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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Address: As above

This exemption request is submitted with the support of:

ema Truck & Engine Manufacturers Association®

EUROPGEN

The voice of the European generating set industry

European Garden Machinery Federation

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: 42

Proposed or existing wording: (Existing wording)

Lead in bearings and bushes of diesel or gaseous fuel powered internal combustion engines applied in non-road professional use equipment:

- with engine total displacement ≥ 15 litres,
- or with engine total displacement < 15 litres and the engine is designed to operate in applications where the time between signal to start and full load is required to be less than 10 seconds,
- or regular maintenance is typically performed in a harsh and dirty outdoor environment, such as mining, construction, and agriculture applications.

Duration where applicable: Maximum validity period (5 years)

☐ Other: _____

3. Summary of the exemption request / revocation request

Lead as an overlay coatings and alloying element is used in a number of bushings and bearings in specific non-road professional use engines. The engines which require the use of lead are ones which have:

- engine total displacement ≥ 15 litres to compensate for slight misalignments that often occur in extreme high load operations,
- engine total displacement < 15 litres and requires a quick (<10sec) signal to start to achieve good reliability as lead acts as the initial lubricant, or
- requires maintenance in harsh and dirty environments where contaminants can be introduced to the system.

Lead provides seizure resistance, resistance to damage, conformability, embeddability, fatigue strength, flexibility, chemical resistance, impact of manufacturing tolerances and tolerance to cold temperature and limited lubrication during start-up.

The development and qualification of lead-free alternatives is underway by bearing and engine manufacturers, however additional time is required to test and qualify potential alternatives. The testing of bushings and bearings can be characterised by the following key steps, each of which brings increased confidence that a solution can be deployed as a viable alternative:

1. Laboratory tests of bearings to determine if they meet required performance criteria
2. Engine trials with new bearings
3. Field trials with finished equipment containing engines that have new bearings that are being tested.

However, it is essential that all steps are undertaken as failures have been identified in the last stage of testing. There is no internationally accepted standard test regime to test bushings and bearings, so each company has developed their own methodology with the most difficult to achieve performance parameters usually being tested first.

Lead-free alternatives, relying upon alternative alloy compositions or polymer overlays (which for some rely upon Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) substances) are starting to show initial signs of suitable performance when tested by bearing manufacturers. The activities undertaken by bearing manufacturers are starting to identify potential alternatives which looks to offer similar key technical characteristics. However, other bearing manufacturers are still in the processes of developing bearings which can offer the same performance as lead-based bearings.

Engine manufacturers in both their current engine designs and new designs are testing potential lead-free alternatives, with the types of testing they undertake being reflective of their own in-service applications. Currently, all testing undertaken by engine manufacturers identifies the lead-free alternative which they tested having significant loss of technical performance in at least one critical parameter. As such, none yet have been determined to be a viable alternative.

Two different engine manufacturers have trialled using lead-free bearings, as testing indicated lead-free alternative in these specific applications, they might have suitable performance. However, in both instances engine failure was observed. Highlighting the importance of testing.

Given current lead-free alternatives still cannot offer the same performance as lead-containing bushings and bearings, this exemption is therefore requested on the basis of the inferior reliability of lead-free substitutes.

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:

Bearings and bushes in internal combustion engines designed for professional use, with either:
(1) a large engine size (≥15L),
(2) highly demanding applications (where signal to start and full load is <10 sec), and/or
(3) or is exposed to harsh and dirty environment during maintenance.

Examples of applications of each of these criteria are as follows:
(2) Emergency generators, fire pumps and uninterruptable power system (UPS) installations
(3) Drills, compressors, rock crushers, irrigation pumps, fire pumps, mine trucks, tub grinders, excavator, screeners, wheel loader, skid steer loader and generators installed temporarily on site. Such applications are used in a number of different industries including mining, agriculture, and construction.

Figure 1 Generator Set

Figure 2 Fire Pump

Figure 3 Irrigation Pump

Figure 4 Screener

Consumer equipment with small engine sizes do not have the same technological and reliability demands, so are not proposed to be included in the scope of this exemption.

Due to the scope of the RoHS Directive, "forms of transport", "professional non-road mobile machinery" and “stationary industrial tools or fixed installations” are excluded from the scope of the Directive. As discussed in the previous exemption request, this significantly impacts the types of internal combustion engines which are in scope of the Directive’s requirements. The key differentiator for many of these applications is whether they are designed to be stationary when in use.

It is worthwhile noting the possible overlap of this exemption with exemption 6c of Annex III of the Directive, for lead in copper alloys, as bearings and bushings produced from copper alloys with up to 4% lead are also used in professional use non-road equipment engines. It is understood that all such applications are to be covered by exemption 6c as long as this exemption is renewed.

Highly demanding applications:

Applications which require the 10 second signal-to-start have many key features which make it a highly demanding application:

- Applications, such as emergency back-up power, will sit for extended periods of time without being exercised and only started for planned maintenance or an actual power outage. During the latter one of these, power is required to be restored within 10 seconds.
- The signal to start requirement is in all weather conditions and can be in situations where ambient temperature is below -4°C, which causes oil to be more viscous and so will move much slower than at higher temperatures and may not reach reciprocating components for minutes, compared to seconds in less harsh conditions.

  It is during this period, where it is only the lubricity of lead in the bearings that enables the engine to move without seizing and with minimal wear to internal components. To enable the quicker flow of oil at lower temperatures, engines are designed with a filtration bypass system to avoid the added restriction of the oil filters and enable faster flow to the reciprocating components. This of course allows for particles of any size to be circulated throughout the engine that can cause damage, until such time as the oil is warmed to the appropriate temperature and the filtration loop is again enabled.
- For engines designed for fast start-up applications, lead is necessary to achieve good reliability.

Harsh and Dirty:

The terminology of harsh and dirty, is once again requested to be included in the scope of the exemption. The inclusion of terminology is important given that many applications require engines to be located in 'harsh and dirty' environments for significant lengths of time, for example in quarries or construction sites, where providing a sufficiently clean environment such that particles will not be introduced to the engine, especially during maintenance, is impossible. Debris may be introduced during service and maintenance procedures or from the environment that the engine operates in.

It is recognised that whenever a term is included in an exemption, to allow for the consistent determination across Member States and companies, it is always preferred that such terminology is accompanied by a quantitative definition. Efforts have been expended in the intervening timeframe since exemption 42 was granted to try to better define the terms, however a consolidated quantitative wording was unable to be defined due to the complex and interplaying factors of what is deemed as acceptable.

There are multiple permissible values of determining 'dirty' which depend on multiple interdependent factors including particle size and distribution, number of particles, particle hardness and engine specific parameters. There are manufacturers' cleanliness standards, which define a permissible particle load for differing types of components, as well as a maximum permissible particle size are outlined. However, these standards vary between companies, both in terms of what are defined as critical parameters and quantitative values listed, with indicative examples listed below:

Company A: 'clean' is defined as parts which are exposed to particles of <850µm debris particle size only.

Company B: Maximum particle size allowed is 80-100µm based upon clearances and tolerances. The maximum size may be less for abrasive particles, which can key on to bearing surfaces.

Company C: Maximum permissible particle size for a metallic crankshaft is 120µm for mineral particles and 600 µm for metallic particles, with a maximum of 1 mineral particle per 1000cm^2 surface in the 80 to 120µm range and 10 metallic particles per 100cm^2 surface in the 400 to 600µm range.

Company D: Maximum particle size 500µm.

The disparity in the values listed by each company reflect the different engine specific parameters (e.g., design, intended use, etc.) which affect the impact of particles including clearances, tolerances, and wear. It is important to note that these standards relate to 'components ready for shipment', rather than parts which are operating in engines in such an environment. As such it is not possible to extrapolate the values listed in these standards to produce a permissible level for whole engines in the field a due to the large numbers of variables that affect engine reliability.

Indications can be seen in some of the companies' standards that critical parameters sometimes require tighter control, however in an operational environment these increase in their complexity, as well as introducing other critical parameters. As an example, the type of particle has a large impact on the bearing or bushing's ability to withstand its introduction, with the hardness and abrasiveness of particles playing a critical role. Dry sand particles compared to moist clay particles have very different impacts on acceptability and listing all potential contaminants in equipment utilising the exemption that are expected to experience would be impossible. Another consideration is the number of particles per cubic meter of air, which to date only one company standard has been identified that gives a permissible number of particles, with most EUROMOT members stating that this is not a measured parameter in real environments.

An indicative estimate provided by a EUROMOT member is no more than 2 grams of particulates ingested through an air intake system, but this is not a transferable parameter as this will also depend on other variables such as engine size and the fact that contamination may also be introduced through handling during maintenance and service, i.e., that it cannot always be attributed to the quality of air in which equipment is operated or serviced.

Harsh can be described in a qualitative way, such as a description provided by an engine manufacturer below, but a quantitative description for particle, size, number, and hardness is impossible to bound in a straightforward way as they are interdependent.

'*A harsh environment is one where dirt and debris particles, that contain abrasive particles, are present and will / may accumulate on machinery (powered by reciprocating engines) or engines, tools used to service engines and technicians / mechanics clothing or person, and / or environment where the dirt, debris and contaminants, including abrasive particles, are airborne in the environment such that contaminates will be present in the proximity of the engine at times of service or maintenance.*

In these environments the dirt and debris, including abrasive particles, can enter the engine at times or moments of service or maintenance when internal passages or surfaces of the engine are exposed to the environment.'

For example, a few small very hard particles may be similarly damaging as a larger number of larger, softer particles. Hence, it has not been possible for the industry to define boundaries for all three variables under all real field conditions.

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: n/a

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:

As a coating or alloying element to produce a tribological interface for bushings and bearings, to provide the required performance and reliability which include seizure resistance, resistance to damage, conformability, embeddability, fatigue strength, flexibility, chemical resistance, impact of manufacturing tolerances and tolerance to cold temperature and limited lubrication during start-up, all of which are discussed in section 4(B).

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

20-90%, depending on application, with higher values attributable to overlay coatings and the lower values as an alloying element.

5. Amount of substance entering the EU market annually through application for which the exemption is requested: 1.73 tonnes

Please supply information and calculations to support stated figure.

The amount of lead used for products in scope of the RoHS Directive varies depending upon bearing and engine design, as well as the engine displacement (larger engines would typically utilise more lead due to larger component size).

The previous exemption renewal request outlined a methodology for calculating the lead placed on the market from this exemption, which has been utilised in this calculation. Much of the previous information which underpins the calculation has been utilised, with the annual genset sales in the EU recalculated based on information from Association of Equipment Manufacturers (AEM) in terms of percentage change of sales. The assumption that non-genset applications add 25% of numbers sold has been used and the data following data taken from the renewal as it is deemed to still be relevant:

- Average engine mass
- Average lead content from bearings
- Percentage of units in scope of RoHS for each power band

Table 1 Calculation of amount of lead in bearings used in engines in scope of this exemption request

Power Band (kVA)	Average engine mass, kg	Average lead content from bearings (% by total engine mass)	Annual genset sales in EU market 2015	% Change in sales from AEM data	Annual genset sales in EU market 2021	Annual engine sales in EU market, add 25% for other applications	Percent in Scope of RoHS Units in Scope	Engine mass in scope, kg	Annual Lead quantity into EU market, kg
7.5-250	447	0.0008%	50241	97%	98975	123718	100%	55302153	442.4
251-750	1020	0.0200%	8453	0%	8453	10566	47%	5065460	1013.1
751-2000	4506	0.0200%	2410	-21%	1904	2380	5%	536186	107.2
2000+	7500	0.0200%	667	270%	1801	2251	5%	844172	168.8

The above calculation indicates that 1.73 tonnes of lead is placed on the EU market due to bearings of new engines that are in scope of this exemption renewal request. It should be noted that professional engines can have new bearings which are installed during the service life of the engine, but this calculation does not account for any spares use.

6. Name of material/component:

Various lead alloys are used as bearings or as layers of bearing surfaces.

Lead bushings and bearings, including the following which is provided as a non-exhaustive list[1]:

- Main bearings,
- Con rod (crankshaft) bearings,
- Piston pin bushings,
- Camshaft bushings,
- Cam follower roller pins,
- Thrust (camshaft and crankshaft) bearings,
- Gear box (gear train) bearings and bushings,
- Turbocharger bearings and bushings,
- Idler gear bearing and bushings (gear box bearing),
- Oil pump bearing and bushings, and
- Valve train (rocker arm) bearing and bushings.

7. Environmental Assessment: n/a

LCA: ☐ Yes

☒ No

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

Lead is used in bushings and bearings, which are mechanical elements providing movement relative to another element with minimum power loss. Bushings are technically identical to a bearing except that they are a single independent one-part device whereas bearings are mostly made of two or more materials or components.

Lead is used as a thin coating (up to 90% lead) to provide a tribological interface between two moving parts which helps to prevent seizure and it can absorb debris which might otherwise cause engine failure. Lead is also used as an alloying element (up to 20% lead), often as a layer below the thin lead-rich coating, which provides conformability to help the bearing to compensate for slight misalignments that often occur following service or extreme high load operations. Lead would typically comprise between 1 and 3% of a complete leaded bearing (based on total part weight). Lead from all these components would typically comprise less than 0.025% of a complete engine.

[1] Note that there are sometimes differences in naming convention of certain bushings and bearings depending on the company in question and location, where possible alternative naming has been indicated.

There are multiple types of bearings and bushes, as outlined by Section 4 to 6, which come in a variety of shapes, designs, and sizes, all of which are required to have a combination of important properties to provide the required performance and reliability for the intended conditions of use and lifetime. The specific requirements for each specific property depend on multiple variables including engine capacity, conditions of use, conditions during rebuild and servicing, rotation velocity, loading, etc.

Bearings may be constructed in three layers as shown in Figure 5, with the steel back providing rigidity, the bearing alloy generally consisting, typically of copper or aluminium plus lead alloys and the thin overlayer that provides anti-friction properties through a high lead content (even when oil lubricant is absent). A bond or dam layer may be deposited between the overlay and the bearing alloy to prevent migration of metals from one layer into another.

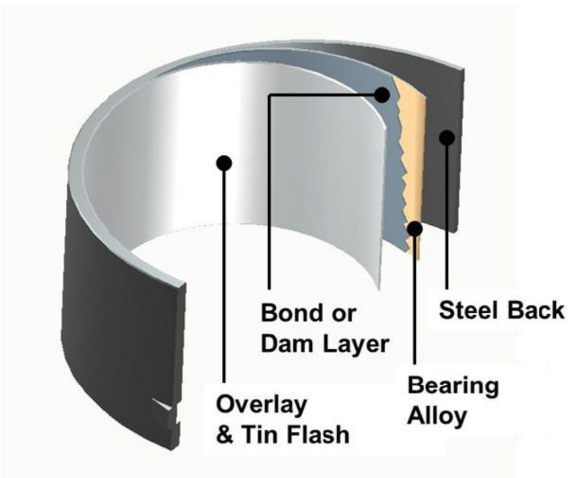

Figure 5 Tri-metal bearing

Lead overlay compositions vary depending on the application and bearing in question, with indicative examples provided in Table 1. The lining material can then either be a copper or aluminium alloy, with lead contained up to 25% of the alloy depending on the alloy used.

Table 2: Examples of Lead Overlay compositions

Lead (Pb), %	Tin (Sn), %	Copper (Cu), %	Indium (In), %	Alumina (Al_2O_3), %
90	-	-	10	-
88	10	2	-	-
88	10	-	-	2
87	10	3	-	-
85	10	5	-	-
82	9	-	9	-
80	18	2	-	-
78	14	8	-	-

Lead (Pb), %	Tin (Sn), %	Copper (Cu), %	Indium (In), %	Alumina (Al_2O_3), %
75.5	12.5	2	10	-

Engine bearings are designed to operate in a hydrodynamic lubrication regime with a lubricant film layer between two moving surfaces, but during starting and stopping, speed and load changes, these two surfaces may not be fully separated by a lubricant film. As such bearings may operate in boundary and mixed lubrication regimes, meaning that the bearing may need to operate with insufficient oil and so require the lead to also provide lubrication. Under these conditions, the contacting material surfaces as well as the engine oils containing additives play an important role in determining the friction and wear. Lubricant starvation can easily lead to metal to-metal contact, without a suitable surface on the bearing this can cause high wear of the bearing surfaces due to severe ploughing, and wear debris can initiate seizure failure.

Each engine contains many different designs of bearings, an indicative example engine is shown in Figure 6.

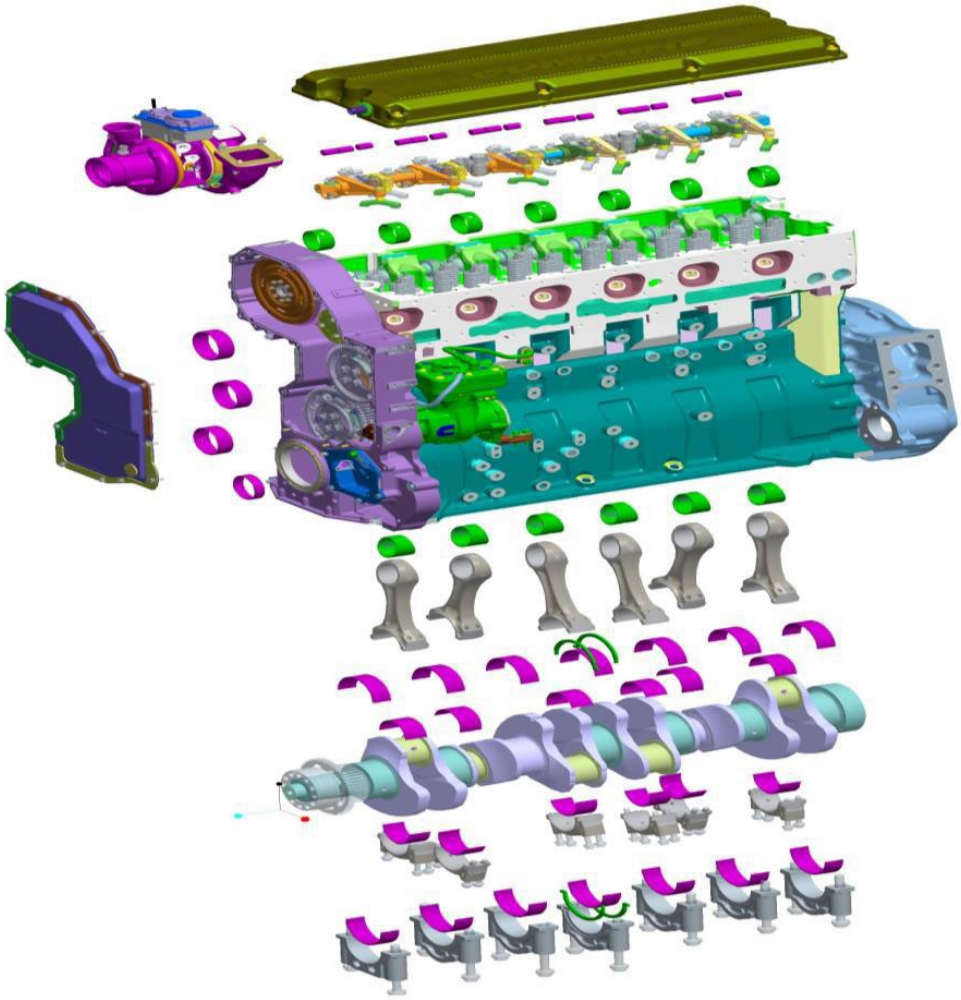

Figure 6 Parts of a typical internal combustion engine with bearings and bushes shown in pink and green in this example

Engines also contain bushings that are made from one leaded alloy and are usually in the shape of hollow cylinders. These can be made of copper alloys that contain lead where the lead acts as a dry lubricant. Some contain <4% lead and so would be in scope of exemption 6c but at some need to contain >4% lead to provide sufficient dry lubricity.

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

Bearings and bushes are required to have many important properties to provide the required performance and reliability for the intended conditions of use and lifetime, which are described below. Usually, a combination of essential properties is required by each bearing or bushing. The specific requirements for each specific bearing or busing depends on one or more of many variables including engine capacity, conditions of use, conditions during rebuild and servicing, rotation velocity, loading, etc. but can be generally described as a combination of the following.

Seizure resistance is the ability of the bearing material to resist physical joining (metal to metal bonding), which is important as it provides a measure of the bearings ability to survive momentary contact with the counter surface when there is not enough oil film to fully separate the two surfaces. This in combination with **resistance to damage** is an important characteristic of bearings covered by the exemption. Seizure usually occurs due to the heat generated, and resultant high temperature, by high friction forces that occur when lubrication fails. All bearings experience some metal-to-metal contact, however under certain circumstances seizure resistance is especially important. One such example is when the bearing experiences cold start and/or oil starvation which are often experienced in applications where the time between signal to start and full load is required to be less than 10 seconds as the lubrication oil drains away. Another factor where high seizure resistance is especially important is when high roughness of the bearing or shaft surfaces is caused by dirt particles being introduced to bushings and bearings. Without the ability to resist seizure, the heat generated at the surface of the bearings can cause the metal surfaces to melt and then seize, resulting in catastrophic failure of the engine.

Conformability is the ability of the bearing material to accommodate misalignments in the geometry of the bearing, without which bearings can experience excessive wear and high specific loading. Misalignment is most notable after when the engine is new or after a rebuild and conformability is essential to compensate for this. This is critical at start-up of all engines in scope of the exemption request, as the metal surfaces are likely to have little or no lubrication. For larger sized engines, small variations in the dimensions of bushings and bearings are more common, which can result in misalignment of parts. Lead's soft properties provides the desired conformability, allowing the bearing to conform to the variation when there is metal to metal contact, allowing the engine to function correctly, which is especially important during the wear in period of a new or reconditioned engine. Poor conformability of the bearing material can result in excessive wear, premature failure of the bearing and catastrophic failure of the engine.

Embeddability is the ability of the bearing material to entrap and trap within the surface layer small foreign particles, such as dirt, engine wear debris, dust, and other abrasive residuals, allowing the continued function of the part. Poor embeddability of a bearing material causes accelerated wear and allows particles to produce scratches on the bearing surfaces, which significantly reduces the lifetime of the engine, and may also lead to seizure. Lead has low affinity for iron that allows it to accept debris in a way that minimises shaft damage and manages energy dissipation in the system to avoid the debris accelerating progressive damage.

Although embeddability is an important characteristic of any bearing, as soot and debris are inherent to the operation of all internal combustion engines, the applications and end-uses in scope of this exemption require regular maintenance activities performed in a harsh and dirty outdoor environment and also to operate in such an environment so that these engines need to be able to function with much more dirt that those engines that can be maintained in clean workshops. This characteristic cannot be overstated in its importance. In such environments the ability to limit dirt ingress is often impossible as there is often significant amount of fine dust within the environment which is therefore expected to enter the engine.

In addition to environmental considerations, embeddability is still an important factor during the running-in of an engine as metal shards or 'chips' can be introduced as part of the normal manufacturing processes.

Fatigue strength is the maximum value of cycling stress that the bearing can withstand after an infinite number of cycles. Cycling stresses applied to the bearings are the result of the combustion and inertia forces developed in the internal combustion engines.

In addition to the key performance behaviours outlined above, the following are also important:

- **Flexibility** of the coatings.
- **Chemical resistance** to resist chemical attack of oxidized and impure lubricant.
- **Tolerance to cold temperature and limited lubrication during start-up.**
- **Low yield strength.**
- **Thermal conductivity.**
- **Load Capacity.** A measure of the maximum hydrodynamic pressure which a material can be expected to endure. Important for some types of engines, as high loads can cause misalignment which lead based bearings can more easily accommodate.
- Ability to withstand some **manufacturing tolerances**.

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.)

Within the commercial internal combustion engine sector, there is in effect a closed loop system for the recycling of mixed metal components generated during the rebuild process and at end of life. Bearings at end of life have a positive metal value whereas disposal to landfill entails a cost and so close to 100% of bearings are collected and recycled, although not always by the original engine manufacturer. The closed-loops are in effect industry-wide as it is not possible for bearing or engine manufacturers to guarantee take back of their own bearings for recycling, however the metals are recovered by traditional metal recycling processes that occur within the EU and are reused, although not necessarily in bearings. Therefore, a closed-loop as understood by Article 4.5 of RoHS does not exist.

2) Please indicate where relevant:

☐ Article is collected and sent without dismantling for recycling.

☐ Article is collected and completely refurbished for reuse.

☐ Article is collected and dismantled:

- ☐ The following parts are refurbished for use as spare parts: ______
- ☒ The following parts are subsequently recycled: All bushing and bearings

☐ Article cannot be recycled and is therefore:

- ☐ Sent for energy return.
- ☐ Landfilled

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

☐ In articles which are refurbished

☒ In articles which are recycled

Professional engines at end of life are recycled as steel scrap and lead is recovered in the EU by steel 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. The amount of lead in end-of-life bearings and bushings that are recycled is the amount used in new engines minus lead lost due to wear.

The amount of lead lost due to wear is expected to be very low, but unable to be calculated. However, it is important to note that any lead lost due to wear would be collected in the engine oil system and therefore not released into the environment.

It is worthwhile noting that bearings are not intended to be replaced during the lifetime of the engine, and as such only an extremely small number of bearings are used as spare parts.

☐ 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

Since EUROMOT submitted the original exemption request for lead in bearings, manufacturers of bearings and of engines have carried out research into lead-free substitutes, however so far without success. This research is summarised below.

To identify if lead-free bearings can be considered as an alternative, they have to undergo multiple stages of testing, involving both bearing and engine suppliers to replicate the environments they will likely see during their operations. Testing involves at least three stages:

1. Laboratory tests of bearings to determine if they meet required performance criteria
2. Engine trials with new bearings
3. Field trials with finished equipment containing engines that have new bearings that are being tested.

As explained in EUROMOT's original exemption request, bearings that appear to meet performance requirements often fail when used in engines, especially during field trials.

For less challenging environments, such as in road vehicles (e.g., private cars), lead-free bearings are able to be used, however the on-going testing undertaken for applications covered by this exemption request indicate that lead-free alternative are not suitable at this time due to decreased reliability and inferior performance.

The first stage involves a review of the inherent properties of the bearing in question, aspects such as hardness, melting point, and strength (tensile, yield) are characterised to ensure the bearing shows enough promise to take forward for testing. Once an alternative is able to demonstrate some of the fundamental properties as outlined in section 4(c), the following are a general description of the main testing phases:

1. **Bearing tests:** Bearing suppliers and also some engine manufacturers investigate promising alternative bearing materials, undertaking testing of basic properties to identify bearing materials which may be suitable alternatives.

2. **Engine testing:** Engine manufacturers then undertake testing of promising bearings (from phase 1) to assess the bearings performance under laboratory conditions that replicate the environment of a heavy-duty engine.

3. **Field tests:** Testing must also be conducted on actual diesel (or gas) engines to identify failure modes which can only be identified with loads and environmental conditions that

are consistent with the entire reciprocating engine assembly working as a complete engine system and at locations where the engines are intended to be used (e.g., on farms, in quarries, etc.).

These tests are routinely executed by engine manufacturers as a manner of procedure whenever one of the following conditions are true:

- Change in material specification or source
- Change in supplier's manufacturing location or process
- Change in OEM's manufacturing location or process

There is no internationally accepted standard test regime to test bushings and bearings, so each company has developed their own methodology for testing which is suitable for the types of engines and end-uses that their engines experience. Variables in testing include rotation speed, force on bearing, chip size and chip composition (these chips can be small metal particles that are generated by wear in new engines or from dirt ingress into engines), and number of particles introduced to try to reflect an accurate representation of the end use and the engine type in question. There have been previous discussions whether an ISO standard for contamination testing could be created however agreement could not be reached on a consistent essential requirement, and it was therefore not able to progress. As such, it is up to each company to determine the critical parameters. The most difficult to achieve performance parameters are usually tested first by direct comparison of new lead-free with lead containing bearings.

Inherent property characterisation

Overlay materials need to be relatively soft to provide conformance and embeddability but should have a higher melting point to avoid seizure due to cold welding or surface melting. In general, soft materials have low melting temperatures so a compromise is needed. The original exemption request outlined the melting points and Brinell hardness of bismuth, indium, and tin, as well as lead-free alternatives, which showed that lead alloys are superior (i.e., softer) to all other materials that are used as lead-free bearing overlays.

It is important to note that some of the polymer alternatives rely upon Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) substances which could be impacted by the upcoming

REACH restriction[2]. If this were to happen, and include bearing applications this could end up as a regrettable substitution

Table 3 Hardness of overlay materials[3,4]

Alloy	Harness (GPa)
Lead($PbSn_{10}In_{14}$ + Al_2O_3)	0.0715
Lead-free 1 (Sn)	0.25
Lead-free 2 (PAI; Al (10-15) PTFE (5-7) Silane 5)	1.65
Lead-free 3 (PAI 45%; MoS_2 55%)	1.25
Lead-free 4 (PAI; MoS_2 44%; graphite 23%)	1.54
Lead-free 4 (Bi)	0.3

Bearing testing:

Bearing manufacturers are continually reviewing lead-free alternatives and where bearing schemes look to be promising, testing is undertaken. The types of testing undertaken by bearing manufacturers depend on the company in question and reflects their customers' technical requirements and expected operational environment. Although the following information is from a limited number of bearing suppliers, this represents a significant proportion of the bearing market.

Bearing Manufacturer A:

During the investigation into lead-free alternative lining and coating materials, this bearing manufacturer undertook chip contamination tests, where the ability to resist seizure is tested via the introduction of chips of different sizes, dynamic seizure tests and stress testing.

[2] https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

[3] Embeddability behaviour of some Pb-free engine bearing materials in the presence of abrasive particles in engine oil, Tribology - Materials, Surfaces & Interfaces, Daniel W. Gebretsadik, Jens Hardell & Braham Prakash, 2019.

[4] Tribological compatibility of some selected Pb-free engine bearing materials with different engine oil formulation, Tribology Online, Daniel W. Gebretsadik, Jens Hardell & Braham Prakash, 2018.

The chip contamination testing showed that lead-containing bearings outperformed most lead-free alternatives. It was only in late 2021 that one potential alternative (LF sintered bronze| LF Galv.) was identified as showing comparable performance to lead-containing alternatives. It is important to note that although comparable attributes are starting to be identified, this has only been as a result of significant development by bearing manufacturers, which needs to be taken forward by engine manufacturers for testing. This testing is outlined in more detail in the engine manufacturers testing, with timeframes indicated in section 7B.

The chip contamination tests are run for 5 hours or until failure occurs. In reality, a bearing would have to survive for the lifetime of the product after any damage has occurred (1000's of hours). Testing was carried out by gradually increasing particle size until failure (such as seizure) occurred. These tests showed the maximum size of particle that each bearing material can withstand. A larger chip size is used than might be seen in reality is used to ensure the test is as representative as possible. The size of the chip introduced cannot exceed >4mm as this will damage the bearing which would cause a fracture, therefore the difference in performance may be even larger than demonstrated.

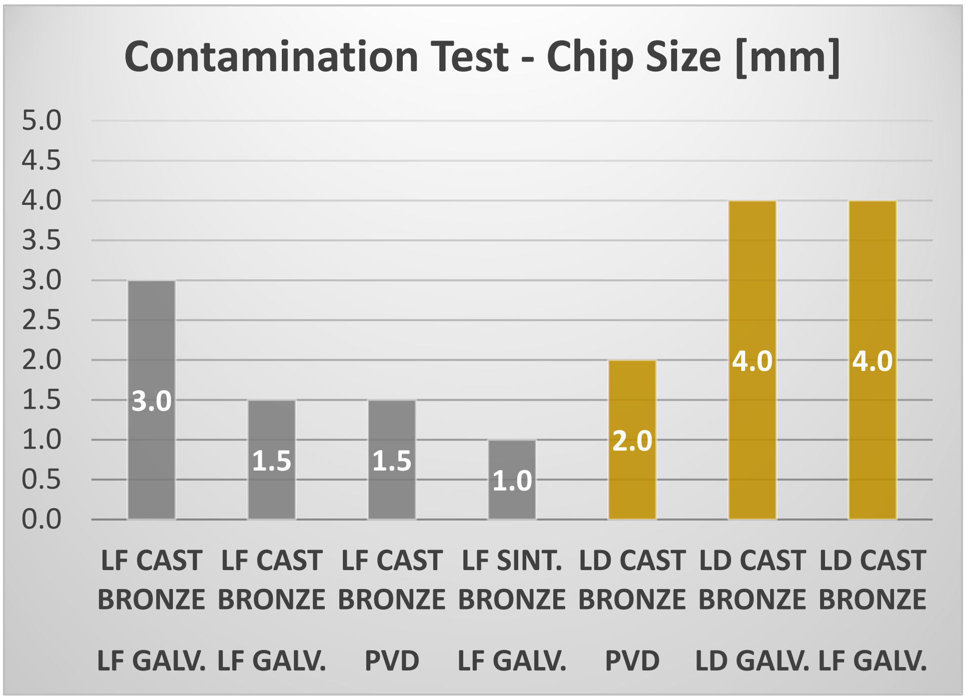

Figure 7 Copper bearing chip resistance testing, with LF denoting lead-free versions and LD denoting leaded, Galv. denoting a galvanized coating and PVD denoting a PVD Sputter coating (Part 1)

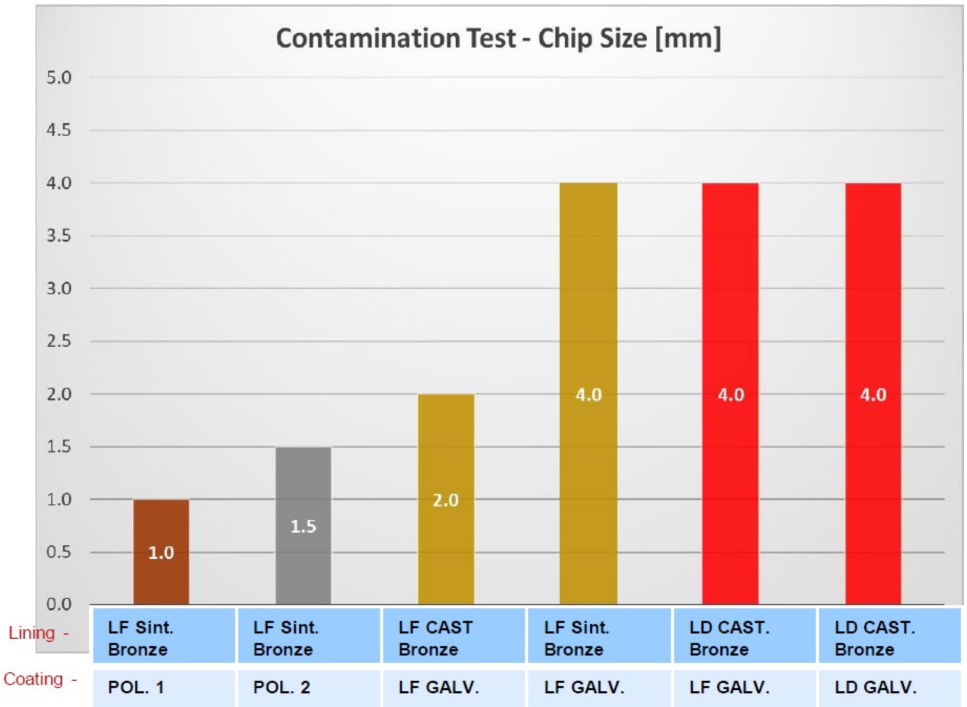

Figure 8 Copper bearing chip resistance testing, with LF denoting lead-free versions and LD denoting leaded, Galv. denoting a galvanized coating and POL. denoting a polymer spray coat (Part 2)

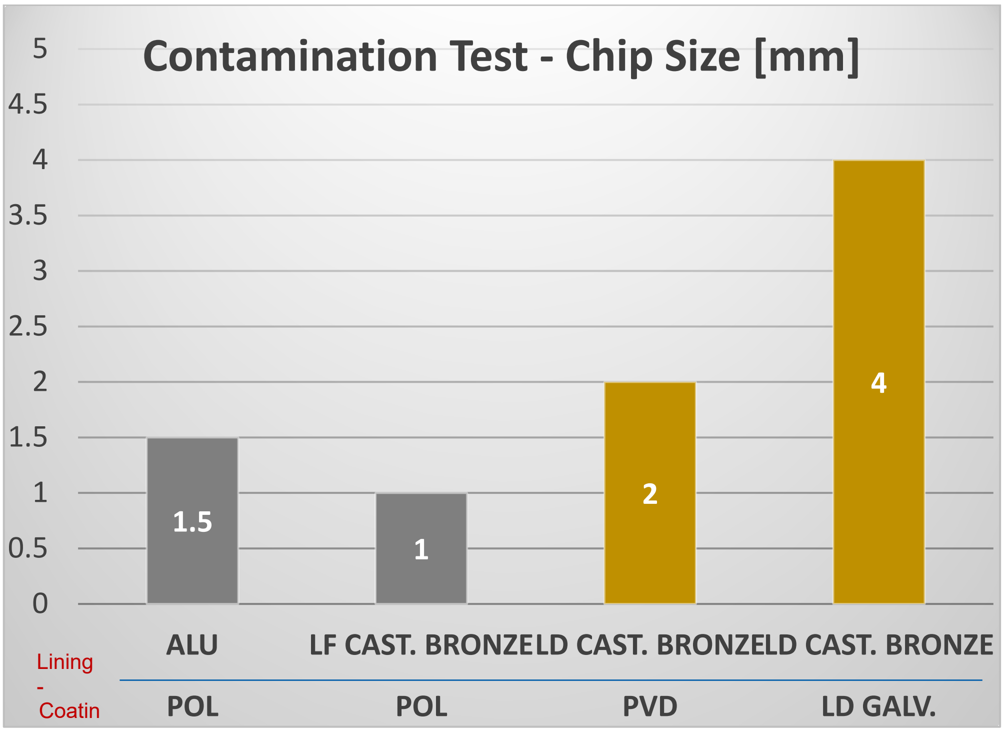

Figure 9 Lead-free aluminium bearing chip resistance testing compared with lead-bronze bearings (LD), with lead-free (LF)

In an effort to further develop the understanding of the bearings in more realistic conditions, dynamic tests were also undertaken. Dynamic seizure testing, also known as oil starvation testing, was undertaken, which is especially key for quick start engines in which bearings must function without oil for a period every time the engine starts. During the lifetime of an engine the cumulative time that the bearing is without oil can be considerable.

The testing outlined in Figure 10 and Figure 11 showed that lead bearing was superior to lead-free but not by a large margin over polymer 2, which was developed from polymer 1 to overcome some of the seizure issues.

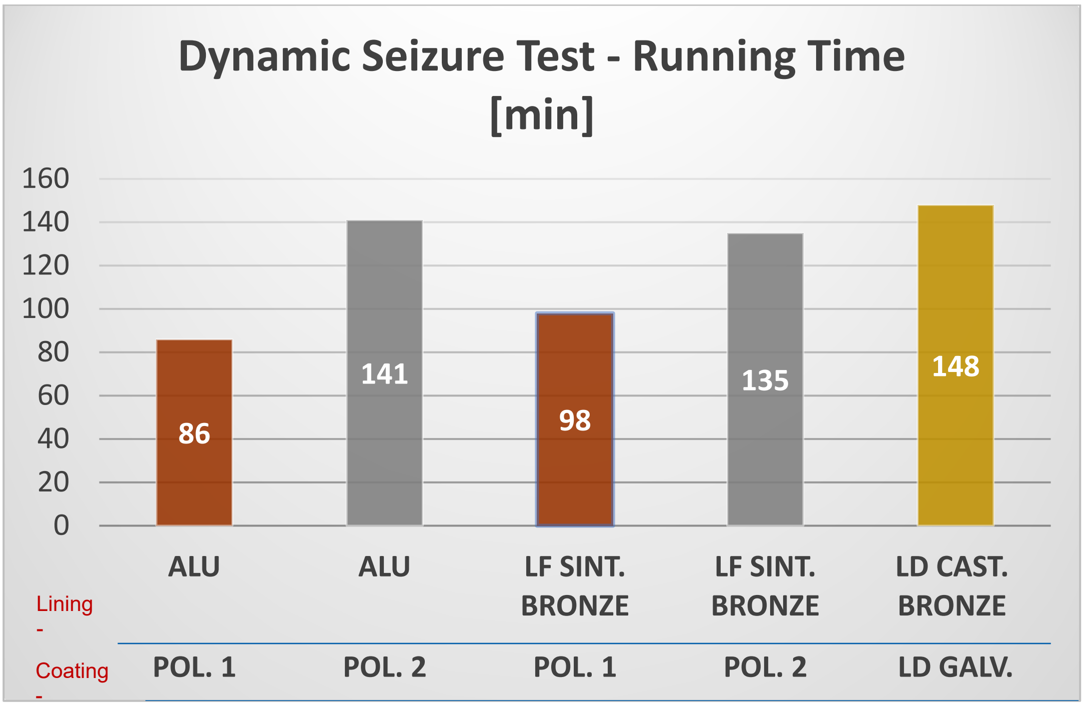

Figure 10 Dynamic seizure tests, with LF denoting lead-free versions and LD denoting leaded, Galv. denoting a galvanized coating, POL. denoting a polymer spray coat and PVD denoting a PVD Sputter coating (Part 1)

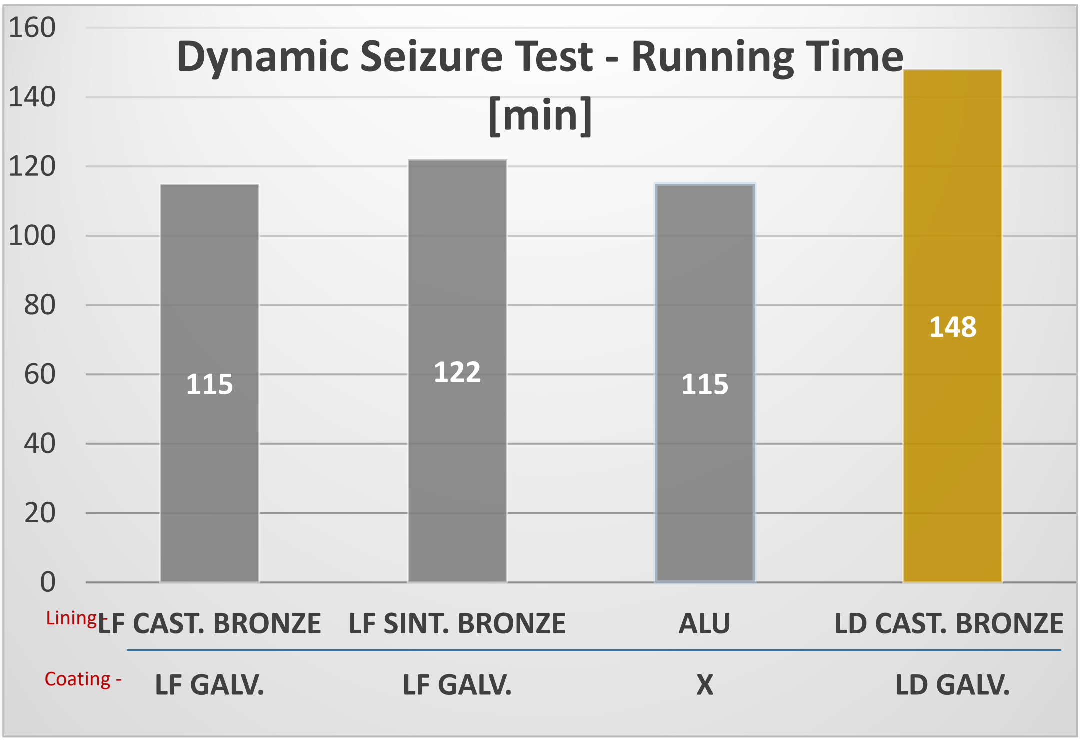

Figure 11 Dynamic seizure tests, with LF denoting lead-free versions and LD denoting leaded and Galv. denoting a galvanized coating (Part 2)

Stress tests were also undertaken to understand the effect if oil lubrication was suddenly taken away, which can be experienced when:

i) an oil pump goes offline,
ii) ii) due to contamination blocking the termination,
iii) iii) during oil aeration which can create a foam and
iv) iv) during the start-up of engine without oil.

This type of test is not used as often as the dynamic seizure test, which is quicker to undertake, as it takes 35 hours per test compared to 200 minutes and so only the more promising materials are tested. However, some manufacturers see the results of this test as being more realistic as the oil interruption is often a short-term interruption in situ. The results shown in figure 6 clearly show that bearings with lead in both the lining material and in the overlay coating is very significantly superior to all of the other materials tested.

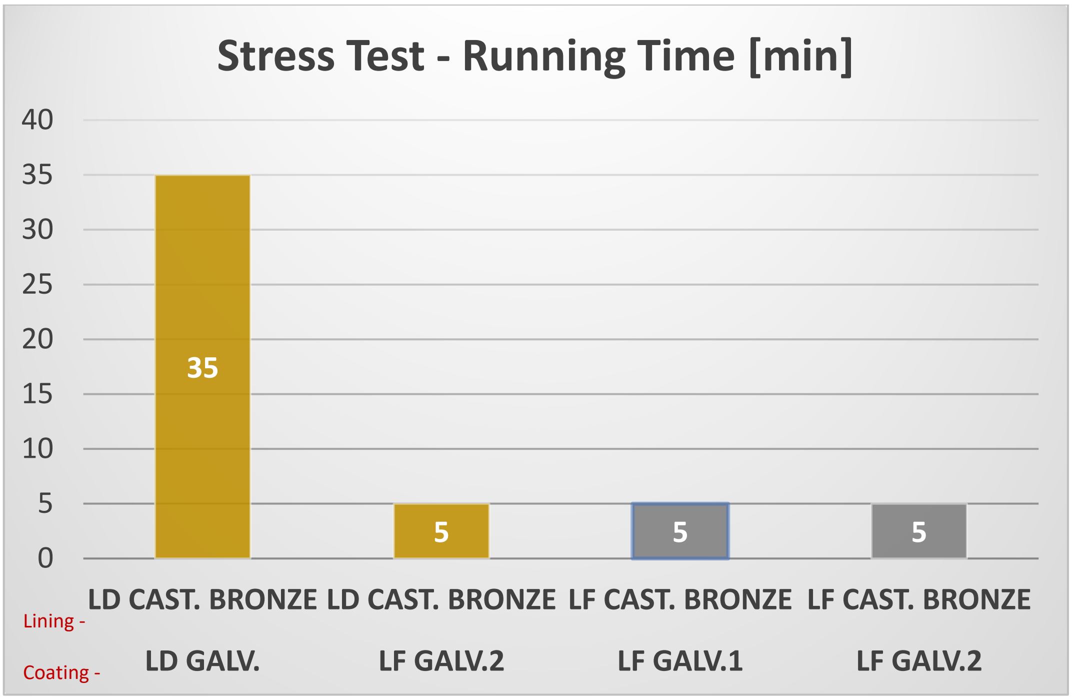

Figure 12 Stress test, with LF denoting lead-free versions and LD denoting leaded and Galv. denoting a galvanized coating

Cap shift test were undertaken by this bearing manufacturer, comparing leaded bronze substrate (LB), lead-free bronze substrate (LF B) and aluminium substrate (Alu), with polymer coatings (pol.), galvanized coating (Galv) and physical vapour deposition coating (PVD). Cap shift test are to determine how well a bearing can withstand misalignment, which can occur during in-service maintenance.

No alternative currently offers the same performance as the lead bearing (Test 5), with the reaming testing showing a significant level of ability to withstand cap shift. Only Test 3, a lead-free bronze substrate with a polymer coating with an aluminium substrate show comparable performance.

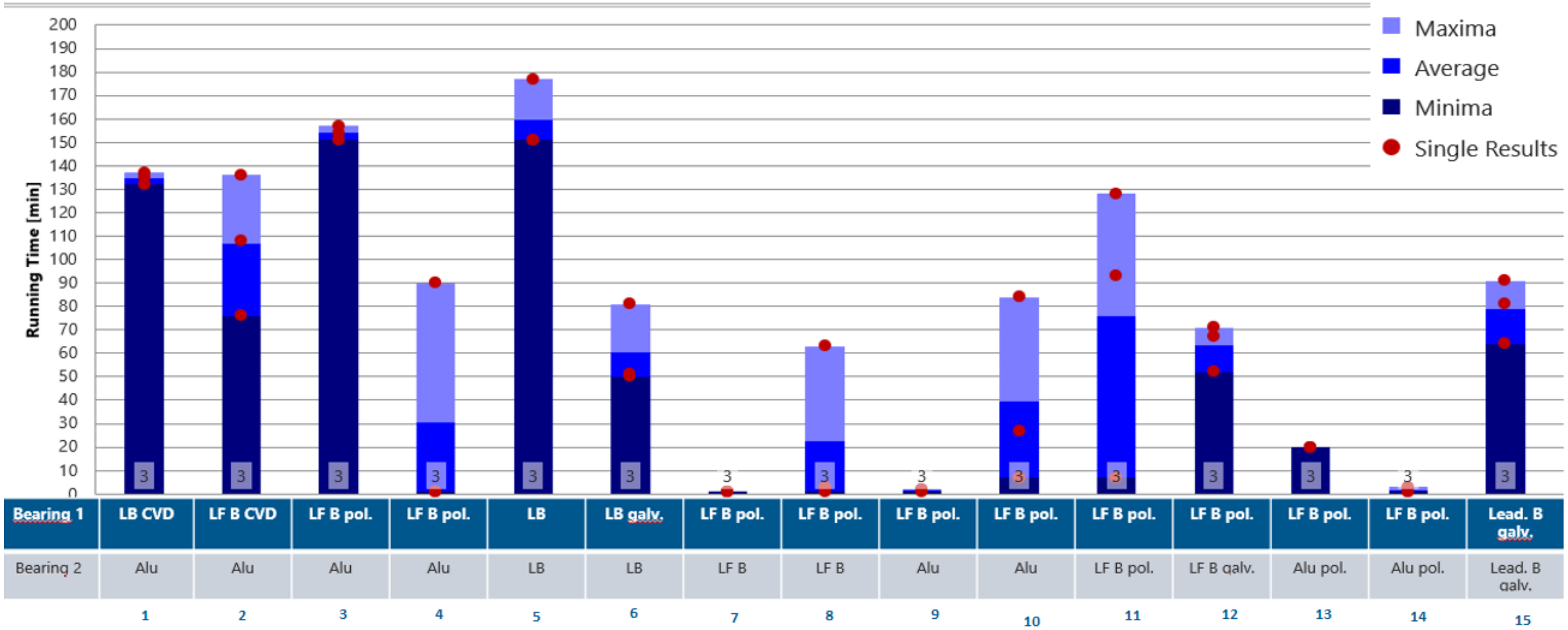

Figure 13 Cap Shift tests

Bearing Manufacturer B:

The testing outlined in Figure 14 was undertaken recently by a different bearing manufacturer using a rotating load machine, using debris amount 5mg (particle size of 63～75μm) undertaken a maximum of 10 times, with the failure determined to be either the temperature reaching 200°C at the bearing back side (Oil Inlet Temperature 100°C) or excess drive torque of shaft (indicative of high friction forces, which will occur when bearings fail) .

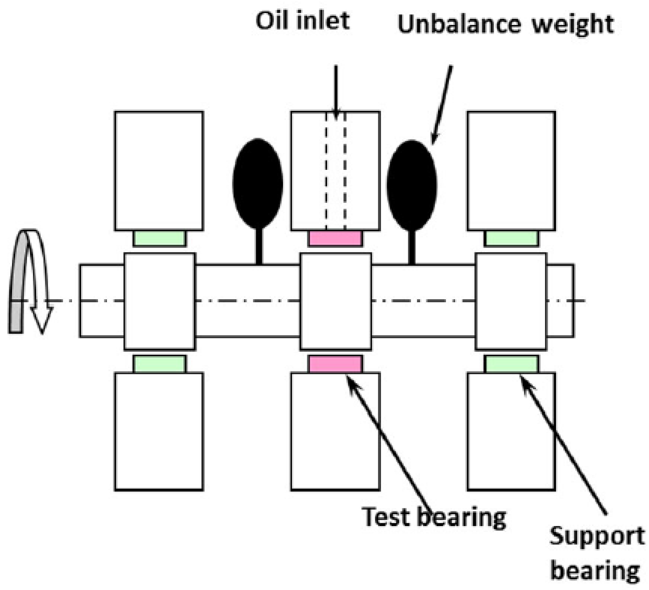

Figure 14 Bearing debris test scheme

Table 4: Bearing debris testing results undertaken in 2018-2019

#	Material (overlay/ lining alloy)	Number of apply debris when seizure occurred					
		Test 1	Test 2	Test 3	Test 4	Test 5	Average number to failure
1	Pb base overlay/Copper base alloy	5	3	4	5	5	4.4
2	Pb base overlay/Aluminium base alloy	No seizure	No seizure	No seizure	-	-	No seizure
3	Pb free overlay/Copper base Pb free alloy	5	4	4	-	-	4.3
4	PVD(sputter)/Copper base alloy	2	1	1	-	-	1.3
5	Polymer overlay/Aluminium base alloy	4	10	9	2	7	6.4

The results in Table 3 show that:

- Material 2 (Pb-based) was deemed by the manufacturer as the best performing due to the value and consistency of the average number to failure,
- Material 5 (Pb-free) gave results that were superior to both 1 and 3. However, the variability in the results of Material 5 is larger which was deemed as not acceptable, and
- Material 1 (Pb-based) and Material 3 (Pb-free) had similar performance.

As, Material 3 have equivalent debris tolerance to one of the conventional Pb-containing materials (#1) and therefore are at the stage where engine manufacturers could undertake testing in their applications to determine its suitability.

Engine Testing:

Once bearing manufacturers have undertaken testing to demonstrate that a lead-free alternative may be suitable, engine manufacturers undertake testing which is more reflective of their own in-service applications.

One such engine manufacturer filled crankshaft rod journals with debris of varies size/sources as shown in Figure 15, as a comparative study between lead bearings and two lead-free alternatives.

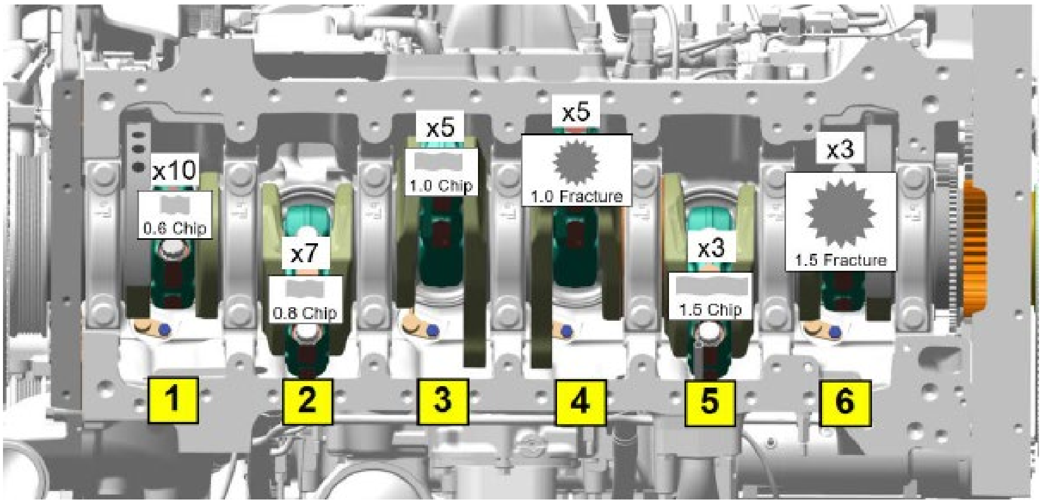

Figure 15 Connecting Rod Bearings comparative testing

Both of the lead free alternatives that were tested failed within the first 5 minutes of testing when debris particles with size of 1.00 and 1.5mm were introduced, compared to the lead bearing in which the engine completed the duration of test without any failure, even when debris with particle size of 3mm was introduced. These leaded bearings showed very minimum wear.

Table 5 Connecting Rod Bearings comparative testing results with increasing particle sizes. Bearing 1 was exposed to the smallest particle size and bearing 6 was exposed to the largest

<table>
<tr><th></th><th>Bearing 1</th><th>Bearing 2</th><th>Bearing 3</th><th>Bearing 4</th><th>Bearing 5</th><th>Bearing 6</th></tr>
<tr><td>Lead-free 1</td><td colspan="3">Rod journal exhibited heat transfer and scratch mark but didn’t fail</td><td colspan="2">Rod journal failed (both cap and the rod side) bearings. See Figure 16</td><td>Invalid result[5]</td></tr>
<tr><td>Lead-free 2</td><td colspan="2">No sign of heavy scratch marks (particle size range is 0.6 -0.8mm)</td><td colspan="2">Starting to show scratch marks</td><td colspan="2">Damage on both top and bottom bearings. See Figure 17</td></tr>
<tr><td>Leaded bearing</td><td colspan="6">No failures and minimal wear</td></tr>
</table>

[5] Debris was pushed out during initial stage start-up so the result was determined to be invalid.

Figure 16 Lead-free test 1, cylinder 4 filled with debris from fracture joint (1.00 mm; qty = 5 chips)

Figure 17 Lead-free test 2, cylinder 6 filled with debris from fracture joint (1.5 mm; qty = 3 chips)

During the development of any new engines, it is commonplace for engine manufacturers to try to transition to lead-free alternatives wherever possible as the testing required to qualify the bearing can be incorporated into the initial qualification programme. This opportunity was embraced by one engine manufacturer who during the development of their latest generation of compression injection engines trialled lead-free bearings. During engine qualification test-runs, several engine failures were observed due to main bearing seizures. The root cause of the issues was identified to be due to the relocation of the crankshaft in the main bearing channel at the high idle operation point of the engine. The contact between the bearing and the crankshaft increased the bearing surface temperature in an unacceptable region and as a result, the bearing failed as shown in Figure 18.

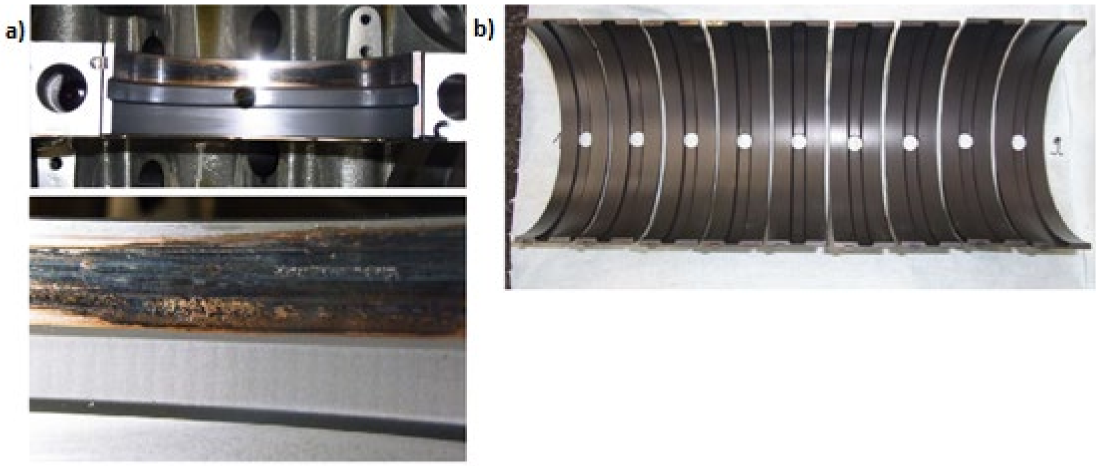

Figure 18 a) Lead-free main bearing showing seizure, b) Main bearing upper (with lead) half showing usual wear pattern

The conclusion reached by this manufacturer was that this was due to the hardness and higher resistance to conformance in the bearing contact area (a bearing with lead is more relenting) of the lead-free bearing. Once lead bearings were used no further failures were observed due to this issue. This issue is especially important to stationary engines, such as power generators, due to their sensitivity during the dry start phase and if lead-free bearings had to be used it should be expected that there would be a significant increase in the failure rate in such applications.

Although testing of lead-free bearing is more easily incorporated at the development stage, engine manufacturers for current engine designs are investigating lead free alternatives. One such engine manufacturer tested lead free bearings in all slide bearings and bushes (specific details of each detailed below), in in both a V8 engine and a L4 engine[6];

- Main bearing (steel back and aluminium running layer),
- Connecting rod bearing (steel back, aluminium alloy, and polymer-running layer), and
- Intermediate wheel bush water pump- fan wheel (steel back and aluminium running layer).

Both engine types were tested for 500h at full load as an endurance test and disassembled afterwards to inspect the bearings. The frame-side main bearings show extreme cavitation damage at the unloaded bearing ends, as shown in Figure 19.

[6] V8 is an eight-cylinder engine with two rows of four cylinders. L4 is an engine with a single row of 4 cylinders.

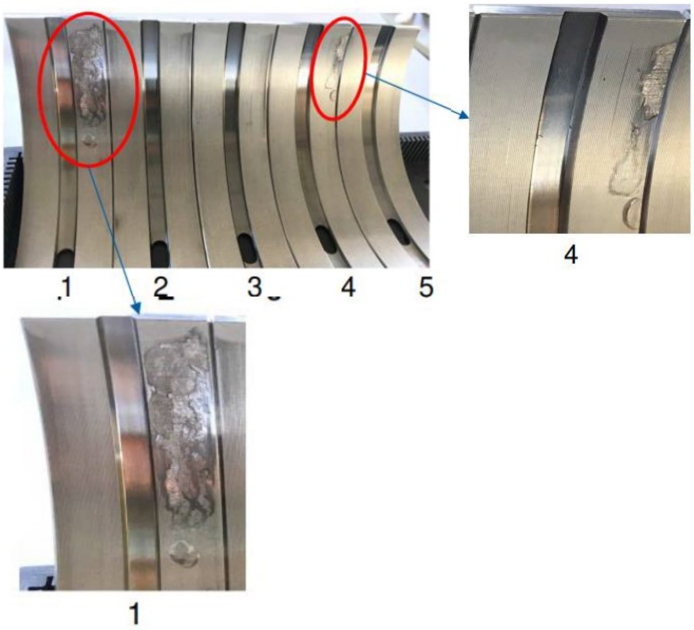

Figure 19 Fatigue outbreaks on upper main bearings

In addition to this, the intermediate wheel bush water pump bearing showed strong edge wear with fatigue of the running layer, as shown in Figure 20.

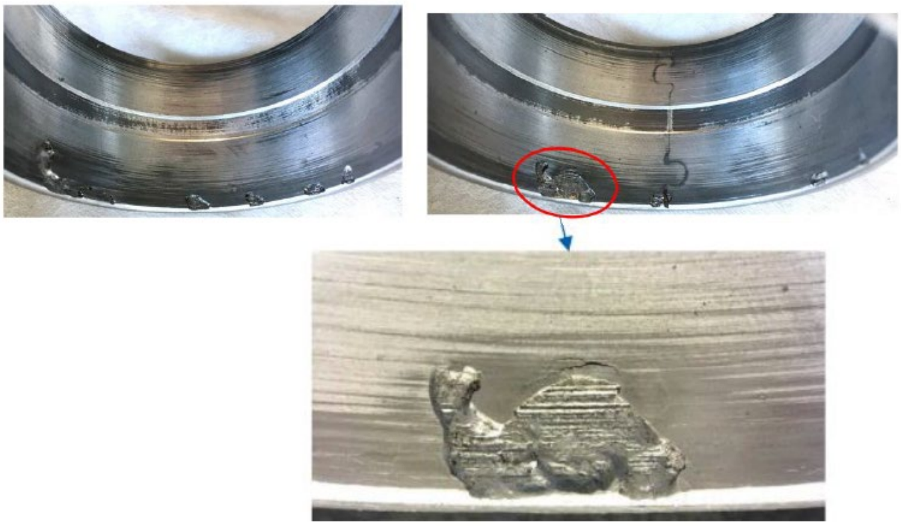

Figure 20 Intermediate wheel bush water pump wear

Lead bearings in other endurance runs had previously already shown smaller cavitation traces, however, these were always classified as not being impactful to the operation of the engine. Cavitation to the extent now seen in the lead-free bearings has never been detected before with leaded bearings and such results would indicate that the lead-free bearings do not have sufficient technical performance to allow substitution as it would result in major engine failures in service.

The test undertaken on the L4 engine after 300h of testing the upper connecting rod bearing was completely destroyed, such that only small pieces remained, and the lower connecting rod bearing is rolled out, as such the test was halted (Figure 21).

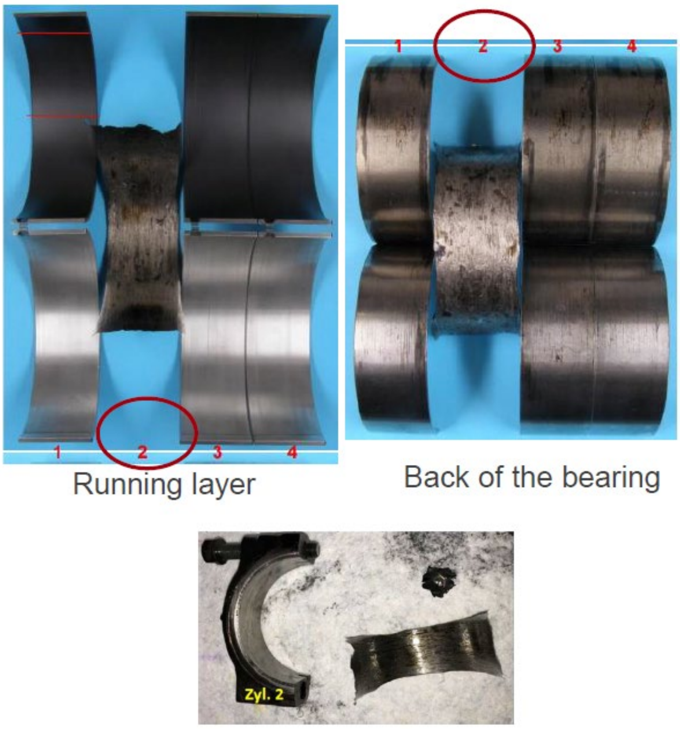

Figure 21 Bearing seizure on connecting rod bearing

Additional mechanical trial test for 1100 h was also undertaken, which resulted in polymer layer breakouts in the edge areas due to overloading in the edge area on the upper bearing and the failure of the connecting rod bearing, Figure 22.

Polymer layer breakouts in the edge areas

Completely destroyed connecting rod bearing (3)

Figure 22 Mechanical Trial test

Another manufacturer is currently comparing the most promising lead-free alternative bearing to the current lead bearing, as outlined in Figure 23. This compares seven performance parameters necessary for their applications for leaded bearings and the most promising lead-free substitute tested by this manufacturer to date.

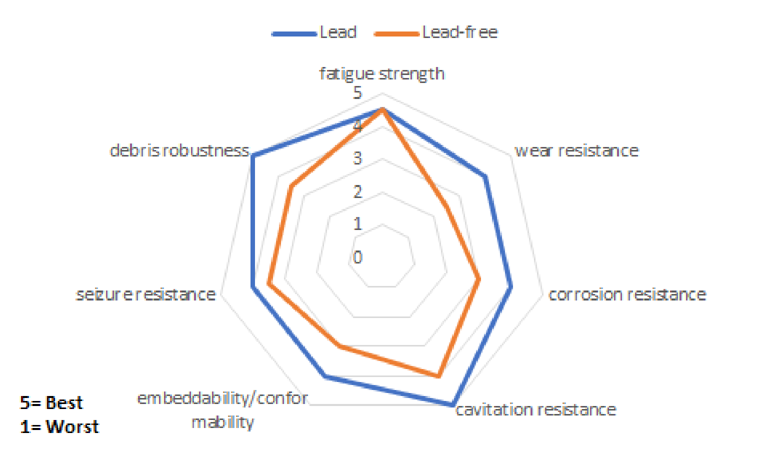

Figure 23 Comparative testing of leaded bearing to lead-free alternative

It can be seen that although the lead-free alternative shows higher performance for some of the tested characteristics, namely cavitation resistance and corrosion resistance, leaded bearings still outperform the tested alternative on the other attributes (wear resistance, embeddability/conformability, seizure resistance and debris robustness). Given the operational environment of the products in scope of this exemption, decreased performance of any of these attributes poses a real risk to causing engine failure. Work to understand the extent to which failures would be experienced on this manufacturer's engines due to the decreased performance is being undertaken, along with investigating if the bearings can be developed further to reduce the decrease in performance.

One engine manufacturer has performed extensive testing on lead-free bearings. Notwithstanding that all prior analyses indicated that that the performance of main and rod lead-free bearings in a specific engine type would be sufficient to allow an alternative bearing to be used, the lead-free bearings showed a high failure rate when used in production. The specific main and rod bearing in this engine type had specific technical characteristics which indicated the lead-free solution was suitable. The failures resulted in seizures in either the main or rod bearing, resulting in engine failure. Investigations and improvements were carried out into the cleanliness of the used facilities, with minimal to no impact on the failure rate. The same failures have not been present in lead bearings.

A different engine manufacturer trialled lead-free rod bearings in 2017, which resulted in 77 catastrophic engine failures, all of which were attributed to localised contamination of main/rod bearings. After investigation it was found 0.100-0.200mm debris were at fault for the failures, but this is within the context of the state of the are cleanliness is thought to be in the 0.400-0.500mm range. Given that the products in question are operated and serviced in dirty environments where contamination is common (see Figure 24) and certainly not within the range of state-of-the-art cleanliness. This manufacture estimates that cleanliness requirements of lead- bearing systems is within the 1.00-1.500mm range which highlights the importance of having bearings with high debris tolerance is essential.

Figure 24 Bearings showing contamination after operation and service in dirty environments

Leaded copper alloy bushings are widely used in engines in scope of exemption 42. As described above, when lead-free substitutes were tested, these always proved to be unsuitable. All bushings function in the same way so that when starved of oil, which always occurs at start up and can occur at other times, the lead acts as a dry lubricant. No other metal is known that can act as a dry lubricant.

Some automotive applications use roller bearings instead of leaded alloy bushings. Roller bearings are however unsuitable in engines which require debris tolerance. Roller bearings require a clean lubricant to function efficiently, as dirt will cause the lubricant inside these bearings to become very viscous and will also damage the bearing surface, causing premature failure.

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

This has been included in section 6(A).

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7. Proposed actions to develop possible substitutes

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

Section 6 outlines the activities that have been undertaken to identify alternatives, however, as explained above, to date no alternative has been identified with either the required technical performance to support products covered by this exemption request, or their long-term reliability was found to be very poor with many premature failures. Testing is being undertaken on a continual basis with other lead-free alternatives when they become available. More time is needed for these to be developed and the necessary testing undertaken with the aim that they give reliable performance comparable to current materials.

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

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.

After laboratory tests, extensive “on-engine” and field testing must be executed to evaluate the reliability and durability of the substitute material. 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 bearings / bushings.

Even then, as evidenced by failures where lead-free alternatives have been incorporated into current manufacturing, real world conditions are impossible to fully replicate with testing.

The following table provides an estimation on the expected timeframes for the development of an alternative, it is important to note that the following are based on the concept that each test will ‘pass’ first time. If any further development is required to resolve technical issues the timeframes outlined would be much longer.

Table 6 Qualification requirements

Stage	Requirement	Indicative Timeframe
1. Search for alternative lining and overlay alloys	Has been underway for many years, with some showing initial signs of suitable performance. However, not all manufacturers are able to demonstrate this and therefore defining a completion date is not possible	Unknown
2. Evaluation in bearings	Solution/design development	1-2 years
3. Evaluation of lead-free bearings in engine assemblies	For some manufacturers industrialization of the solution is required	6 months
4. Engine redesign	Some alternatives may not be a drop-in replacement and affect the overall engine design.	Up to a year
5. Evaluation of lead-free engines in the field	Can begin this phase only when bench testing of engines with lead-free bearings shows that these are reliable, and performance and emissions are not adversely affected	2 years
Total	**5 years once a solution is developed by bearing suppliers**	

Internal combustion engines are required to comply with emission legislation. As changing a bearing material may affect emissions and so compliance must be confirmed before a new design can be placed on the market. The EU, USA, Canada, China, Japan, and many other countries all have their own specific emissions legislation, with for global approvals this also needs to be considered. This will require between 1-3 years depending on the engine manufacturer, which for the majority of engine manufacturers will be in addition to the above timescale.

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

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

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

   ☐ Authorisation

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

   ☐ Restriction

   - ☐ Annex XVII
   - ☐ Registry of intentions

   ☒ Registration- https://echa.europa.eu/registration-dossier/-/registered-dossier/16063

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

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

(B) Elimination/substitution:

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

   ☐ Yes. Consequences? _____

   ☒ No. Justification: _____

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

   ☐ Yes.

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

   ☒ No.

   Justification: _____

3. Give details on the reliability of substitutes (technical data + information):_____
4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to
   1) Environmental impacts: _____
   2) Health impacts: _____
   3) Consumer safety impacts: _____

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

(C) Availability of substitutes:

a) Describe supply sources for substitutes:
To establish if a possible lead-free bearing is suitable, the first stage is for the bearing and bushing manufacturers to develop materials equivalent in tribological properties to lead. As outlined in section 6, testing to demonstrate this baseline requirement, is only recently starting to provide some alternatives which might offer suitable technical performance. The bearings which do show promise will be taken forward to the next stage of testing, however it is important that multiple avenues of supply must be developed to avoid monopolistic situations and preserve healthy market competition which ensures high quality, and uninterrupted supply.

b) Have you encountered problems with the availability? Describe: Bearing suppliers are only just developing bearings which offer suitable technical performance to engine manufacturers. Each engine manufacturer needs specific technical performance that relates to their engine type and demands. Therefore, engine manufacturers are only now starting to test these 'new' bearing types. Availability of bearings compared to the market demand will only be known once engine manufacturers qualify lead-free bearings for their uses.

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? n/a

(D) Socio-economic impact of substitution: n/a

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

☐ Increase in direct production costs.

☐ Increase in fixed costs.

☐ Increase in overhead.

☐ Possible social impacts within the EU

☐ Possible social impacts external to the EU

☐ Other: _____

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

9. Other relevant information

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

_____

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10. Information that should be regarded as proprietary

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