.

When used as part of the construction each component application has a unique combination of essential requirements which include:

1. Binding/adhesion:

Lead-containing glass has excellent wettability (affinity) with metals and ceramics, and can improve binding/adhesion in bonds between the different materials in the components.



Material A	Ceramics	Ceramics	Metal	Glass
Material B	Ceramics	Metal	Metal	Ceramics

Figure 1 Example of bonding between different substrates[5]

Engines are used in Northern Europe where night-time temperatures can drop to -40°C and then while operating, the electronics attached to engines can reach +150°C and some components will be even hotter (e.g. when close to the exhaust system). This very wide temperature range imposes significantly more severe stresses on glass bonds than are experienced by most other types of electrical equipment such as those used in consumer, household or IT equipment, etc. Many of EUROMOT's members products are used for two or more decades and so these bonds experience a high degree of thermal cycling over a long timeframe. It is therefore essential that the bonding material used can withstand low cycle fatigue with high cyclic stresses. If this glass is substituted by a lead-free glass, the heating-cooling cycling (needed to melt the glass so that it flows over the substrate, and then cool so that the glass is annealed and does not contain high stresses) can cause cracks and delamination in the bond due to stress generated by the difference in thermal expansion coefficients between different materials being bonded. As a result lead-free glasses can result in the premature failure of components.

Lead containing glass is also used for bonding different materials in electronic components that are subjected to severe vibration. Engines are designed with withstand up to 12g, with engines expected to operate at full loading for all of their operational time. Due this the vibration profile of the components is severe. Although there are mitigating measures which can limit the vibration experienced by the components, the heat experience due to the proximity to the engine and the exhaustions sources cannot be prevented.

Engines can vibrate for long periods, and this can cause high frequency fatigue to connections and seals due to the repeated strain imposed. This is due to the fact that when component are connected to a vibration load, they undergoes large bending and deformation, and large alternating stresses and strains are generated on the joints and seals. The mechanical alternating stress will make the joint undergo cyclic tension and pressure, which may cause the generation, expansion, and extension of cracks.

In addition to the vibration experienced during operation, although equipment with engines in scope of RoHS is used at fixed locations, it is moved between locations. This can be over very rough terrain such as in quarries and building sites and this can cause sudden shocks which impose very high g-forces on leaded glass and ceramics (similar to dropping equipment onto a hard surface).

Lead provides a variety of essential characteristics to the glass bonding materials including fluidity when molten, low stress when cooled, suitable thermal expansion coefficient and low melting point. Essential characteristics are application-specific and usually only known to the manufacturer of the electronic component. However, leaded bonding glass will need to melt at about 300-340°C to achieve good bonding without deteriorating the performance of other materials. As with all sealing involving glass, adapting the thermal expansion of the components to be joined with solder glass is a necessary prerequisite for stable, gas-/leak-tight joins. The maximum service temperature of leaded glasses is generally higher, with the exact temperature depending on the glass type and have better electric insulating properties.

2. Weather resistance/corrosion resistance:

Lead-containing glasses, such as those used to seal sensors will be exposed to the external environment. In EUROMOT applications these include exposure to marine conditions (salt spray) corrosive substances that are used in factories, exhaust gases, lubricants or coolant fluids, depending on their location. Due to the high chemical stability of leaded glasses, that has been proven in engines over many decades, these materials show low signs of degradation even when exposed to these types of environments.

Leaded glasses are required to withstand substantial vibration over prolonged periods as engines vibrate, and so high cycle fatigue resistance is also an essential requirement.

3. Breakdown voltage:

Due to its high chemical stability, lead-containing glass is less susceptible to dielectric breakdowns even if high electric loads (volume resistivity at 350°C, 4.00e+7 Ohm-cm, at 250°C 4.00e+9 Ohm-cm[5]) are applied and they have excellent breakdown voltage characteristics.

4. Mechanical strength:

Lead containing glasses used to encapsulate electronic components are subjected to thermal shock caused by rapid temperature changes, vibration or mechanical shock due to the operating environment or environmental conditions of the application. If the material used has insufficient mechanical strength, it becomes easier for the glass to break down due to thermal shock, etc., which will cause deterioration of the equipment's reliability.

Lead containing glass is known for its excellent crack resistance properties which are due to its characteristic low porosity. The presence of voids in the glass matrix acts as a stress intensity factor which increases the possibility of crack initiation and propagation, therefore a structure with low porosity is preferred for applications exposed to high and low temperature cycles and vibrations.

5. High temperature operation:

Electronic ceramics lose their electrical functions above a certain temperature (Curie temperature), however lead-containing electronic ceramics have high Curie temperatures and can perform at high temperatures.

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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.)

Although some engines are returned to the original manufacture, a significant proportion are disposed of by other organisations so no closed loop system exists specifically for these components. Rather the lead glass and ceramic is incorporated into the larger electric and electronic devices and should be recycled according to the requirements of the WEEE Directive and EU waste legislation.

[5] Material data from https://www.matweb.com/search/datasheet.aspx?matguid=2873442d080b4979a169d45e7a2dee55&ckck=1

2) **Please indicate where relevant:**

☐ Article is collected and sent without dismantling for recycling

☒ Article is collected and completely refurbished for reuse Some engines are refurbished

☒ Article is collected and dismantled: Some spare parts are recovered and refurbished to be used in refurbished engines.

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

☐ The following parts are subsequently recycled: ______

☐ 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:**

EUROMOT members estimate that 10% of engines are refurbished, and therefore 90% are recycled:

☒ In articles which are refurbished 0.15 kg – 1.15kg

☒ In articles which are recycled 1.35 kg – 10.35kg

Professional engines at end of life are recycled as metal scrap and lead is recovered in the EU by recycling processes. The number of engines and quantity of lead are not recorded consistently in the EU, so a calculation on quantities is difficult, especially as the engines reaching their end of life currently are over 30 years old. In a stable market, the quantity of lead used in new engines will be similar to the amount reaching the end of life.

☐ 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

EUROMOT's members do not make electronic components rely on their supply chain, which has the necessary expertise, to carry out research into lead-free alternatives. As such, the following is a summary of published literature on research on possible lead-free components. Additional work by EUROMOT's members‘ suppliers may have been carried out but as this is confidential it has not been divulged to EUROMOT's members. Only when suitable substitute components and bonding materials are developed and proven to be reliable by these suppliers will EUROMOT's members be able to start the systems level qualification and recertification activities which will require additional time.

Since RoHS was first proposed, a huge effort has been made to develop alternative lead-free glass and ceramic materials but with only limited success. The main candidates at present are:

1. Lead-free piezoelectric ceramics,
2. Lead-free PTC thermistors,
3. Low melting point glasses,
4. Lead-free glass alternatives.

Lead-free piezoelectric ceramics have been investigated as possible alternatives and potassium sodium niobate (K, Na)NbO_3 (KNN) ceramics, composed of potassium and sodium niobates have been identified as one of the most promising alternatives.

Currently available (K, Na)NbO_3 lead-free piezoelectric ceramics have the following disadvantages compared to PTZ that do not enable the achievement of lead-free electronic components in practice at present:

- Low piezoelectric performance (piezoelectric constant), so in order to achieve equivalent electrical performance it is necessary to increase the element size several times. There are significant space constraints in engines which would make this impossible for many components.
- Inferior thermal properties, so operating condition temperatures must be lowered in order to achieve the required electrical functions. The operational environment of the engine exposes components to high external temperatures, as well as the high temperatures of the engine and as such this would not be able to be lowered for EURMOT uses.
- Inferior fatigue properties and mechanical strength, resulting in the reduction of the present service life of the product being reduced within a range from several tens to several hundreds of times, which would create more waste.

The sintering reaction of (K, Na) NbO_3 ceramics is more difficult to progress when compared to PTZ, as alkali metal elements (K, Na) have higher volatilization rates (due to higher vapour pressure) and produce alkali metal vapours during the firing process making it difficult to control the firing atmosphere. For this reason, firing stability is not possible, and the process yield cannot be ensured and is usually low as material with an incorrect composition cannot be used.

Due to poor yields, when trying mass production in order to meet the demand for piezoelectric ceramics, a large amount of by-product waste would be generated, causing an increase in environmental load due to the massive consumption of energy and resources, in addition niobium is a critical raw material so may also present a resource supply risks.

The most recent breakthrough was achieved in 2019, when Li et al. reported Sm-doped $Pb(Mg_{1/3}Nb_{2/3})O_3$ (PMN-PT) crystals. However, despite the exceptionally high electromechanical properties, PMN-based crystals suffer some drawbacks, like the relatively low depolarization temperatures (60–150 °C), compositional variations, and poor long-term stability[6]. As components in engines can operate at 150°C, over long timeframes (up to two decades) KNN does not offer the necessary performance requirements and therefore cannot be used.

Bismuth sodium titanate ($Ba_{0.5}Na_{0.5}TiO_3$; BNT) have also been investigated and shows promise for applications at room temperature. However, due to the large remnant polarization (Pr~38 µC/cm2), it holds a complex perovskite structure and rhombohedral phase, with a transition temperature of 200°C, above which it changes to the anti-ferroelectric phase. When such transition occurs the Curie temperature (Tc) drops to 320°C, making the substitution unreliable[7].

Inorganic perovskites have also been investigated, however researches have showed that current compounds show lower efficiency due to structural instabilities. Those instabilities have been observed to be related to the concentrations and types of dopants and doping techniques, however those materials are still at the research development stages and will take further development to be a feasible alternative for the current applications.[8]

TiO_3-based ceramics composed of potassium, sodium and bismuth have been investigated to achieve electrical functions at high temperatures, but in all of these cases, product design is impossible due to large electrical function variations that occur with temperature changes.

Due to all of the differences in performance, these potential alternatives currently cannot offer the required technical performance to enable systems level testing to be started by EUROMOT members.

Positive Temperature Coefficient thermistors, have a linear resistance-temperature characteristic, with a slope that is relatively small through most of their operational range. They may exhibit a negative temperature coefficient at temperatures above 150°C. PCT thermistors have temperature coefficients of resistance of about 0.7 to 0.8% / °C. Industry has conducted research and development activities to find materials that are candidates for lead-free PCT thermistors, such as alkali metals, alkali earth metals and bismuth as additive elements in substitution of lead. However, to date they have not offered the necessary technical performance to enable EUROMOT members to identify promising potential alternatives. For example, under actual operation conditions, part of the alkali metals will precipitate in the crystal grain boundary and causes the electrical resistance to change, hindering the long-term

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[6] Koruza, J., Liu, H., Höfling, M., Zhang, M., & Veber, P. (2020). (K,Na)NbO3-based piezoelectric single crystals: Growth methods, properties, and applications. Journal of Materials Research, 35(8), 990-1016. doi:10.1557/jmr.2019.391

[7] https://www.azom.com/article.aspx?ArticleID=20882

[8] O.O. Bello, M.E. Emetere, Progress and limitation of lead-free inorganic perovskites for solar cell application, Solar Energy, Volume 243, 2022, Pages 370-380, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2022.08.018. (https://www.sciencedirect.com/science/article/pii/S0038092X22005643)

stability of electrical functions and reliability. Service life is also reduced to one tenth of the original lifespan.[5]

Low-melting point (LMP) glass solders

The melting temperatures of lead-free glasses are typically at least about 120-160°C higher than those of lead-based glasses. This means a higher bonding temperature is required causing larger stresses due to the thermal expansion forces generated and which can result in cracks in the bonds, substrates, etc. As well as difficulties in maintain the sealing/bonding integrity and electrical insulation required which has the overall effect of increasing the risk of component failure.

The increase in the glass bonding temperature would also have a negative effect on the wettability of the glass on metal surfaces, resulting in bonding strength degradation and bonding failures. Over the last 20+ years multiple attempts to create alternative low melting point glass mixes, such as β-eucryptite, zirconium vanadate (ZrV_2O), and zirconium tungstate (ZrW_2O_8) or $BaO(SrO, CaO)$-B_2O_3-Bi_2O_3 systems, have been made. However, these materials resulted in non-homogeneous or crystalized seals, or they did not wet to metals, and as such did not create a reliable seal or one which is vacuum-tight.

Alternative inorganic sealants which are claimed can be used to seal some types of electronic components are currently available on the market. Some of these new materials have melting temperatures that are below 400°C but only two are below 350°C and both of these have a relatively high coefficient of thermal expansion value which may not be suitable for some applications[9]. Before new material can be used, it is necessary to determine its resistance to thermal cycling, vibration, high humidity, etc to ensure long term reliability. These are essential for high temperature thermal cycling and extreme environments that EUROMOT's applications require. Use of an inappropriate substitute could lead to shortening of service life and early failures with corresponding poor reliability.

Sealing glasses must have specific properties for each application, including low melting point, specific coefficient of thermal expansion properties at all use temperatures, dielectric

[9] https://www.yekglass.com/glass-frit-powders-paste

properties and high electrical resistance. Lead-free alternatives do not show the same properties, with the void residues issues outlined in Figure 2.

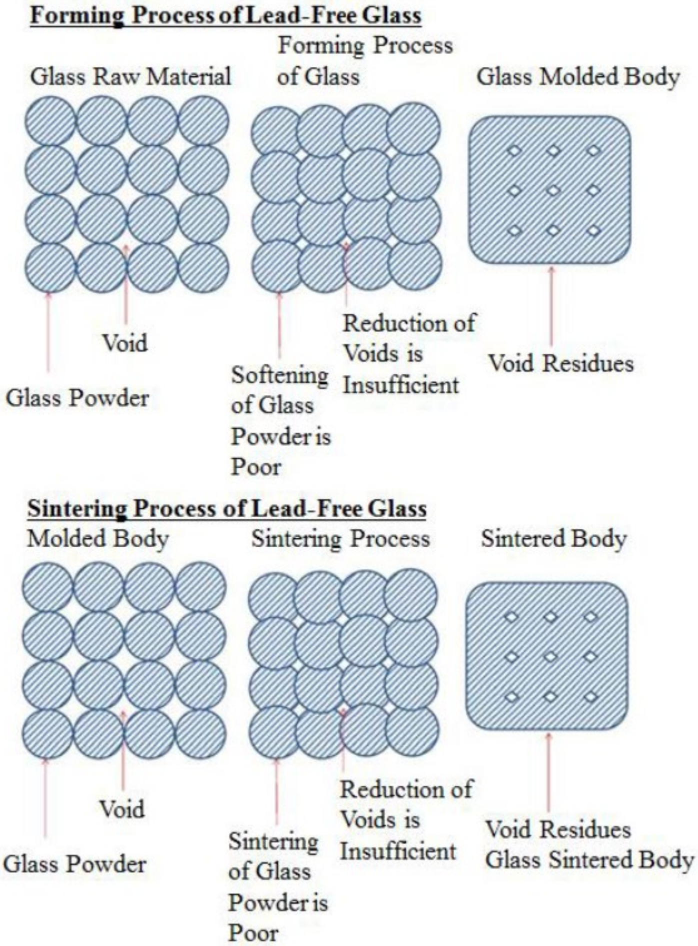

Figure 2 Lead-free glass forming and sintering process, sourced from the umbrella project renewal

The other technical characteristics which differ include:

- Bonding to NiFe alloys (used as component substrates) and other materials which an equivalent level to that of leaded glass is yet to be found.
- Dielectric constants (breakdown voltage) of lead-free compositions are within the range of 3.9<ε[10], whereas lead glasses such as 8531 have values of 9.5 and ultra-high lead-containing solder glasses ~20.
- Lower chemical stability when compared with lead-containing glass, showing inferior weather resistance/corrosion resistance, such as moisture and acid resistance characteristics.[5]

In addition to these properties, the thermal expansion coefficient (CTE) and meltdown temperature, as outlined in Table 1 are also significantly different.

Table 1 Technical characteristics of lead and lead-free glasses

Glass family	CTE (ppm/K)	Melt-down Temperature (°C)	Remarks
Lead glass	7.5-9	300 – 340	Provided for comparison.
Lead-Borates	5 - 15	< 500	Due to sufficient crystallization stability the addition of CTE-reducing fillers is possible.
Lead-Alkaline-Phosphates	13 - 20	< 500	No fillers needed due to intrinsically matching CTE . Does not crystalise.
Zinc-phosphates	13 – 16	450 - 600	Crystallization tendency is unacceptably high.
Lead-free borosilicate	~5	(softening point) 825	Lower CTE and too high melt temperature.
Lead-free glass (#8228[11])	1.3	700	Thermal expansion differs so widely from that of the partner component that direct sealing is impossible for stress reasons, must be sealed with intermediate sealing glasses.
Lead-free glass (#8229[11])	2.0	600	

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

Lead-containing glasses and ceramics are an essential material used in EUROMOT's members engine systems and currently there are no suitable lead-free substitutes for applications where they are used. Once alternatives have been identified by EUROMOT

[10] Technical glass review, Schott Row,14-04-2020

members supply chain, the lead-free components will need to be tested by EUROMOT members to ensure their reliability, but as yet this work has not yet been able to be started.

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8. 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.

Manufacturers of lead in glass and ceramic in electronic components have been carrying out research on substitutes for lead in glass and ceramic for over 20 years, with some of this research described above. Some of the lead-free alternatives described in section 4 above have been developed but are unsuitable for use in engine systems. This research is continuing and is being monitored by EUROMOT members and its suppliers so that if suitable substitute is discovered, it will be evaluated and tested for its use in engines.

When promising lead-free alternative becomes available, careful scrutiny will be needed by manufacturers of engines and their components to maintain the required high quality in the production process and high reliability of products to avoid failures of equipment with engines. Therefore, the adoption of any new technology will take many years, as explained in Section 7(B).

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

EUROMOT's members rely on their suppliers to develop suitable substitute lead-free alternatives. The electronics industry is continuously researching alternatives, however currently lead-free alternative technology is not available at present for all of the many end-uses of EUROMOT's members to evaluate.

For EUROMOT's members to replace lead in glass and ceramic for all uses in an engine, first, their suppliers must carry out research on new components, then EUROMOT members will then have to test them in systems they are used in and for some components the systems as a part of the engine to ensure that they offer the necessary technical performance and will be no less reliable. Due to the operational environment and an expected service for up to and beyond 20 years, material testing and development activities necessarily take many years to complete to ensure long term reliability. Conversion to lead-free processes cannot begin until alternatives are developed and perfected by component manufacturers, and made available to EUROMOT's members and their suppliers.

Details of timescales to ensure high reliability of engine systems with substitutes materials and components are given at the end of this section. After laboratory tests of materials / components, extensive "on-engine" and field testing must be executed to evaluate the reliability and durability of the substitute material/parts. This testing needs to be undertaken by each engine manufacturer to ensure the testing reflects the demands of their application and the tolerances that are inherently in-built into each system. The reliability of the system then needs to be proven with an estimated 500,000+ cumulative hours of testing to understand if the alternative is equal to that of current leaded materials.

It should also be mentioned that the EEE industry and automotive industry have an extensive overlap in their supply chains. For example, many components are used in both EUROMOT's members engines that are in scope of RoHS as well as by the automotive industry. EUROMOT would recommend that the EU maintain consistent wording between this exemption and ELV exemption 10 where feasible.

When manufacturers are qualifying changes to specific components the following are some of the tests which engine manufacturers must undertake. The following tests are not intended to be an exhaustive list, as different manufacturers have different testing requirements, but rather indicate the number and variety of tests which have to be undertaken.

<u>Sensors:</u>

- Vibration testing
- Vibration resonant sweep: a shaker test used to detect if any resonances in the component may adversely affect the device
- Humidity testing
- Water intrusion testing
- Thermal Shock: extreme temperature swings are used to stress the assembly
- Salt fog testing
- Electromagnetic compatibility testing
- Connector housing testing, such as durability testing, chemical stress fracture etc.
- Combined Environment: sensors are subjected to a combination of temperature and vibration to evaluate the component assembly for the expected life of the item, testing functionality such as pressure, differential pressure, temperature, positions, speed of sensor results and performance.
- Engine system testing to ensure that, as a system, the component is suitable for the application and has the necessary performance

In addition to these there are also sensor specific testing which is required for certain sensors such as gravel bombardment testing or exhaust system mounted sensors, flow velocity testing for sensors in high flow locations, or chemical compatibility if there are external material changes.

Actuators:

In addition to many of the tests required for sensors, actuators also commonly have to undergo the following additional tests:

- Circuit analysis- examined at maximum temperature voltage and duty cycle combinations and shown to be in the devices specified operational envelope
- Immersion testing
- Electrostatic discharge (ESD) exposure robustness testing
- Temperature cycling durability
- Electrical field immunity testing-radiated immunity and high voltage spike
- Software testing to ensure compatibility and no errors
- Lifetime mechanical wear

Each of these tests would need to be undertaken for each sensor or actuator used, with testing times varying from around 15 hours per test to around two months per test. Testing timeframes for each of these tests cannot be further accelerated as some attributes are non-linear, such as long-term reliability or durability.

Timescale once substitute components become available to EUROMOT members

If a promising lead-free alternative is developed, then this must next be tested under realistic engine conditions by EUROMOT's members. The timescale will vary depending on how significant the changes, the types of engine and their end-uses. For example, if the component's electrical and functional properties are apparently identical, then minimal testing is necessary. However, substitute materials often given different characteristics so more extensive testing is needed. Sometimes substitution results in component suppliers withdrawing their products from the market and replacement by a different component (this is common with ICs) in which case EUROMOT's members may need to redesign circuits and this could affect engine emissions and so recertification will be required.

This will involve some or all of the following:

- Production of prototype parts/ circuits and laboratory testing to determine suitability and reliability. This would include accelerated environmental testing such as thermal cycling, vibration, high humidity, corrosion tests, functional testing of circuits, etc. However, if there are many components to assess, this could take longer due to limitations in the availability of suitable trained engineers.
- Construction of engines using the lead-free replacement components and bench testing to determine reliability. This is the only reliable way of assessing new bonding methods.
- Field trials in end-use equipment. This is important because it is not possible to reliably reproduce field conditions in laboratory testing environments. This is realistically essential to assess long term reliability.

- If use of substitute bonding materials or new components requires significant changes, such as re-design of circuits or of the engine, then approvals under the Non-Road Mobile Machinery (NRMM) Emissions legislation will be required.

The timescales for these stages vary between five and up to eight years depending on the type of component substitution, type of engine and its end-uses. For example assuming the exemption is used in a large number of parts (200-300 assemblies in the case of EUROMOT applications), it could take more than five years to integrate an available alternative. If those alternatives were not „drop-in replacements“ the estimated time would be much longer to produce emission certificates and safety approvals.

- Timescales for above:
  - Without NRMM Emissions Regulation re-approval 5 - 7 years after lead-free substitutes become available
  - With NRMM Emissions Regulation approvals at least 6 - 8 years after lead-free substitutes become available

In addition to the above timescale, as a minimum, to consume existing stocks of components, 7 years is required from confirmation that a substitute exists and is reliable.

EUROMOT members have engaged extensively with their supply chain and, although information is scarce it has been made apparent that lead-free alternatives for EUROMOT applications are not available from the manufacturers and therefore a timeline for assessing the transition to a lead-free alternative is difficult to predict.

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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 Lead metal is a REACH SVHC

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

   ☐ Restriction

   - ☐ Annex XVII None relevant to this exemption renewal request
   - ☐ Registry of intentions

   ☐ Registration

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

(B) Elimination/substitution:

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

☐ Yes. Consequences? ______

☒ No. Justification: See Section 7(A) and 7(B). No suitable substitutes at present. If any are developed in the future, the reliability in engines will not be assured until full testing is complete.

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

☐ Yes.

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

☒ No.

Justification: See Section 7(A) and 7(B). No suitable substitutes at present. If any are developed in the future, the reliability in engines will not be assured until full testing is complete.

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

There is no available and functionally equivalent alternative, so no reliability assessment data is available for any of the current uses in engines.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to
   1) Environmental impacts: Not applicable
   2) Health impacts: Not applicable
   3) Consumer safety impacts: Some applications utilising this exemption are safety relevant and may cause accidents in case of failure.

⇨ Do impacts of substitution outweigh benefits thereof? Not applicable
Please provide third-party verified assessment on this:

(C) Availability of substitutes:

a) Describe supply sources for substitutes: Substance manufacturer

b) Have you encountered problems with the availability? Describe:

Not directly due to lead glass-ceramic, but the global shortage of semiconductors.

EUROMOT's members are reliant on their suppliers who are at present unable to provide suitable reliable substitutes for the components, sensors and actuators that use this exemption.

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?

See above.

(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:

If this exemption is not renewed and include all of the applications in engines made by EUROMOT's members, engine and end-product manufacturers will be forced to stop selling products that do not comply with RoHS. At this stage, it is not known which products would be affected for the following reason. The European Commission's consultants have recommended renewal of 7cI but with a limited scope. The proposed scope will include many of the components used by EUROMOT's members, but may not include all of them for the reasons explained above in section 4 (B). Therefore, this could affect many types of end-users in the EU. For example, construction and other industries may not be able to operate if essential equipment is not available. If supply of emergency generators is affected, this may affect, for example, hospitals who use these during power cuts. There would be a risk to patient's survival during operations or other medical procedures (such as MRI examinations and monitoring patients in intensive care) may not be possible if emergency generators are not available. Manufacturers of affected engines and their end-products would also be negatively affected causing loss of competitiveness, potentially leading to loss of jobs.

Due to the uncertainty over which products would be affected, it is not possible for EUROMOT to determine quantitative impacts.

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:
