Exemption Request Form

Date of submission: 20 January 2023

1. Name and contact details

(A) Name and contact details of applicant:

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

Company: EUROMOT
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This exemption request is submitted with the support of:

EGMF European Garden Machinery Federation

AEM Association of Equipment Manufacturers

EUROPGEN The voice of the European generating set industry

EMA Truck & Engine Manufacturers Association®

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: 7a

Proposed or existing wording:

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more of lead) used in engines, engine components and ancillary components and in end-products in which they are used

Duration where applicable: 5 years (maximum validity period)

☐ Other:

3. Summary of the exemption request / revocation request

High temperature melting point (HMP) solder containing lead are used to electrically and physically join two elements in internal combustion engines, associated components and end-products in which they are used. Lead provides essential characteristics such as high melting point, strong heat conduction, high electrical conductivity, high ductility corrosion resistance and high reliability. Component using HMP solder are subject to aggressive environments, vibration and temperatures. Alternative technologies with similar ductility and strength as lead alloys and that can survive a standard reflow process (or several) on PCB with either leaded or unleaded solder are as yet unavailable for the intended uses EUROMOT members require them for.

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 solder manufacturers. Testing then 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 to understand if the alternative is able to offer the required technical characteristics. As such the qualification timeframe is estimated to be 5 - 7 years (without NRMM Emissions Regulation re-approval) and 6 - 8 years (with NRMM Emissions Regulation approvals) from the date a promising alternative is identified.

EUROMOT recognises that there is the recommendation to limit the exemption scope to sub-divided scope listing out specific uses. EUROMOT members, as end equipment suppliers does not have the necessary technical information to be able to determine if all of the HMP solder uses are listed. However, EUROMOT members are of the opinion that this scope is too restrictive and will likely preclude to necessary technical use of HMP solders in applications not listed. 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 they 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 categories 1 - 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: Solder alloys are used to electrically or physically join two elements. Lead provides essential characteristics such as high melting point, strong heat conduction, high electrical conductivity, high ductility and high reliability.

4. Content of substance in homogeneous material (%weight): >85% by weight of homogeneous material.

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

   Depending on the type of equipment the amount of lead will vary significantly, therefore an estimation was unable to be quantified.

   Please supply information and calculations to support stated figure. n/a

6. Name of material/component: Solder

7. Environmental Assessment:

   LCA: ☐ Yes

   ☒ No

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

Description of the supply chain and product sectors

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[1]). 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 solders that are used by EUROMOT members need to comply with RoHS[2].

EUROMOT's members use commercially available electronic components but select those that are specified for use at higher temperatures where these are necessary. High melting

[1] 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.

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

point solders are used in these components only if standard eutectic solders cannot be used because of the temperatures that are experienced.

Lead is used as the majority constituent in High Melting Point (HMP) solder alloys to make electrical connections. Based on the type of application, a lead level >85% is necessary to achieve the required melting temperature and other material properties.

Table 1 lists example types of binary tin alloys and their melting temperatures for solders currently used in applications falling under this exemption although ternary (such as Pb92.5-Ag2.5-Sn5), and more complex alloys are also used commercially. For reference, it also lists melting temperatures of solders containing 85% or less of lead which are restricted under the RoHS Directive but may be covered under other exemptions. As shown in Table 1, the proportion of lead has a direct impact on the melting temperature of the solder.

Table 1. Composition and Melting Temperatures of Tin-Lead Solders

Solder Type	Alloy Composition [wt %] (Main Components Only)	Melting Temperatures (Solidus Line / Liquidus Line)
High temperature type lead-containing solder (Falling under exemption 7a of RoHS Directive)	Sn-85Pb	226 / 290°C
	Sn-90Pb	268 / 302°C
	Sn-95Pb	300 / 314°C
Lead-containing solder (Use restricted under RoHS Directive and may be exempted by exemptions 15)	Sn-37Pb (Conventionally used)	183°C
	Sn-60Pb	183 / 238°C
	Sn-70Pb	183 / 255°C
	Sn-80Pb	183 / 280°C

Provision of a comprehensive list of uses of lead-high melting point solders is problematic for EUROMOT as there are likely to be many electronic components supplied to its members that contain these materials, but this information is not always provided. These components include all of the types that are used by other electrical industry sectors, such as those listed by the Umbrella Project in its exemption 7a renewal request and its answers to clarification questions[3]. The following is an illustrative list of uses of exemption 7a obtained from EUROMOT members and from other sources of information:

- Solders used to attach components, sensor, etc to wiring looms, etc.
- Internal solder bonds in sensors that operate at high temperatures (>180°C in exhausts)
- Solders used to lead wire for ignition coil, motor etc..

[3] https://rohs.exemptions.oeko.info/exemption-consultations/2020-consultation-2/aiii-ex-7a

- First and second level soldering inside components where these bonds must not melt when components are solder reflow bonded to circuit boards
- Voltage transient suppressors
- Field effect transistors
- Switching ICs and many other types of integrated circuit including voltage regulators and current monitors, used as die attach (a wide range of die size may require HMP solder especially if the components are used in engines (more details are given in the Umbrella Projects answers to questionnaire 5)
- Engine Control Units (ECUs) which can operate at temperatures of 150°C
- Bridge rectifiers
- Various types of diodes
- High power transistors
- BGAs with lead HMP solder balls
- Thermistors
- Fuses, solder used for hermetic sealing and for electrical connections
- High power resistors and other passive components such as relays, inductors, potentiometers, sensors, transformers, oscillators, capacitors, etc. Note that most standard passive components do not use HMP solder, but some of these that need to be used in high temperature environments may require lead HMP solder to be used, e.g. for internal bonding or as a hermetic seal.
- MOSFET (Metal Oxide Semiconductor Field Effect Transistor), as die attach
- Crystal components for internal bonding and as hermetic sealing
- Internal solder bonds in components that use high temperature over-moulding (this is for superior sealing from moisture and environmental pollutants)
- Sensors and actuators

These electronic components of the engines in scope of RoHS can experience severe operating conditions of temperature, vibration and corrosion and must be reliable for at least several decades, although service conditions and lifetime are end-product dependent.

Standard lead-free solder has a melting point typically of 210°C. If a component is used in an environment of 150°C or hotter because most electronic components self-generate heat, they can become so hot that standard solders will melt and so failure will occur. Therefore, solders with higher melting temperature are needed both inside these components and often also to attach components.

Also, some widely used types of electronic components are designed with internal high melting point solders as the internal solder needs to have a melting point higher than the temperature that is used for re-flow soldering of components onto printed circuit boards. Standard lead-free solders are typically reflowed at up to about 240°C. Therefore, the internal high melting point solders need to melt at 280°C or higher, although this should not be so high as to damage the materials used for components when this solder is melted during component construction. This means that electronic high melting solders must melt in the range of about 260°C to 320°C to avoid damage to the polymers used in electronic components and to not melt during reflow soldering or in use with engines.

Table 2 lists intended uses and related products in which HMP lead solders under RoHS exemption 7a are utilised and their critical functionality.

Table 2 Intended Use and Examples for Related Products in which HMP lead solders are utilised

Intended HMP solder use	Examples of related products	Reasons for necessity
For combining elements integral to an electrical or electronic component: - a functional element with a functional element; or, - a functional element with wire/terminal/heat sink/substrate, etc.	Resistors, capacitors, chip coil, resistor networks, capacitor networks, leaded inductors, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, power transformers, resistance temperature devices, electromechanical relays for automotive[4] and industrial uses See Figure 1 to Figure 4	Stress relaxation characteristic with materials and metal materials at the time of assembly is needed. When it is incorporated in products, it needs heatproof characteristics to temperatures higher than 250 to 260°C (the typical solder reflow temperature used for PCBs and wave soldering) Electrical characteristics and thermal characteristics during operation: high electric conductivity, high heat conductivity/ thermal dissipation, etc. High reliability for temperature cycles and power cycles due to stress relaxation from higher ductility material, etc
For mounting electronic components onto sub-assembled modules or sub-circuit boards	Hybrid IC, modules, optical modules, etc. See Figure 5	

The following images show some illustrative examples of types of devices and locations of HMP solder that are used by EUROMOT's members.

[4] Included for reference

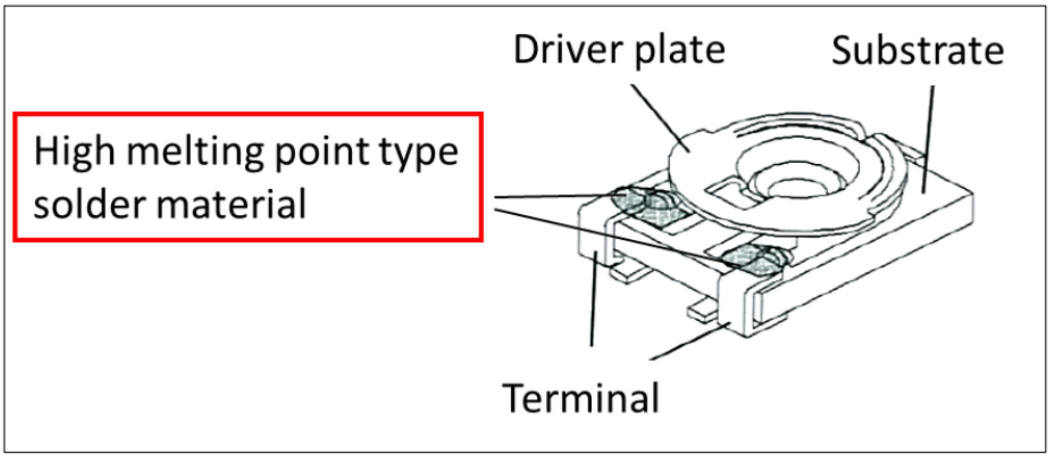


Figure 1 Schematic view of potentiometer with HMP lead solder visible from the outside (used for example in throttle position sensors)

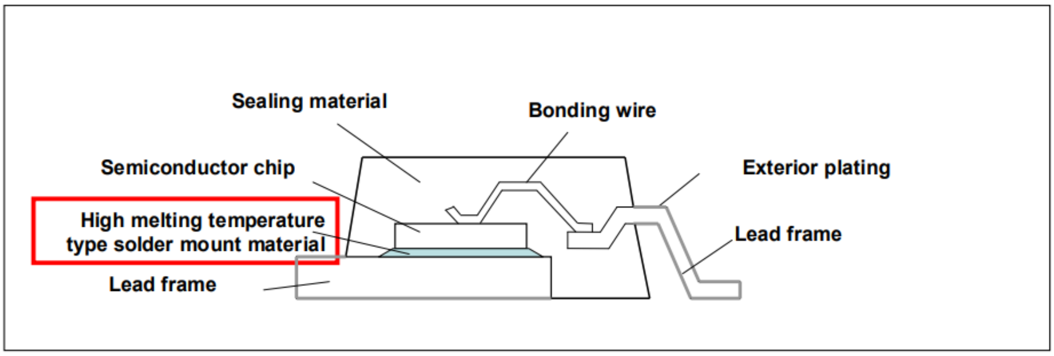


Figure 2 Schematic cross-sectional view of power semiconductor

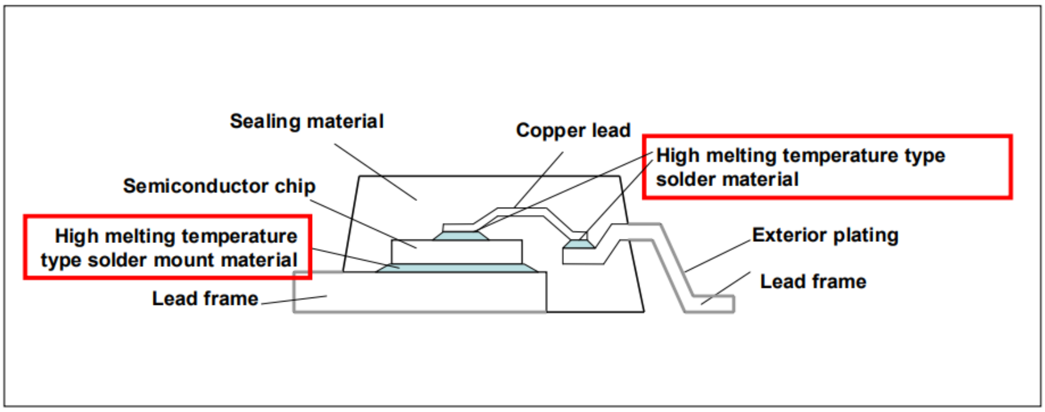
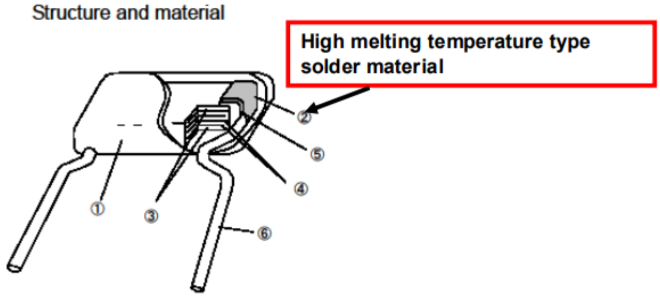


Figure 3 Schematic cross-sectional view of internal connection of semiconductor

Structure and material

1. Structure



2. Material and Description

No.	Material	Description
①	Enclosure	Epoxy resin
②	Inner solder	Sn-Pb type solder *1
③	Dielectric	Ceramic
④	Inner electrode	Ni or Pd or Ag/Pd
⑤	Outer electrode	1)Ag/Pd or 2) Ag or Ag/Pd or Cu + Ni plating + Sn plating
⑥	Lead wire	Solder(Sn-2.5Cu) coated copper wire or Solder(Sn-2.5Cu) coated CP wire

*1 Lead in high melting temperature type solders (Pb;85% or more) are exempted from the requirements of RoHS.

Figure 4 Schematic view of capacitor with lead wire

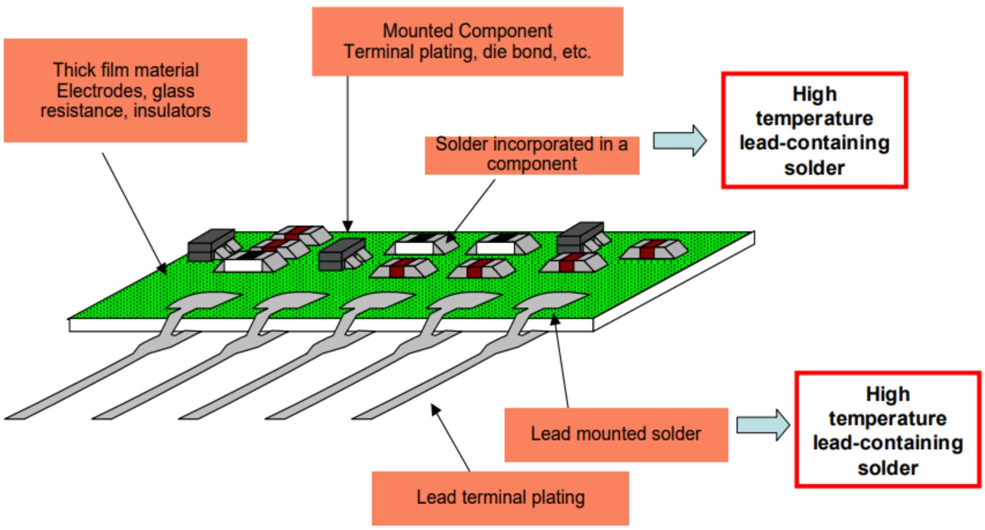


Figure 5 Schematic view of circuit module component

Thermistor bonding

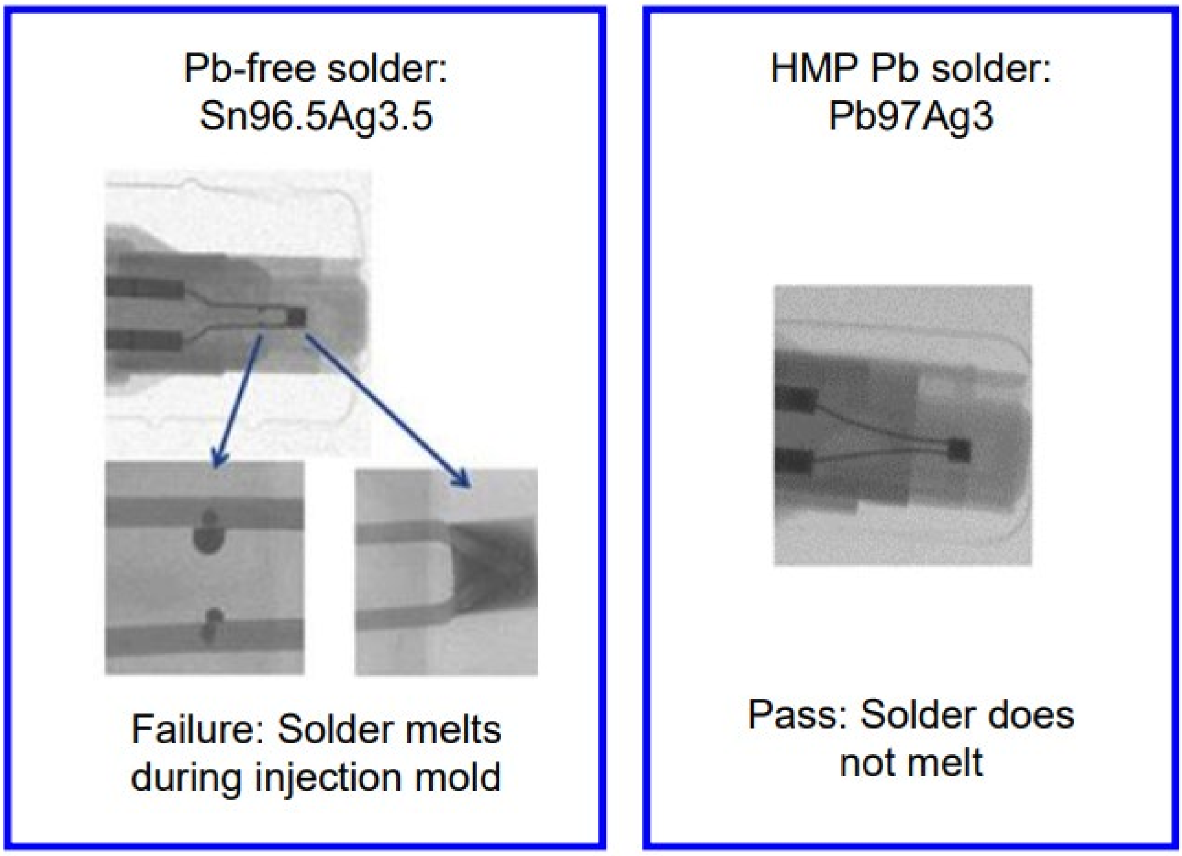


Figure 6 Thermistor Requirement for HMP Lead Solder

Figure 7 explains why a thermistor (e.g. used to measure temperature of engine lubricants and coolants) requires high melting point solder. Thermistor devices are used in high temperature/harsh applications. This temperature requires plastic overmolding with materials having a working temperature of ~ 260°C. High temperature solder is required to avoid any reflows (melting of solder) which would weaken or debond the connecting terminal to thermistor adhesion. The picture on the left details the solder re-flow from plastic overmolding with lead-free type solders showing that the solder has melted and de-wetted from the terminals. This will cause an open circuit. The picture on the right depicts high temperature lead base solder in the same overmolding operation. The solder dimensions are unchanged so that the solder bond is unaffected.

Similar circumstances are relevant with current limiting thermistor products (these, for example, are used to limit inrush currents that can occur when some types of devices are switched on). Current limiting thermistors can reach temperatures up to 240°C during normal operating conditions in the field. In order to stay above the plastic/melting point of the solder for this application, ductile high lead content solders are the only commercially available solution at this time.

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 does not have the necessary technical information to be able to determine if all of the HMP solder uses are listed. However, EUROMOT members are of the opinion that this scope is too restrictive and will likely preclude to necessary technical use of HMP solders in applications not listed. Engagement with EUROMOT members supply chain in on-going to identify if any specific uses are not outlined. In the meantime it is essential that the original scope of the 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.

When used as part of the construction of electronic components, sensors, or actuators etc., each application can have a unique combination of essential requirements. which include:

- Very good thermal and electrical conductivity, as the die attach conducts heat away from the self-heating semiconductor whilst also being part of the electrical circuit in some components.
- A melting point that is higher than standard solders used in joint formation, which is directly proportional to the lead composition as shown in Table 1.

For example, when HMP solder is used for die-attach, the HMP solder's melting point must be higher than both the component's internal temperature in use, taking into account self-heating, and also must be higher than the temperature used to solder the component onto a circuit board.

Due to the nature of manufacturing processes and the limitations of other materials that are used (e.g. polymer insulation is damaged if too hot) in these processes (solder reflow or with soldering irons, etc.), the temperature range of the bonding process is limited.

- Ductility.
- Withstand large numbers of thermal cycles without imposing too high stress levels on the semiconductor chip which can cause de-bonding or chip fracture.

This is important because the thermal coefficient of expansion (TCE) of the lead-frame alloy will usually be larger than the TCE of the semiconductor. Therefore, the solder die attach material must be sufficiently flexible to avoid imposing high stress on the chip. This is important in all types of integrated components (ICs), diodes, rectifiers, MOSFETs and other types of components where HMP solder is needed to bond a metal to a semiconductor.

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 solder bonds than are experienced by most other types of electrical equipment such as consumer, household, IT, etc. Many of EUROMOT's members products are used for two or more decades and so these bonds can experience very large numbers of very wide temperature thermal cycles in their lifetimes. It is therefore essential that the bonding material used can withstand low cycle fatigue with high cyclic stresses.

- Corrosion-resistivity,

Some solder bonds, such as those that make connections to sensors will be exposed to the external environment and so can be exposed to marine conditions (salt spray), corrosive substances that are used in factories and high levels of dust such as in quarries and building sites, etc. Other solder bonds are located inside engines and therefore can be exposed to exhaust gases, lubricants or coolant fluids, depending on their location.

- Withstand substantial vibration over prolonged periods as engines vibrate, and so high cycle fatigue resistance is also an essential requirement,
- Appropriate oxidation nature, and
- Wettability by the solder to surfaces that it is required to bond.

Lead is the only known element which gives all these properties.

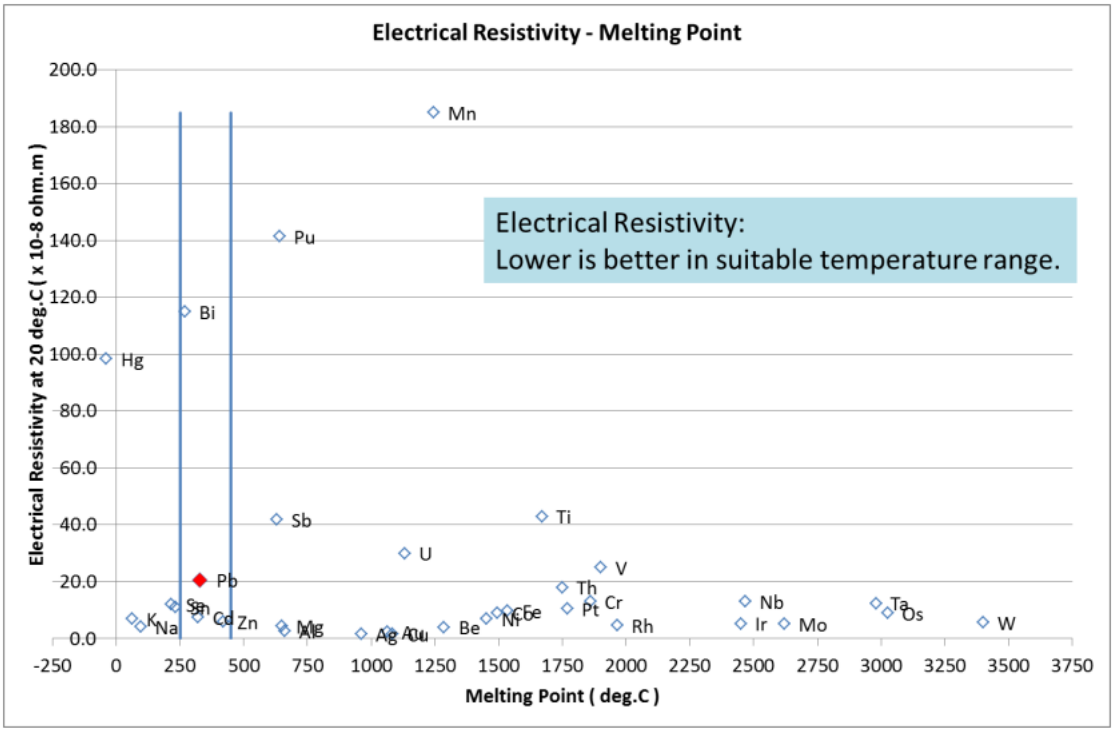
Table 3 below shows the properties required for HMP solders, reasons for the necessity, function of lead for each property and their data. It is the combination of physical and chemical properties of the alloys that are important. Some combinations of elements (e.g. AuSn) will meet some criteria, but the essential requirement is for the unique combination of all of the essential properties, not any single property.

Table 3: Required performance of the high melting point solder and role, function of the lead content

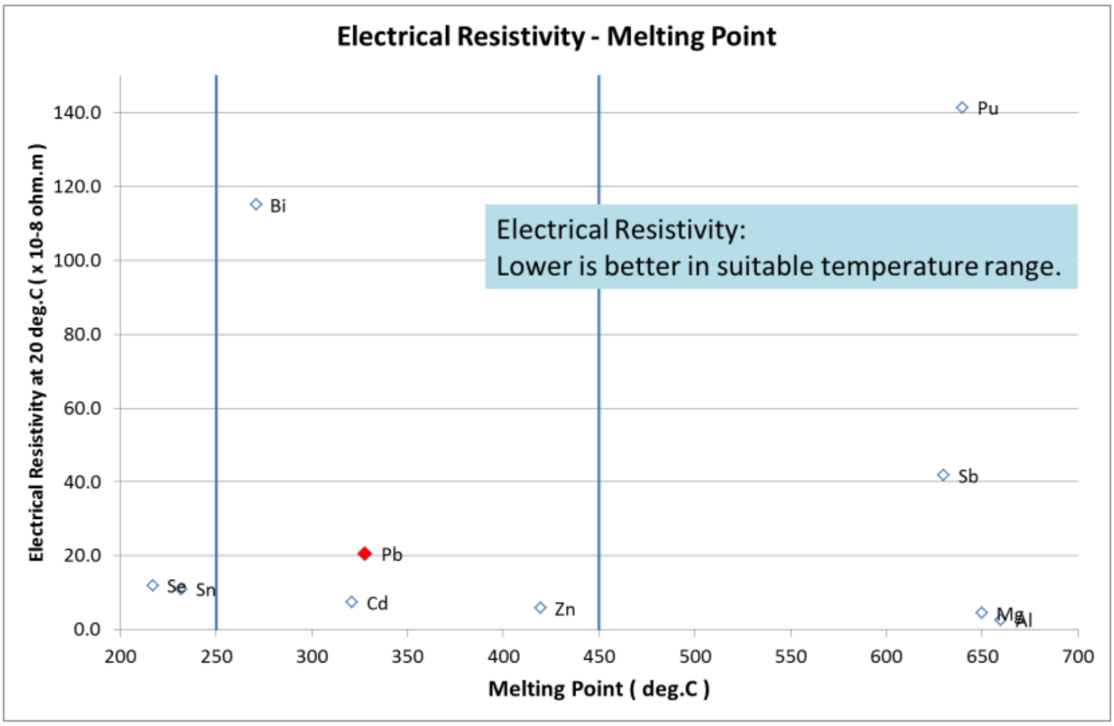
Performance Requirements	Reasons for the Requirements	Function of Lead	Data
High Melting Point	Not to melt during subsequent thermal processing or during use in the finished equipment when the components self-heat and are heated by the engine. Functionality of electrical parts not to deteriorate	HMP solders require a minimum melting point of at least 250°C. Solder processes have a maximum limit of 450°C (usually much less) to avoid damage to other materials. There are limited materials in this this temperature range	Melting points Graph 1 Graph 2 Graph 3 Graph 4 Graph 5 Graph 6 Graph 7 Graph 8 Graph 9 Graph 10

Performance Requirements	Reasons for the Requirements	Function of Lead	Data
			Graph 10
Electrical connection	Electrical functionality	Lead has the ideal balance of properties of melting point, electrical & thermal conductivity, mechanical reliability & chemical stability	Electrical resistivity Graph 1 Graph 2
Thermal conduction	To ensure the reliability of electronic components due to the heat dissipation		Thermal conductivity Graph 3 Graph 4
Ductility	To join the materials having the different coefficients of thermal expansion together (to ensure mechanical reliability)		Young's modulus Graph 5 & Graph 6
Corrosion resistivity	To ensure the reliability		Ionization tendency (Very low next to hydrogen, therefore difficult to oxidize) Graph 7 Graph 8
Oxidation nature	To prevent oxidation at the secondary mounting; To ensure the reliability		Standard electrode potential Graph 9 Graph 10

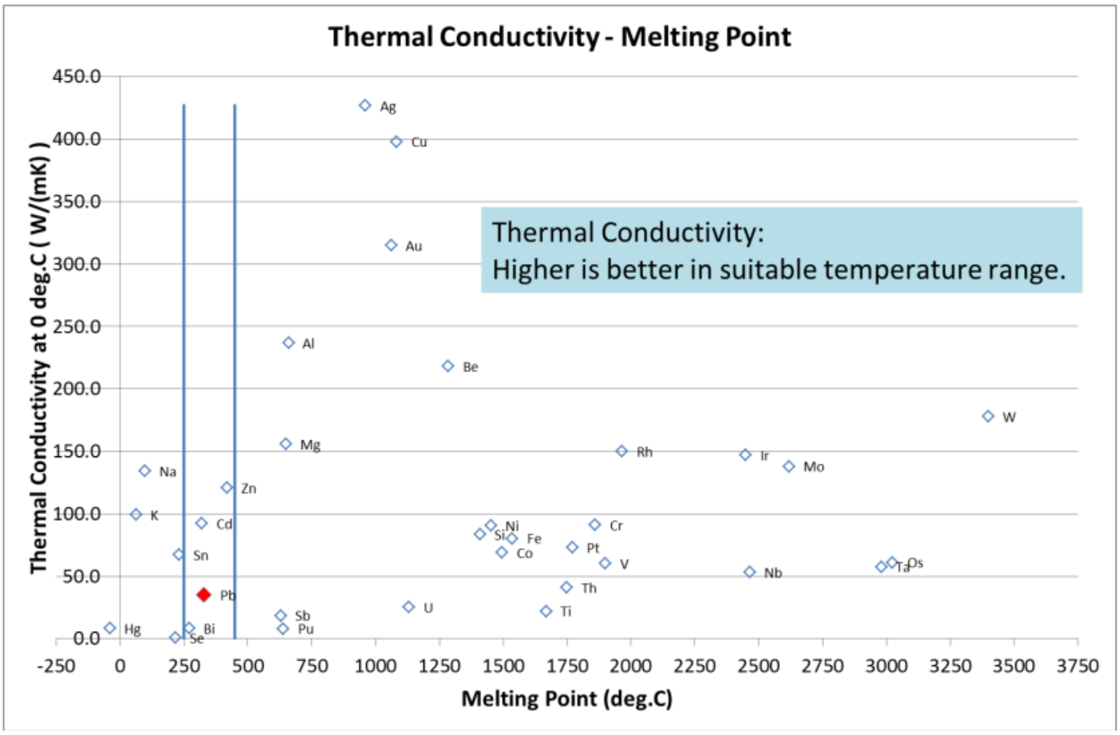
The following Graphs (Graphs 1 to 10) plot various important properties for HMP solders, including electrical resistivity and thermal conductivity against melting point. HMP solders require a melting point of at least 250°C. Whereas solder processes have a maximum temperature limit of 450°C to avoid damage to other materials. The blue vertical lines in each graph illustrate these temperature boundaries.



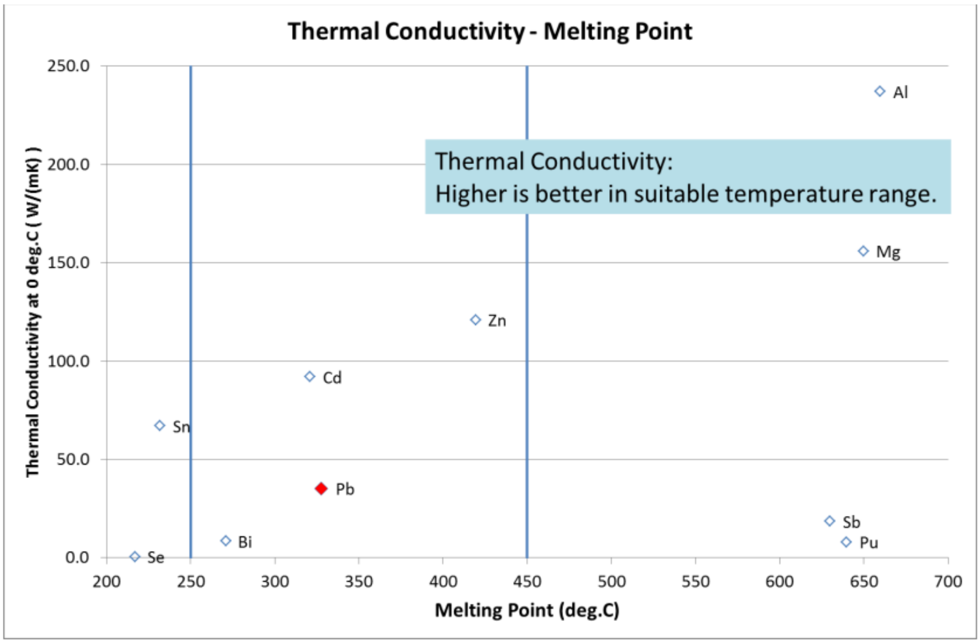
Graph 1 Electrical Resistivity – Melting Point. (Wide temperature range)



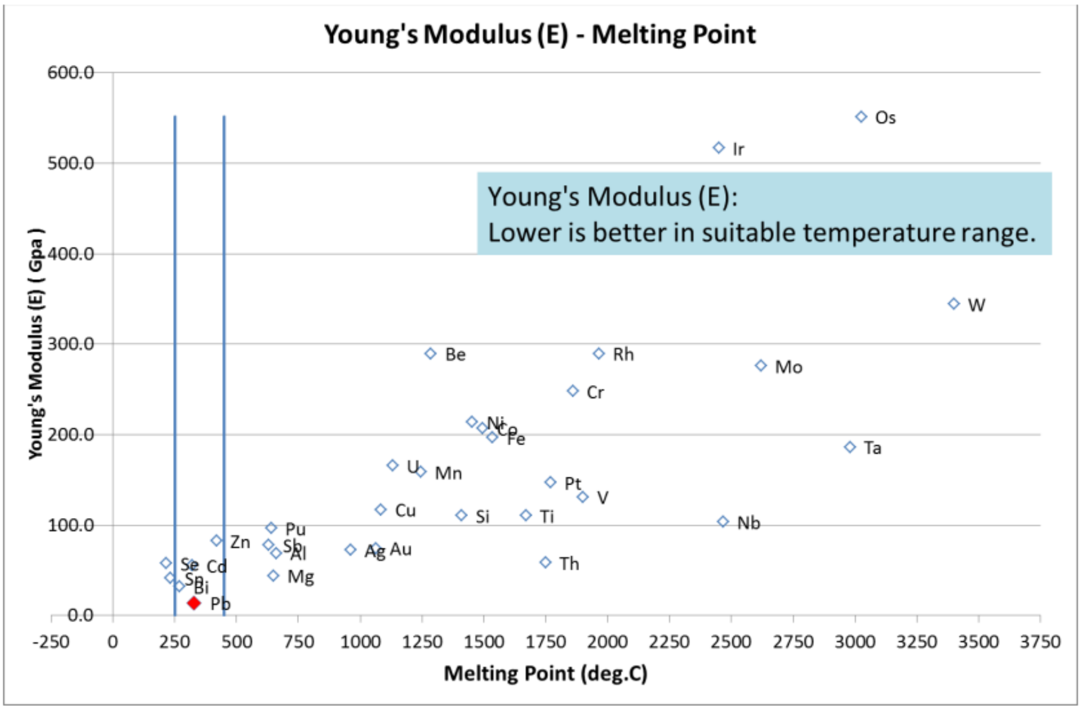
Graph 2 Electrical Resistivity – Melting Point. (Narrow temperature range)



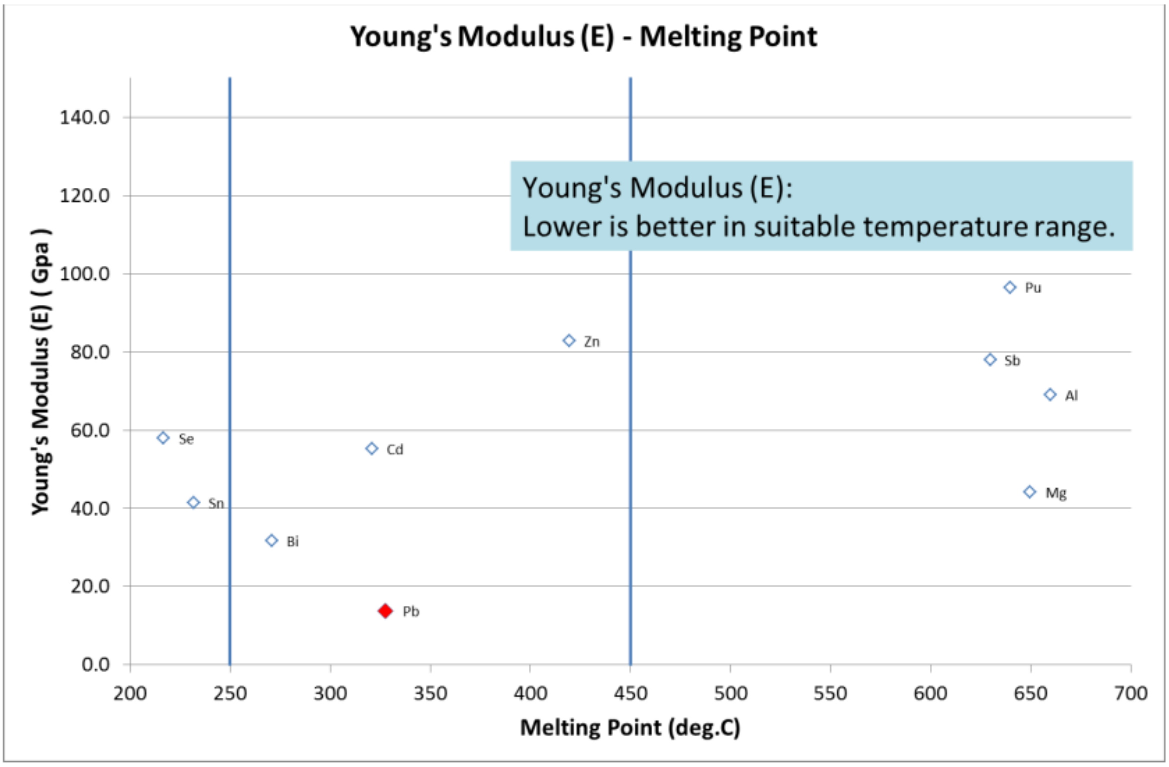
Graph 3 Thermal Conductivity – Melting Point. (Wide temperature range)



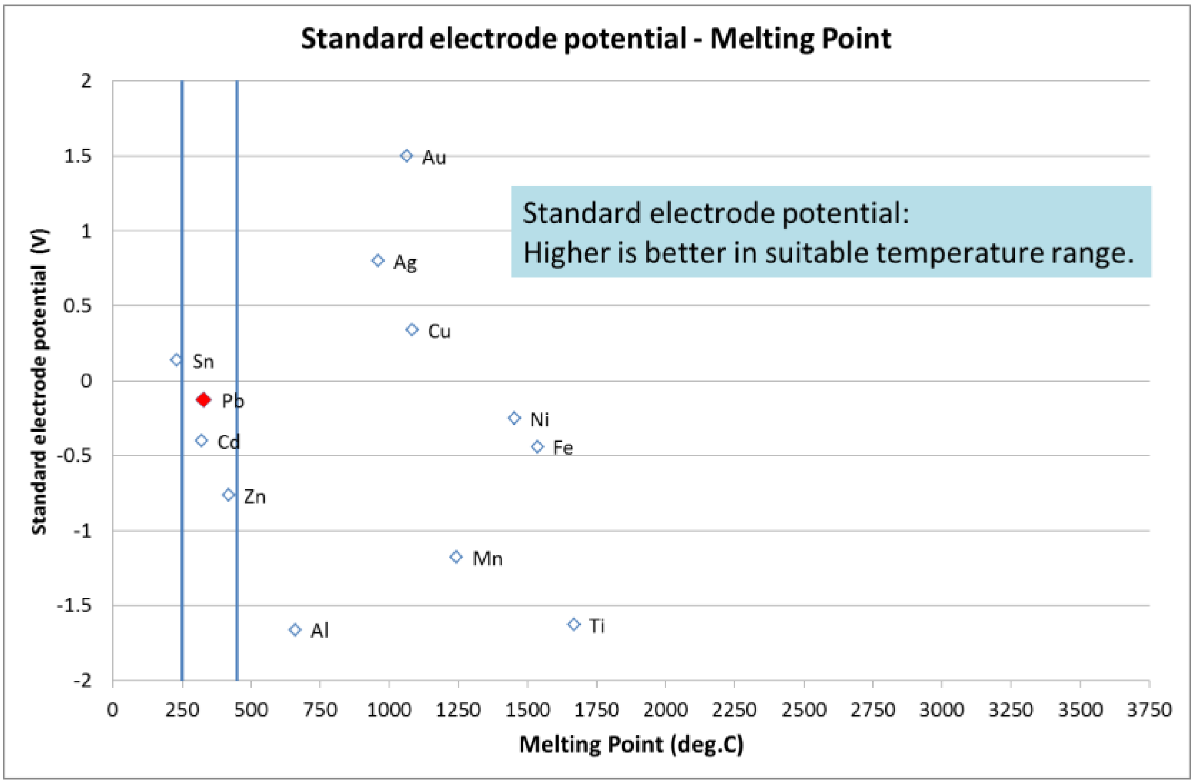
Graph 4 Thermal Conductivity – Melting Point. (Narrow temperature range)



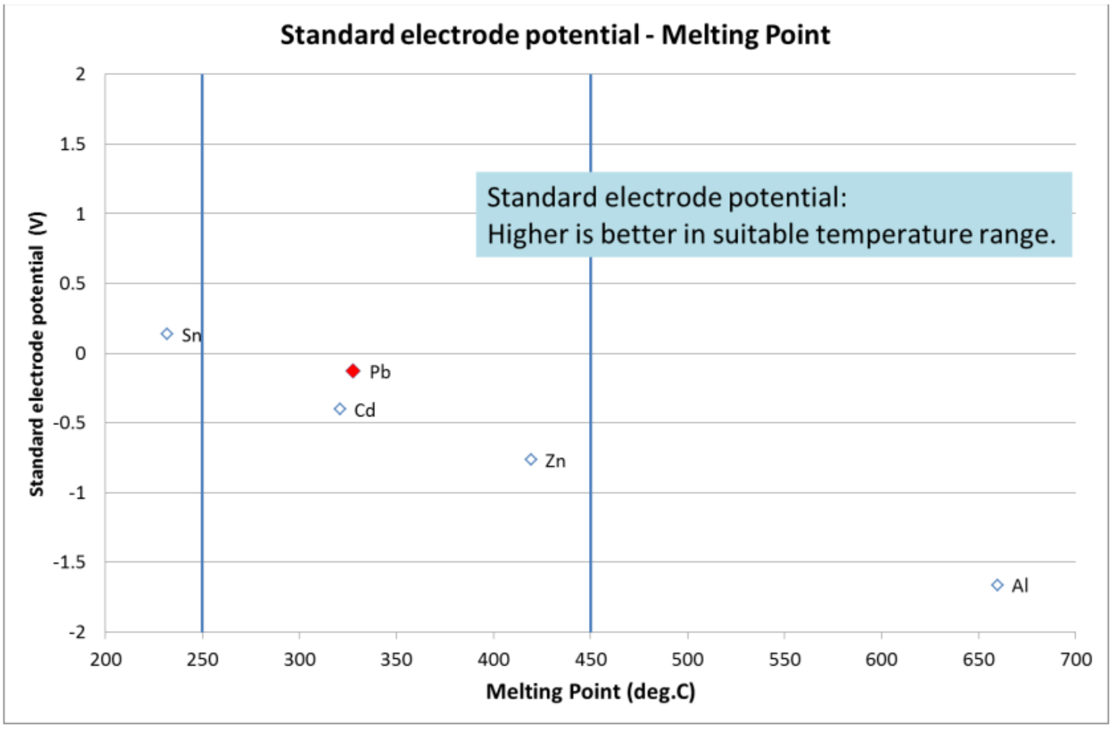
Graph 5 Young's Modules (E) (an indication of ductility) – Melting Point. (Wide temperature range)



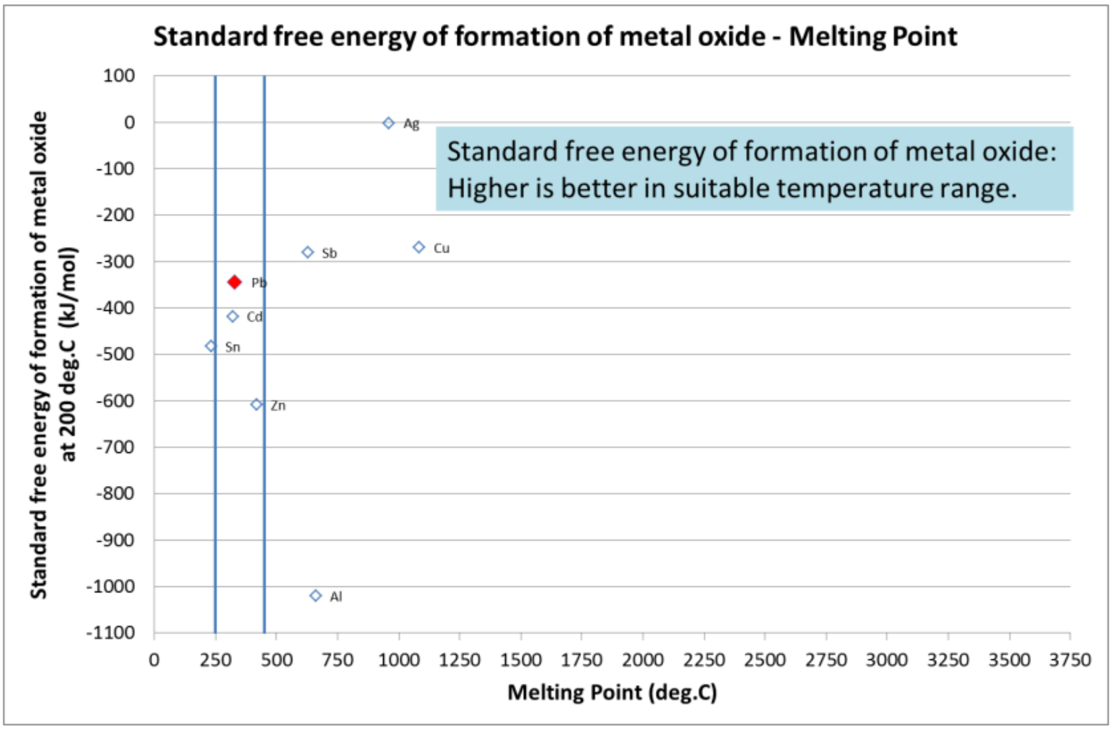
Graph 6 Young's Modules (E) (an indication of ductility) – Melting Point. (Narrow temperature range)



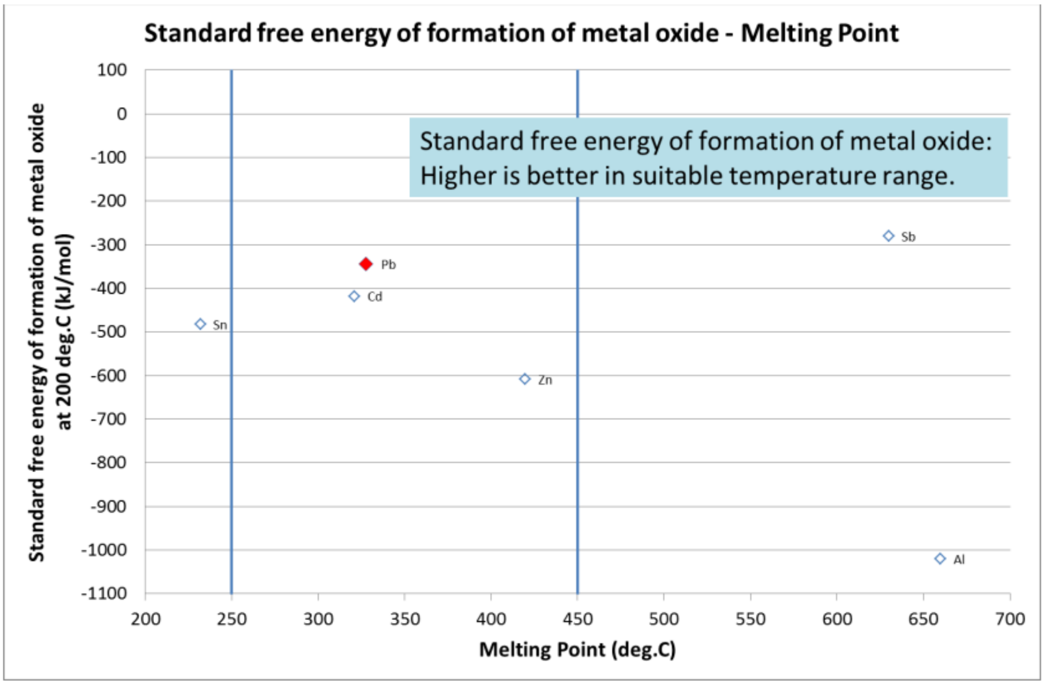
Graph 7 Standard electrode potential (an indication of corrosion resistance) – Melting Point. (Wide temperature range)



Graph 8 Standard electrode potential (an indication of corrosion resistance) – Melting Point. (Narrow temperature range)



Graph 9 Standard free energy of formation of metal oxide (resistance to thermal oxidation) - Melting Point. (Wide temperature range)



Graph 10 Standard free energy of formation of metal oxide (resistance to thermal oxidation) - Melting Point. (Narrow temperature range)

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

(A) 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 HMP but rather the solder is incorporated into the larger EEE and should be recycled according to the requirements of the WEEE Directive and EU waste legislation. As outlined in the Umbrella project 7a exemption renewal request[5], while dedicated closed loop recovery for lead- HMP solders specifically is not practical, recovery and recycling of lead is well established for the larger flow of WEEE where these solders are used.

(B) 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

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5 Submitted by STMicroelectronics srl in January 2020 https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_22/Exemptions/7a/Application_UP_7_a__Exemption_Request__31012020_final.pdf

☒ 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: Any engine part that is required for refurbishing or repair

☐ The following parts are subsequently recycled: _____

☐ Article cannot be recycled and is therefore:

☐ Sent for energy return

☐ Landfilled

(C) 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 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

Since RoHS was first proposed, a huge effort has been made to develop alternative lead-free solders. This has been largely successful for standard solders where SnPb has been replaced by high-tin content lead-free alloys, although reliability is not yet assured for all end-uses. Research has also been carried out to identify substitutes for lead-HMP solders but with only limited success. The main candidates at present are:

1. Alternative solders
2. Conducting adhesives
3. Metal Sintering
4. Transient Liquid Phase Sintering (TLPS)
5. Brazing or welding – due to the much higher temperature required (>400°C for brazing and several thousand degrees for welding, these are not suitable for use in engines or for all of their components. One manufacturer has substituted lead solder by welding in an

application where the high temperature does not damage other parts or materials and reliability was proven to be at least as good as the solder.
6. Other innovative bonding methods – discussed below.

Alternative Solders would appear to be the best solution due to a robust manufacturing process, with repeatable solder application, stable wetting angles and surface compatibility (e.g. with the chip's backside and the lead-free chip coating finish). However, reliability is an issue with voiding / cracking / disruption after stress, growth of brittle intermetallic phases at high temperature and disruption during temperature cycling or vibration.

Solders can be made from metallic elements that have melting points of less than 1000°C,but this must also not be too low. It is also essential that they are ductile, non-toxic and are not highly reactive. This severely limits which metallic elements can be used in an HMP electronic solder. The alkali metals are too reactive, indium and gallium are very ductile but solders made using these metals have too low melting temperatures. Antimony and bismuth are both very hard and brittle and so are used in solders only for niche applications. Cadmium is toxic and its use is also restricted by RoHS so is not considered. This leaves tin, lead, gold, silver, copper and zinc as the only possible main constituents, with small amounts of other metals such as bismuth.

Current alternative Pb-free solders are:

Zn-based Alloys

Currently only available in wire form and its low wettability requires special equipment. As the process temperature is very high (above 410°C) there is a high risk for incompatibility with chip technologies and most polymers would be damaged. Present alloys demonstrate growth of brittle intermetallics at high temperatures which adversely impacts reliability. Zinc solders are also very susceptible to corrosion.

There is a risk of Zn re-deposition, but this will only be able to be assessed in high-volume manufacturing.

Bi-based Alloys

These alloys have low thermal conductivity and low melting point. As their performance is inferior to high lead solder, they are not a viable replacement option

Tin-based solders

Standard solders having a high tin content (>95% in lead-free) react with most types of substrate metals to form intermetallic phases and this is what creates solder wetting and strong bond formation. This is a problem, however, when the component is used at high temperature, as the tin present in the solder bond continues to react so that the substrate metal is consumed and form too thick an intermetallic layer. Thin bonding layers containing small amounts of intermetallic compounds (such as Cu_6Sn_5[6]) are essential for good bonding, but if the intermetallic phase layer becomes too thick, as these layers are brittle, bond failure is likely to occur. High melting point solders with a high lead content either have a low tin concentration (typically 5% or less) or no tin and so although it can be more difficult to create a good bond, once formed, there is no risk from formation of brittle thick intermetallic phases. Lead is unusual in that it does not form intermetallic compounds with most substrate metals or dissolve in these materials. This therefore is a limitation of solders with a high tin content when exposed to high temperature for significant lengths of time. For example, Sn-5%Sb is a lead-free solder with melting point of 235°C is not suitable for most uses in engines.

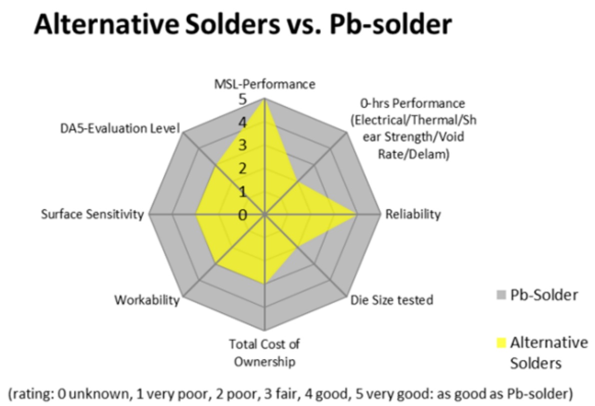
SnSb-based Alloys with higher Sb content

Although materials are offered in paste and as pre-form, workability still needs to be improved with respect to voiding and die cracking). They have limited surface compatibility (chip backside, Pb-free finishes) and their secondary reflow and reliability have not yet been demonstrated.

Vishay, a member company of DA5, have reported that J-alloy (SnAg25Sb10) was evaluated and even in production for internal die-attach of several Vishay diodes and thyristors for a couple of years. However, due to brittleness of the solder material, frequent assembly/reliability issues (die cracks) occurred. Use of J-alloy finally had to be stopped.

SAC-SnSb mixed Alloys

These new materials are offered in paste and offer good reliability performance. However, workability needs to be improved, with respect to voiding and compatibility to different chip metallisations is yet to be proven.



- DA5 now uses a new rating system with revised criteria (Pb-based solder reference set to 5 for all criteria) for the technology comparison
- DA5 assessment refers to the best material tested in its class
- DA5 assessment only valid for die thickness > 120µm

Chart DA5 – 4; Key performance indicators comparing current performance of Alternative Solders with Pb Solder

[6] https://www.copper.org/applications/industrial/DesignGuide/performance/coppertin03.html

Alternative Pb-free solder alloys have been researched for properties such as melting behaviour, microstructure, interfacial compounds and structures, as well as mechanical properties and reliability issues. This has highlighted deficiencies, obstructing their substitution for high-Pb HMP solders.

Solder alloy properties can be improved by modifying the microstructure of the alloy by changing the number and/or character of the phases. Researchers have used the fundamental principles of phase transformations and diffusion to high-temperature solder alloys, mainly focussing on the nucleation/growth during solidification and interfacial growth. The microstructure of the solder and the response of the alloy to heat treatment as well as the resulting mechanical properties are crucial to the evaluation of solder joint reliability. Owing to the high service temperature experienced in engines, it is imperative to characterise these properties at high temperatures and to realistically test substitutes in ways that reflect use conditions of engines in the field.

A recent review (Harsh Environment Electronics: Interconnect Materials and Performance Assessment, Chapter 2 High-Temperature Lead-free Solder Materials and Applications, 2019) reviewed all the lead-free solder materials available at present. Despite the review being relatively recent, the papers cited range from 1999 to 2017, highlighting the dearth of research currently in this area. This would indicate the difficulties in replacing lead containing HMP solders in certain applications.

Table 4 below, indicates the current proposed replacement systems, where the authors state that they may possibly be used and the problems associated with their use, restricting their usage at present.

Table 4; Comparison of various high temperature Pb-free solder alternatives (Sabri, Ali, & Said, 2019)

Solder	Potential Applications	Disadvantages
Zn-Al	Die-attach material for power devices	Highly susceptible to corrosion, poor wetting, low workability, relatively hard, Al presence affects miniaturization drive
Zn-Sn		Highly susceptible to corrosion, low wetting, formation of liquid phase at 199°C
Bi-Ag		Poor workability, low conductivity
Bi-Sb		Low conductivity, toxic
Au-Sn	Component packaging, die attachment of chips	Brittle Au–Sn IMCs
Au-Ge		Difficult to manufacture

Solder	Potential Applications	Disadvantages
Sn-Ag-Cu/ Sn-Ag Sn-Cu	Component packaging	Microstructural coarsening and mechanical degradation during high thermal aging

Table 5 outlines currently available lead-free solders and technical characteristics which currently make the use of such solders in EUROMOT applications unsuitable.

Since the previous exemption RoHS 7a renewal request was submitted in December 2014, no new lead-free HMP solder alloys have been discovered. This is hardly surprising as extensive research was carried out when RoHS was adopted in 2002 and all possible combinations and permutations of chemical elements available in the periodic table have been evaluated. However, industry-led projects such as DA-5 are continuing to research substitute technologies.

Table 5: Melting ranges and Engine specific Disadvantages of some High Temperature Lead-free Solutions

Candidate System	Typical Composition	Melting Point	Disadvantages
Bi system	Bi—2.5 Ag / BiAg	263 – 320°C	Low Ductility (too brittle), low strength and High Electrical Resistivity
Au-Sn System	Au-20Sn	280°C	Low Ductility (too brittle)
Sn-Sb	Sn->43Sb	325 – 420+°C	Low ductility and Sb on REACH CoRAP list[7]. Requires soldering temperature likely to damage other components
Zn-Al System	Zn-(4-6)Al(Ge, Ga, Mg)	350 - 380°C	Brittle, Low Ductility, Susceptible to Corrosion & early failure and requires soldering temperature likely to damage other components
Sn system & high melting temperature type metal	Sn+(Cu, Ni, etc.)	230 - >400°C	Possibility that molten part may exude to outside of a component. High joint formation temperature and low ductility. Brittle as joint is mainly inter-metallic compounds
Electrically conductive	Polymer – Silver (or other metals)	N/A	Poor heat and electrical conductivity which can deteriorate with age.

[7] Community rolling action plan (CoRAP).

Candidate System	Typical Composition	Melting Point	Disadvantages
adhesive system			Susceptible to humidity and difficult to repair. Insufficient reliability for higher (Tj_{max} = 175°C or above) junction temperature Concern of some components' toxicity (classified as CMR[8])
Silver (Ag) sintering systems		N/A	Additional stress during processing (pressure assisted sintering) on the chip. Susceptible to humidity (porosity of Ag sponge). High stress on chip due to stiff die-attach material. Does not flow so cannot be used where flow soldering is required. Concern of some components' toxicity (classified as CMR)

As shown in Table 5 above, all the current known proposed substitute materials have disadvantages that seriously limit their use as they do not at least meet the required functionality and reliability for the uses identified in Section 4(A). The bonding materials industry, however, does continues to develop potential future alternatives in conjunction with component manufacturers.

The DA5 Project started in April 2009 when five companies involved in Die Attach decided to form a consortium to focus on the use of high melting solder in semiconductor applications, especially for die attach in power packages. This was in response to ELV Annex 2, exemption 8(e) and RoHS 7(a) that cover the use of lead in high melting temperatures type solders in various applications. All the DA5 companies are committed to the environment and sustainability and are working together to eliminate high-lead solder, where feasible. The DA5 has been working with suppliers to identify and evaluate alternatives to HMP lead solders and to develop a Pb-free die-attach solutions. The project is ongoing and the most recent status report, from April 2022 can be downloaded[9]. Currently they are focussing on alternative

[8] Carcinogenic, mutagenic or toxic to reproduction (CMR).

[9] https://www.infineon.com/dgdl/DA5+Customer+Presentation+19092022.pdf?fileId=5546d4616102d26701610905cfde0005

solders, conductive adhesives, metal sintering and Transient Liquid Phase Sintering materials as they offer the most likely route to a solution.

Although the DA5 evaluations recognise continuous improvement in the evaluated materials, they still do not meet the technical requirements for quality, reliability, and manufacturability, as further covered in the following section.

Vishay provided summary results of their evaluation of promising lead-free materials for internal die-attach. Solder pastes and solder wires based on the BiAg, AuSn and SnAgCu systems were evaluated, also silver sinter pastes, sinter epoxy and silver epoxy from several suppliers. In conclusion, none of the evaluated materials have proved capable of replacing lead-HMP solder in terms of manufacturability, quality, and reliability.

The DA5 consortium claim that many solutions are still under development and constantly being revised, but are strictly guarded by suppliers under non-disclosure agreements.

Conductive Adhesives have been available for many years, but cannot replace lead-HMP solders in engine systems because:

- The resins will decompose at high temperature
- Electrical and thermal conductivity are inferior and degrade over time
- The metal fillers used, silver and/or copper corrode and become insulating when exposed to traces of hydrogen sulphide, a common environmental pollutant
- Oxidation/corrosion can occur during the intended 25+ year's lifetime
- Vibration due to engine operation is likely to cause delamination

The DA5 consortium have developed new materials (specifically for die attach) that can achieve a higher electrical and thermal conductivity by an increased silver filler content with very dense packing of filler particles. Using micro and nanoscale particle sizes stimulates a sintering of the silver particles during the resin cure process. The remaining resin content is a key factor determining the physical properties of the material where hybrid adhesive/ sinter materials combine the advantages of a silver filled adhesive (thermal-mechanical stability, low sensitivity to surfaces) with the high conductivity of a sintered silver material.

The applications this can be used in has been limited as the materials contain solvents to improve rheology for dispensing. This requires careful handling and control of the manufacturing process and bears a risk of lead-frame and die surface contamination. The process window (bond line thickness, curing conditions) must be determined for every die size, with a maximum die size (~50mm²) strongly depending on package design and materials. A backside metal is required. The sintered structure has a high elastic modulus leading to mechanical stresses and a higher delamination risk.

Projected material use is limited in high power devices and where the moisture sensitivity level is greater than MSL3/ 260°C. Material usage is only possible for die thickness >120μm for the moment. The DA5 consortium's comparison of conducting adhesive with lead HMP solder is shown below.

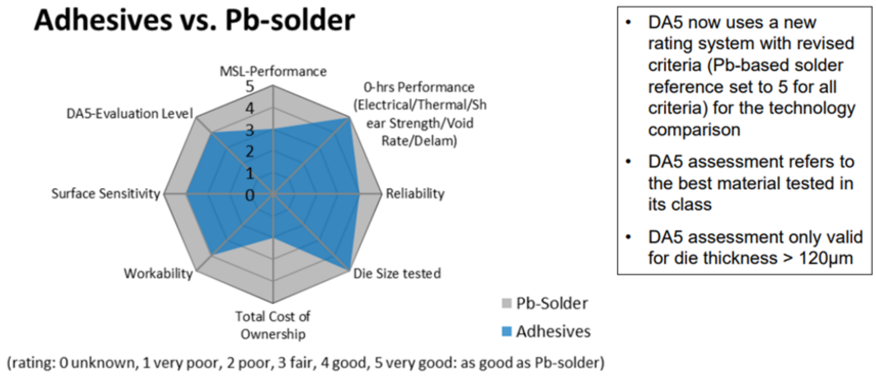


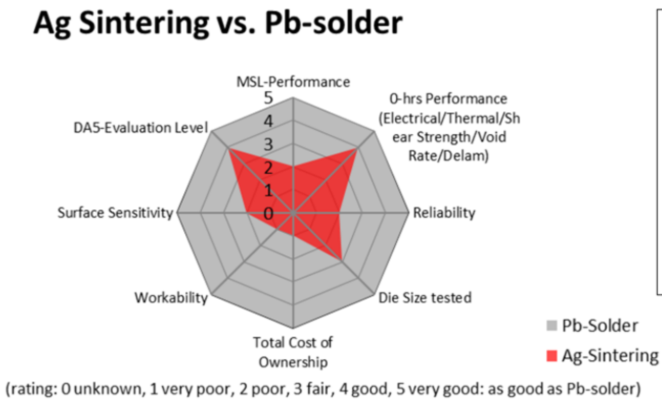
Figure 7 Key performance indicators comparing current performance of Conducting Adhesives with Pb Solder from DA5

Metal Sintering is being investigated by the DA5 consortium and encompasses Ag- or Cu-sintering pastes where micro to nano scale silver or copper particles are mixed with organic coating, dispersants and sintering promoters. These are dispensed, the die placed and then sintered under N_2 or in air inside an unpressurised box oven. The resulting die-attach layer is a porous network of pure, sintered silver or copper which can have significantly better thermal and electrical performances than lead solder. However, self-alignment as with solder wetting is not possible and nanometre scale metal particles are at risk of being banned[10]. As this is a new concept in moulded packaging there is no prior knowledge of feasibility, reliability or physics of failure and production equipment changes might be needed (low-O_2 ovens, sintering presses), requiring significant time for changeover.

Research to date has found limitations in die area/thickness, lead-frame and die finishes, as well as potential reliability issues: die cracking, breaks inside the bondline, delamination or die lift, organic contamination, thickness reduction due to continued sintering, interface degradation or electromigration of silver.

In reliability tests oxidation and delamination of interfaces is common, even before reliability testing, which lowers adhesion as well as electrical and thermal performance. This technology is clearly not yet ready for commercialisation. The DA5 consortium's comparison of this technology against lead solder is shown below.

[10] Nanomaterials are regulated by the REACH and CLP Regulations. Any future restrictions will be based on the hazards posed by the form of these materials and nano-forms may be different to forms with larger particle size.



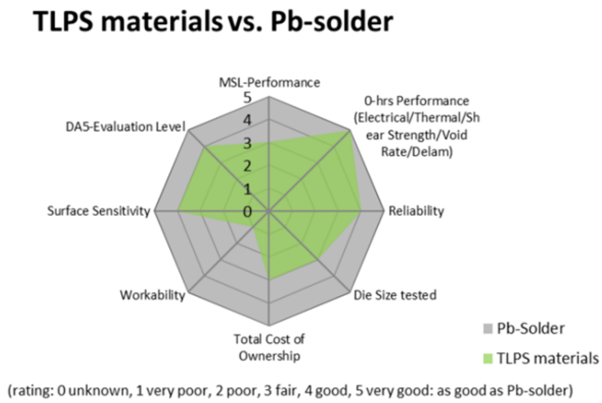
- DA5 now uses a new rating system with revised criteria (Pb-based solder reference set to 5 for all criteria) for the technology comparison
- DA5 assessment refers to the best material tested in its class
- DA5 assessment only valid for die thickness > 120µm

Figure 8 Key performance indicators comparing current performance of Ag-Sintered materials with Pb Solder from DA5

Transient Liquid Phase Sintering (TLPS) is another die attach option of the DA5 consortium which uses a mixture of a high melting metal powder (for example Cu or Ag) and a lead-free solder powder (for example Sn based) in an organic flux. After curing a matrix of pure Cu, CuSn alloy (melting temperature > 400°C) and resin is formed. In principle it is compatible with existing assembly methods and is possible in a reflow oven or batch oven. However, it is still a relatively new concept in moulded packaging, with limited knowledge of feasibility or reliability. It is not compatible with thin dies due to the high modulus (stiffness) and high CTE inducing die stresses. Although thermal and electrical performance are in the range of lead solder, there large differences between various versions.

There are numerous quality and reliability risks associated with TLPS materials, including delamination and die crack risk (for larger die sizes) due to high modulus and high CTE and potential Kirkendall voiding during intermetallic phase growth, e.g. during high temperature storage at 175°C.

According to DA5, some suppliers have stopped their TLPS material development. At the current development stage TLPS is not a reliable alternative for high lead solder for die attach and clip attach. DA5's comparison is shown below.



- DA5 now uses a new rating system with revised criteria (Pb-based solder reference set to 5 for all criteria) for the technology comparison
- DA5 assessment refers to the best material tested in its class
- DA5 assessment only valid for die thickness > 120µm

Figure 9 Key performance indicators comparing current performance of TLPS materials with Pb Solder from DA5

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

As described below in section 7(A), lead-containing high melting point solders are an essential material used in EUROMOT's members engine systems and currently there are no suitable lead-free substitutes. Research carried out previously is described above in section 6 and this includes comparative studies of lead-HMP solder with a wide variety of potential alternatives bonding methods and materials. The results summarised above show that all of these potential substitutes have inferior reliability and / or performance and so are unsuitable for use in EUROMOT's members engine systems. EUROMOT's members do not make electronic components and so rely on the supply chain, which has the expertise, to carry out this research. Only when suitable substitute components and bonding materials are developed and proven to be reliable will EUROMOT's members be able to test these in their engine systems which will require additional time.

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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.

Manufacturers of solders and electronic components have been carrying out research on substitutes for lead HMP solders for over 20 years and some of this research is described above. Some of the alloys described in section 4 above have been developed as possible substitutes but along with the existing lead-free alloys, have been found to have different properties and so are unsuitable for use in engine systems as are also the other bonding methods described above. This research is continuing and is being monitored by EUROMOT's members and its suppliers so that if an apparently suitable substitute is discovered, this could be evaluated and tested for reliability in engines.

When promising substitution production technologies 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 and this will continue to be the case. 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 solder alloys and components made using lead-free bonding. The electronics industry is continuously researching alternatives, however currently no lead-free alternative technology is available at present for EUROMOT's members to evaluate.

For EUROMOT's members to replace lead solders for all uses in an engine, first, their suppliers must carry out research on new components and then these must be thoroughly tested in engines to ensure that they will be no less reliable. If possible, substitutes are identified for the widespread conversion from lead HMP solders in related applications, qualification will take time based on the long-term reliability requirements of EUROMOT's members products. 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 solder manufacturers and component manufacturers, processes and new equipment are installed and implemented within component manufacturing lines, components are qualified, and those components are made available to EUROMOT's members and their suppliers for:

- development of new processes,
- assessment of products from new processes, and
- replacement with alternative products.

Details of timescales to ensure high reliability of engine systems with substitutes solders 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.

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 to understand if the alternative is able to offer the required technical characteristics.

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 RoHS exemption 7a and ELV exemption 8e where feasible[11].

Figure 14 below shows a typical timescale from identification of a suitable substitute (for example of a lead-free component) to commercial use to produce electronic components but does not include subsequent steps such as reliability testing in engines or global approvals.

[11] https://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/ELV_PACK_3_draft_20191001_Published_20191014.pdf

Gaining global approval for new designs of components can take up to two years, but approvals under the Non-Road Mobile Machinery Emissions Regulation will take much longer if needed. Note that the steps in Figure 14 must be completed before EUROMOT can start to evaluate new components.

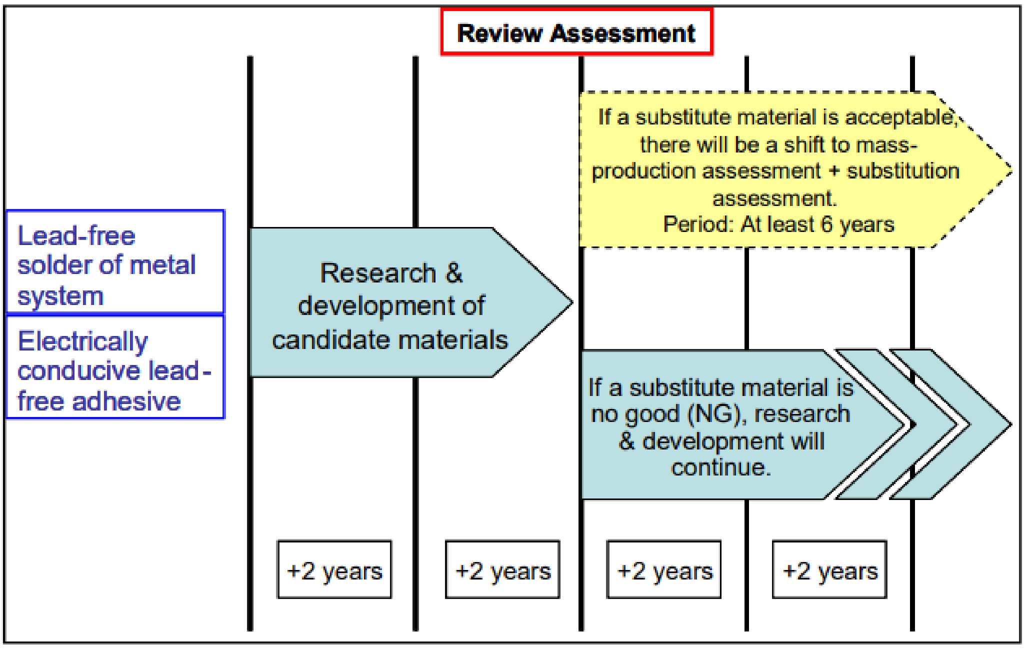

Figure 10 Material Transition Process

Looking at lead HMP solder for die-attach within semiconductor packages, the DA5 consortium is working with selected material suppliers on the development of an appropriate replacement for lead solder (DA5 scope). The properties of the needed die-attach material are specified by the DA5 (material requirement specification) and provided to the material suppliers. Selected material suppliers offer their materials, which are evaluated by one of the DA5 companies together with the supplier. The detailed results are discussed with the material suppliers and all DA5 companies on a regular basis. The results drive further optimisation, and the combined results are published by DA5 (Customer Presentation). After a material is chosen and development is frozen, another 3 to 5 years will be required to qualify the new material through the whole supply chain. Based on current status with DA5 a date for customer sampling cannot be predicted as no suitable materials have yet been identified.

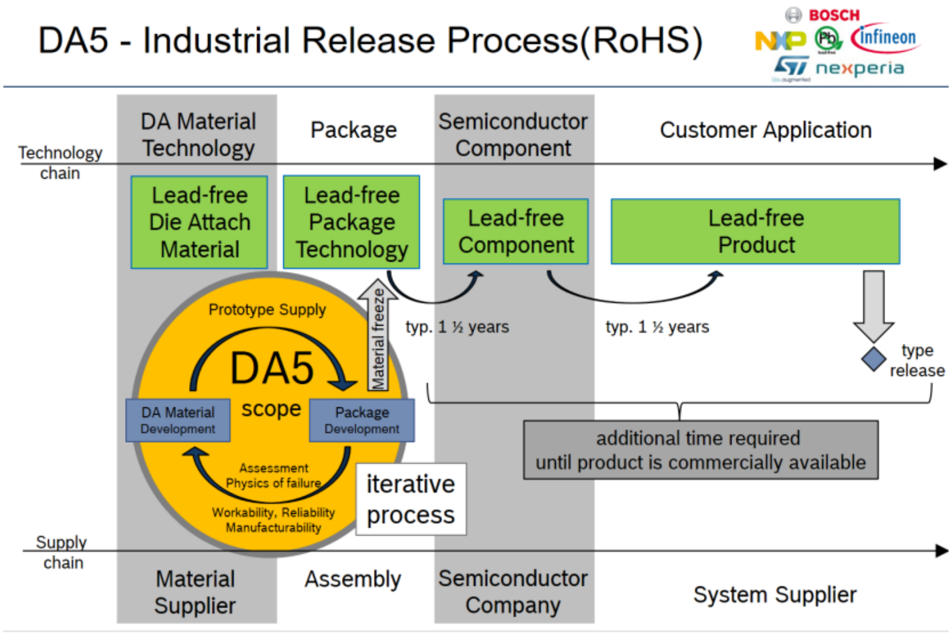

Figure 11 Cycle Time to Conversion (DA5)

Timescale once substitute components become available to EUROMOT members

If a promising lead-free bonding process 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. 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 HMP material 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.
- If use of substitute bonding material requires significant changes, such as re-design of circuits or of the engine, then approvals under the NRMM Emissions legislation will be required.
- Installation and evaluation of new production processes able to use new materials.

Timescales for above depending on the type of component, engine and the end-uses:

- Without NRMM Emissions Regulation re-approval 5 - 7 years
- With NRMM Emissions Regulation approvals at least 6 - 8 years

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.

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. See reliability documentation within DA5 charts under Sections 7(A) and 7(B) for potential reliability problems[9].

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: Solder manufacturers

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

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

☐ Yes ☒ No

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

There is no functionally equivalent alternative, so EUROMOT is not able to provide availability assessment data. Material Suppliers continue to modify formulations for proposed alternatives in order to improve thermal/mechanical/electrical performance, reliability and manufacturability. Material Suppliers are only providing samples of these materials under a strict NDA until patents are complete. No single solution has emerged from this development/evaluation process. Once a solder material is available with supplier commitment for at least 15 years of stable production, EUROMOTs members and their suppliers will need to develop and install compatible manufacturing processes and equipment before qualifying and ramping up production. This process will take many years to complete. Based upon the history from lead terminations, the conversion process could extend for up to 10 years and probably longer for EUROMOT’s members products.

(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, 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, but could affect many types of end-users in the EU and the UK. 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:
