4.10 Exemption no. 8a – stakeholder proposal part C (i)

“Lead in high melting temperature solders, i.e. lead based solder alloys containing above 80% by weight of lead”

4.10.2 Description of exemption

ACEA et al. (2009a) propose the following exemption without an expiry date:

Lead in high melting temperature solder i.e. lead based solder alloys containing above 80% by weight of lead.

The stakeholders say that an expiry date cannot be defined as a technical solution currently is not foreseeable. The exemption shall be reviewed after 2015 (ACEA et al. 2009a).

High melting point solders with lead are used in several applications and technologies. The following list gives examples and solder compositions (in % of weight) (ACEA et al. 2009e):

- internal connections: ≥ 85%;
- die attach: ≥ 90%;
- sealing: ≥ 85%;
- over-moulding: ≥ 90%;
- ceramic BGAs: ≥ 90%.

The details of the different applications will be explained in the subsequent sections of this chapter.

ACEA et al. (2009e) list automotive applications using such electrical applications, like, for instance, starters, alternators, converters, electrical assisted steering, engines & gearboxes computer-control devices, electrical brakes, ABS & ESP systems, etc.

ACEA et al. (2009e) state that nearly all automotive electronics products contain components utilizing high melting point (HMP) lead solder. The majority of high powered components are found in steering, braking and powertrain electronic control units (ECU). Assuming the amount of lead used in solder in the above applications is ~0,003 g per component, then typical automotive ECU’s would contain (ACEA et al. 2009e):

- for Braking ECU approximately 30 affected parts;
- for Steering ECU approximately 20 parts;
- for Powertrain ECU approximately 40 affected parts;
- for Power Management (Generator Diodes) approximately 9 affected parts;
- & other ECU’s within the vehicle about 20 parts.

This equates to (ACEA et al. 2009e):

- for Braking ECU 0,09g/vehicle;
- for Steering ECU 0,06g/vehicle;
- for Powertrain ECU 0,12g/vehicle;
- for Power Management (Generator Diodes) 0,14g/vehicle;
- & other ECU’s (e.g. body control modules, climate control, seat memory, roof modules, etc.) 0,06g/vehicle.

The stakeholders calculate the total amounts of lead as follows (ACEA et al. 2009e):

Assuming 16 million vehicles registered per year (ref: ACEA 2007, EU27 + EFTA), the total amount of lead is 16 million x 0,47g = 7,5 t of HMP solder per year. With a lead content of at least 85%, the amount of lead in these solders is at least 6,4 t per year in the EU27 + EFTA.

The following sections will provide details on the several applications of lead-containing HMP solders as submitted by the stakeholders.

4.10.3 Justification for exemption

Justification for the use of lead in high melting point solders

ACEA et al. (2009e) put forward that thermal fluctuations during normal operations cause strain due to differences in the thermal coefficient of expansion within the assembly (thermal mismatch). Thermal fluctuations can be produced by heat being dissipated or by environmental temperature changes. Repetition will produce cyclic strain which will cause the solder joint to fail through fatigue.

The reliability of the solder joint will depend upon the alloys resistance to fatigue, and the magnitude of the strain generated. The fatigue life of a solder joint can be approximated by the Coffin – Manson equation (ACEA et al. 2009e):

$$N_f = C \, \Delta\varepsilon_p^{-n}$$

N_f is the number of thermal cycles to fatigue failure, C and n are material constants and $\Delta\varepsilon_p$ is the strain generated. The smaller the strain, the greater the fatigue life.

The strain generated due to CTE mismatch can be calculated approximately (ACEA et al. 2009e):

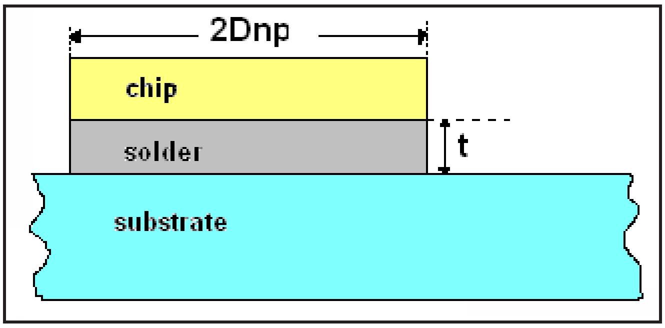


Figure 12 Cross section of solder joint

- ΔT is the temperature excursion, dependent upon the power dissipation and the change from minimum–maximum operating temperature,
- Δα is the difference between CTE of the substrate and the component chip,
- Dnp is the distance from neutral point – the larger the die or packaged component, the greater the strain generated.
- t is the solder joint height. The larger the solder joint height, the less strain is generated.

ACEA et al. (2009e) say that automotive electronics differs from consumer applications in that the desired number of cycles N_f is much larger, and the environment is much harsher.

Table 14 Differences between consumer and automotive electronics (ACEA et al. 2009e)

	Consumer	**Automotive**
Life	3–5 years	up to 15 years
Environment	0–40ºC	-40º to 125/155ºC

There are basically two types of solder:

- ‘soft solders’ based on Sn-Pb, lead, tin, indium alloys;
- ‘hard solders’ based on gold eutectics such as Au-Sn, Au-Ge.

Die attach and applications which require some ductility within the joint have to use soft solders, which can compensate the strain in the solder joint and thus transmit very little stress to the die and/or to a ceramic body. These solders, however, will degrade due to thermal fatigue during temperature or power cycling.

ACEA et al. state that Figure 14 and Table 15 on page 98 show that there are no soft solder alternatives which have appropriate melting points.

Hard solders based on Au-Sn do not usually degrade by fatigue due to the high mechanical strength. Ceramics and silicon dies are brittle materials and will crack if they are subjected to any tensile or torsional stress, resulting in lower product reliability. High temperature solder is used for die attachment (silicon to copper alloy) or as a lid seal (e.g. Analogue Sensor packaged in a CLCC (ceramic body, steel lid). The CTE mismatch will exert considerable stress on the die, ceramic body and may fracture in some cases, if the solder is too brittle (ACEA et al. 2009e).

ACEA et al. (2009e) describe the example of new generation stop-start systems under development. They require the use of high melting point lead containing solder because of higher constraints, such as electric current circulation up to 50ms@1000A + 600ms@600A + permanent 150A in combination with an increase of thermal environment up to 170 deg C. Tests performed with six types of lead free solders show a drastic decrease of number of cycles to failure, and so an unaccepted level of reliability, as the next table shows.

			Number of power cycles to failure (Welbull B50) Test @ 50 A DC / 40 mm² die Failure is Short-Circuit			
TC_{min}	TC_{max}	ΔTj	High lead solder		Lead free solder	
			Vacuum reflow	Laser reflow	Vacuum reflow	Laser reflow
75°C	165°C	110°C	11 000 to 15 000	13 700 to 14 200	4 500 to 5 100	4 800 to 5 050

Figure 13 Power cycling test results comparing HMP lead solder and lead-free solders (ACEA et al. 2009e)

ACEA et al. (2009e) state that for long life reliability no other material than high melting point (HMP) lead containing solder has been found. HMP solders have a unique combination of melting point, mechanical, thermal, electrical and chemical properties.

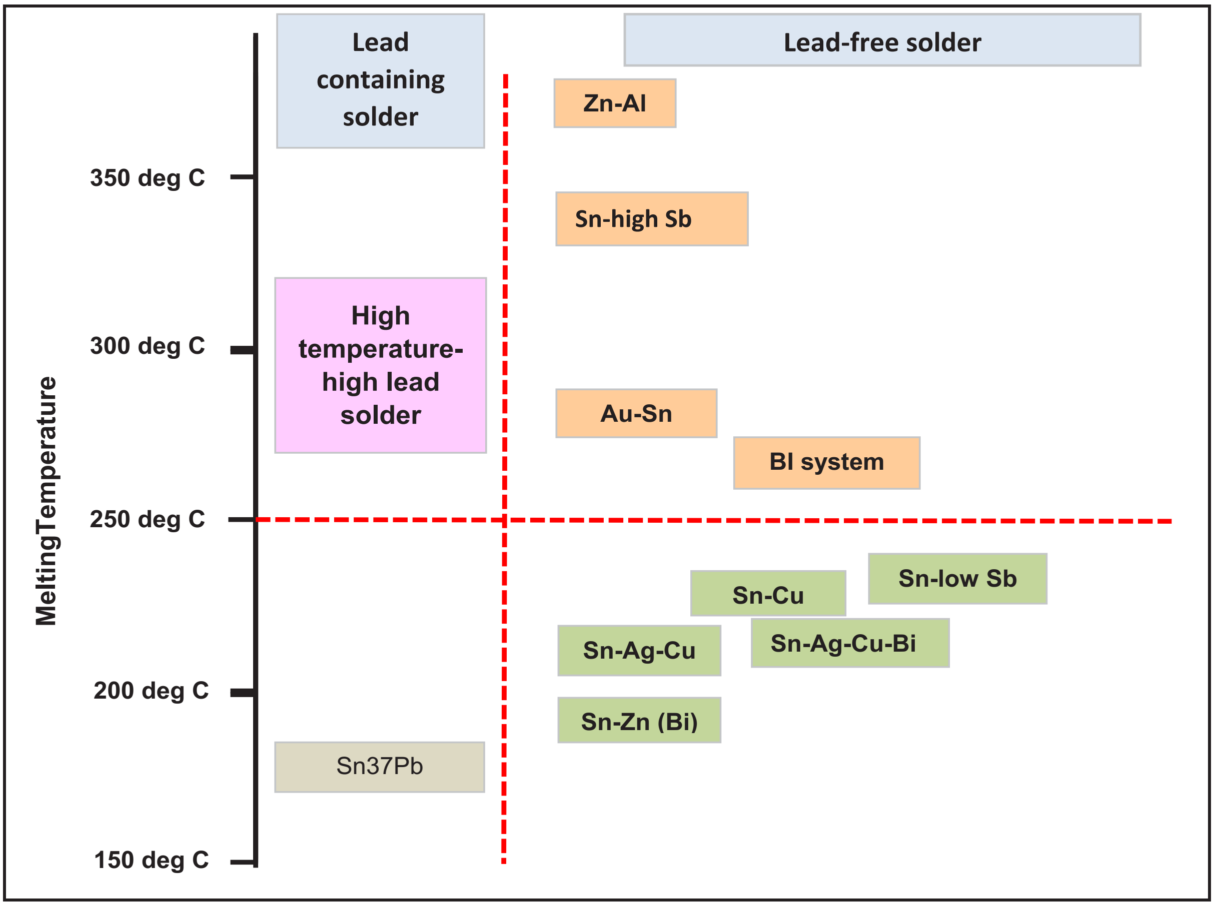


Figure 14 Melting points of different lead-free solders (HMP solders with 80% and more of lead: „high temperature – high lead solder“ (ACEA et al. 2009e)

Table 15 Alternatives for HMP solders with lead (ACEA et al. 2009e)

Solder Type	**Alloy**	**Melting Point °C**	**Comments on Unsuitability**
Sn-Zn (Bi)	Sn 8Zn 3Bi	190–197	Melting point too low
Sn-Ag-Cu-Bi	Sn 2,5Ag 1Bi 0,5Cu	213–218	
Sn-Ag-Cu	Sn 3Ag 0,5Cu	217–220	
Sn-Cu	Sn 0,7Cu	227	
Sn-low Sb	Sn 5Sb	235–240	
Bi systems	Bi 2,5Ag	263	Melting temperature only slightly higher than SAC Low Ductility, Low Strength
Au-Sn	Au 20Sn	280	Low Ductility, Negative environmental impact due to being Au based
Sn-high Sb	Sn >43Sb	325–>420	Melting point too high
Zn-Al	Zn (4-6)Al (Ga,Ge<Mg)	350–380	

ACEA et al. (2009e) describe in more detail main alloys of each group.

Tin, Silver, Copper – (SAC) Alloys

These lead-free solder alloys are based on Tin, Silver and Copper and are the solders most commonly used in lead-free board assembly. If SAC alloys were used for die attach, internal connections, and sealings, they would lose strength and become ‘pasty’ during the board assembly process resulting in movement inside the components and reduced reliability (ACEA et al. 2009e).

Tin Gold System (SnAu80)

The melting point is 280 deg C which would be acceptable in terms of processing, but SnAu forms a brittle intermetallic compound which would result in poor thermal fatigue and mechanical shock performance resulting in a reliability hazard.

Other solder systems exist with a higher melting point but could result in component issues.

Electrically Conductive Adhesives

These will be acceptable for addressing process thermal excursions, however they have a poor thermal conductivity compared with solder which would make them unacceptable for die attach and internal connectivity including BGAs. They would also not form a hermetic seal which would be unacceptable for sealing applications (ACEA et al. 2009e).

Solder alloys with high lead content stay solid up to (ACEA et al. 2009e)

- 235 deg C for a 85% lead content alloy;
- 270 deg C for a 90% lead content alloy;
- 385 deg C for a 95% lead content alloy.

When above those temperature levels, the alloy becomes pasty and so looses its mechanical properties (ACEA et al. 2009e).

ACEA et al. (2009e) state that no reliable substitutes are available to replace lead in HMP solders. Other stakeholders support this position (Umicore 2009; ON Semiconductor 2009).

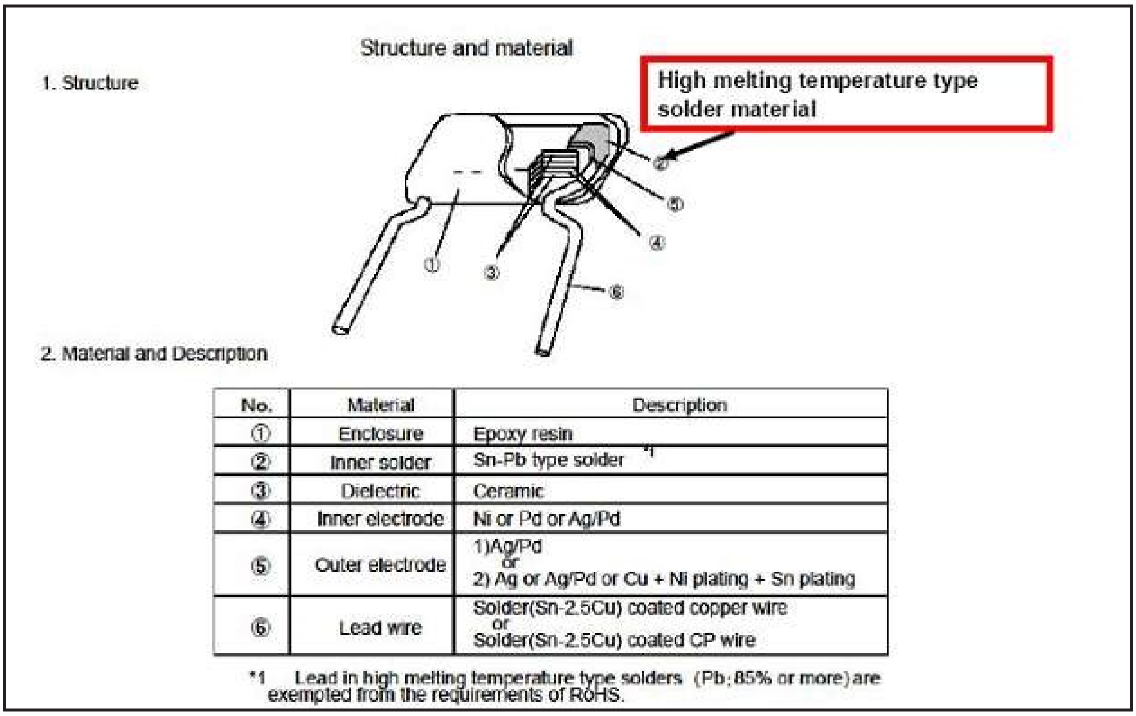
Examples for uses of lead HMP solders

The stakeholders provide examples on specific applications and technologies where the HMP lead solders are applied (ACEA et al. 2009e). The below listings are not exclusive. There may be uses of HMP lead solders, which are not included in the below descriptions. In agreement with the stakeholders involved in this review of exemption 8a, it is therefore not recommended to enact these example exemptions and to restrict the use of lead HMP solders to these exemptions. A specification of the HMP solder exemption away from a material specific towards an application and technology specific exemption would require another stakeholder consultation in order to make sure all stakeholders worldwide have chance to have their applications of lead HMP solders reviewed. The same proceeding was proposed for the lead HMP solder exemption in the RoHS Directive.

As the below HMP lead solder exemptions are not thought to be transferred into the Annex II of the ELV Directive, the reviewers did not review and assess them. They are just listed with the information provided by the stakeholders, without further critical review.

Internal electrical interconnections in components

High melting point lead containing solders are used to form high reliability internal connections in electronic components, as shown in Figure 15.



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 15 Capacitor with HMP solder inner interconnects (no. 2) (ACEA et al. 2009e)

The stakeholders explain that for high reliability internal connections in electronic components, the melting point of the solder must be higher than the reflow temperature for lead-free assembly. The higher melting point is particularly important considering higher lead-free processing temperatures. When components are soldered onto printed wiring boards in reflow or wave soldering processes, soldering temperatures up to 260°C or even higher are applied. If the melting point of the solder used for interconnects inside the components does not have a considerably higher melting point, the inner solder joints remelt during the soldering process, which may damage the component, or reduce its reliability (ACEA et al. 2009e).

Substitution or elimination of HMP lead solders, according to ACEA et al. (2009e) is not possible because automotive electronics are used in harsh environments often in an enclosed environment at elevated temperatures, where convection cooling is not an option. They are used in safety applications and are expected to have 10–15 year lifetime. Automotive electronics also have to be commercially viable. Expensive thermal management techniques are not commercially viable (ACEA et al. 2009e).

During the life of the product, the electrical interface connections are subject to wide range of temperature, vibration and humidity. To replace the high temperature solder would require a dramatic reduction in the internal solder joint stress. This can only be achieved by the use of new component packaging materials, which would require extensive characterization and validation to ensure long term reliability (ACEA et al. 2009e).

Die Attach

High melting point lead containing solders are used to attach dies for power devices and discrete semiconductors providing both an interface with high thermal conductivity and electrical reliability (ACEA et al. 2009e).

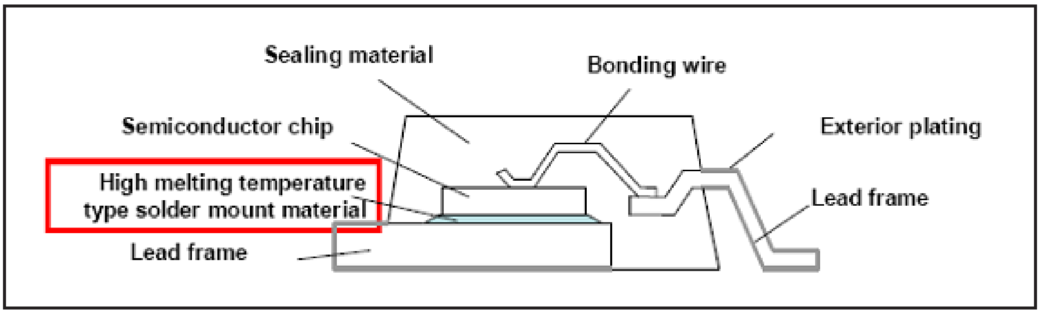


Figure 16 Example for use of HMP solders with lead for die-attach (semiconductor chip) in a power semiconductor (ACEA et al. 2009e)

ACEA et al. (2009e) explain that HMP lead solders have some unique properties that are necessary in this application. In die attach processes, high stress is generated due to the increase in junction temperature, die size and mismatch of the Coefficient of Thermal Expansion (CTE) between component materials. The solder must have low modulus of elasticity (high elasticity) to withstand a high number of thermal fatigue cycles required in automotive applications. The die attach is also required to possess high thermal conductivity since power and semiconductor devices generate significant levels of heat which must be dissipated (ACEA et al. 2009e).

According to ACEA et al. (2009e), in an automotive environment the ambient temperature can be in excess of 125°C. In order to maintain product reliability over 10–15 years, the junction temperature of the silicon die must not exceed 150°C (175°C for some specific power components). During operation the die temperature rises due to the power dissipation. In order to minimise the temperature increase, a material with high thermal conductivity is required.

Stress is also generated due to the CTE mismatch between the silicon die and copper heat slug/leadframe. If excessive stress is generated, de-lamination will occur resulting in a decrease in thermal performance, die fracture, and possible movement of the die causing wire bond failure (ACEA et al. 2009e).

Automotive electronics are used in harsh environments often in an enclosed environment where convection cooling is not an option. They are used in safety applications and are expected to have 10–15 year lifetime. Automotive electronics also have to be commercially viable. Expensive thermal management techniques are not commercially viable.

During the life of the product, the electrical interface connection and die attach are subject to wide range of temperature, vibration and humidity. To replace the high temperature solder would require a dramatic reduction in the internal solder joint stress. This can only be achieved by the use of new component packaging materials which would require extensive characterization and validation to ensure long term reliability (ACEA et al. 2009e).

Hermetic Sealing

High melting point lead containing solders are used as a substance for hermetic sealing (ACEA et al. 2009e).

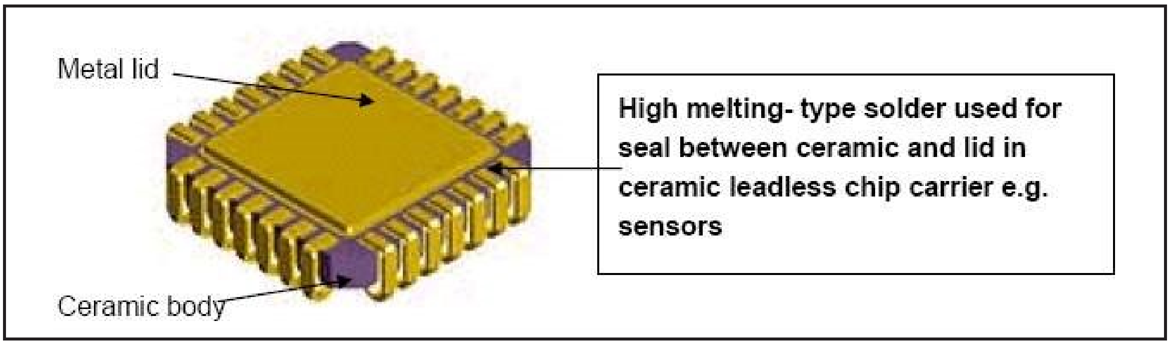


Figure 17 Example for use of HMP solders with lead in ceramic leadless chip carrier (ACEA et al. 2009e). Remark: “Leadless” chip carrier does not refer to the substance lead (Pb), but describes a component without leads, which form a carrying part in other, not leadless components (ACEA et al. 2009e).

According to ACEA et al. (2009e), hermetic sealing on the one hand requires a material that can be applied at sufficiently low temperature so as not to overstress the internal device. On the other hand, the solder used as a sealing substance between ceramic and metal must withstand processing temperatures of 260 deg C in soldering. It must accommodate the CTE mismatch between the lid and base. Therefore, they must form an intermetallic compound with the base and lid resulting in a solder joint which is not brittle and has sufficient ductility to accommodate the CTE between base and lid. Further on, the solder must provide hermetic sealing so as not to impair the performance of the device, e.g. crystal oscillators and sensors.

ACEA et al. (2009e) point out that any substitute has to be commercially viable which rules out alternative hermetic sealing methods.

Availability of substitutes for RoHS equipment

A stakeholder had applied for an exemption in the RoHS Directive for the use of lead in a similar application (SMMT 2009). The exemption request was assessed and recommended not to be granted, as another stakeholder at that time offered lead-free solutions (Swatch 2009). Although the application specific conditions in automotive electronics are different from those in RoHS equipment, an assessment of this exemption in a later phase should take into account the result of this previous review.

Plastic overmoulding

High temperature plastic overmoulding (>220°C) uses high lead containing solder for component attachment, which is required to withstand the higher temperatures of the moulding process (ACEA et al. 2009e).

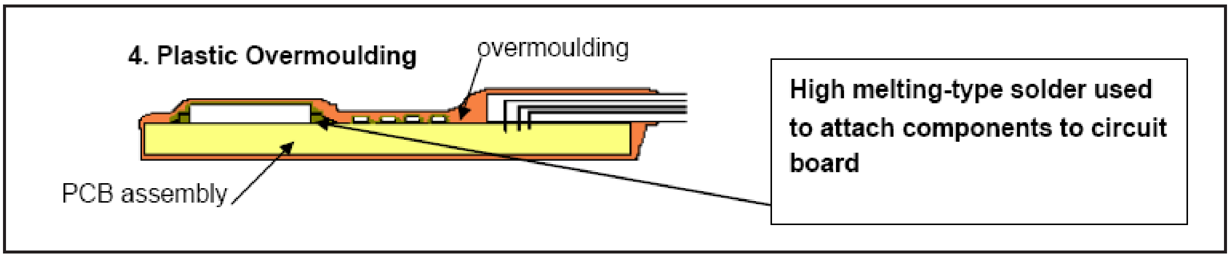


Figure 18 Example for use of HMP lead solder for component attach in plastic overmolded components (ACEA et al. 2009e)

ACEA et el. (2009e) explain that the components are attached to the printed circuit board (PCB) and then over-moulded. The solder joints must have sufficient strength above 220°C to withstand the temperature and force generated during the moulding process. The assembly must then be reliable in a harsh automotive environment over the life of the product.

ACEA et al. (2009e) say that lead-free HMP solders do exist that would give sufficient strength during the overmoulding process. They would however not meet the reliability requirements (see Figure 14 on page 98 and the stakeholders’ explanations there).

Ceramic BGA

Ceramic BGAs require high melting point lead containing solder balls for electrical connections.

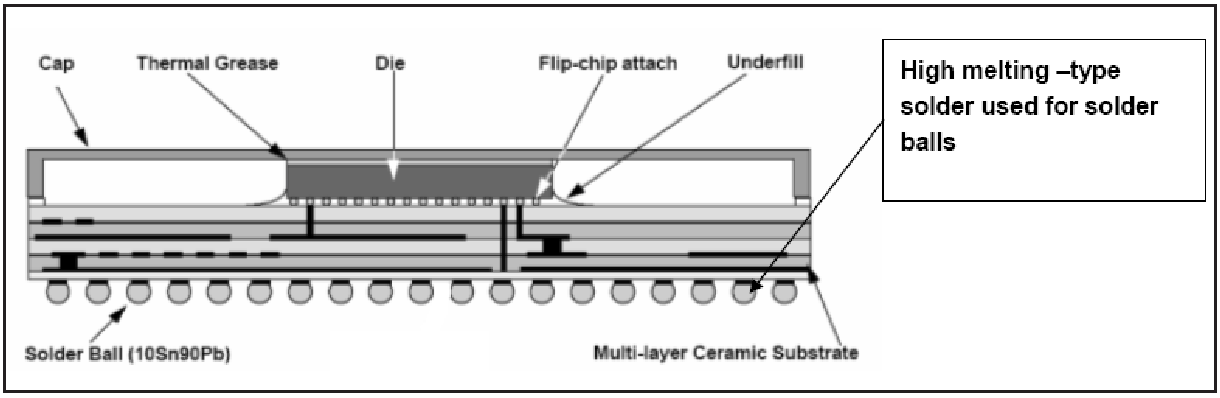


Figure 19 Example for use of HMP lead solder in ceramic ball grid arrays (BGA) (ACEA et al. 2009e)

ACEA et al. explain that ceramic BGAs have a large CTE mismatch between the board and BGA. In order to fulfil automotive requirements, the strain has to be minimised. HMP lead solder does not collapse like a SAC lead-free solder during processing. Therefore, the solder joint stand-off height – distance between the BGA substrate and the printed circuit board to which the BGA is attached – is maintained (ACEA et al. 2009e).

This improves the thermal fatigue robustness. The strain generated within the solder joint is inversely proportional to the solder joint height. Increasing the solder joint height decreases the strain and increases the fatigue life (ACEA et al. 2009e).

High Power Applications

High power applications require high melting point lead-containing solder to maintain internal electrical integrity due to internal power dissipation (ACEA et al. 2009e).

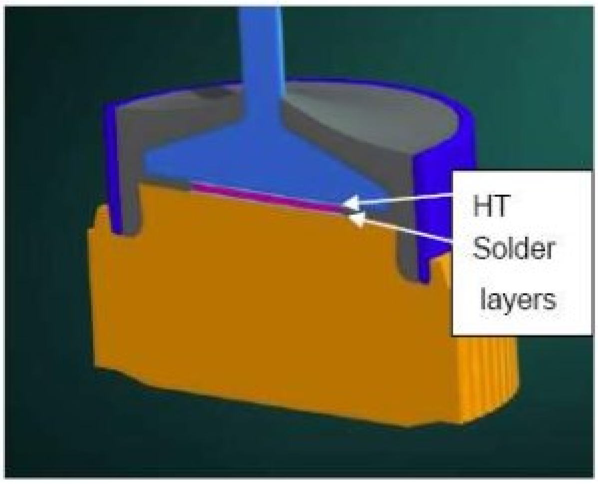


Figure 20 Example for use of HMP lead solder in a generator diode (ACEA et al. 2009e)

High power applications generate heat during use and require high melting point lead-containing solder to prevent the internal interconnections melting during operation. Generator/alternator diodes, e. g., to rectify the current for board net must survive temperatures of 280°C (ACEA et al. 2009e).

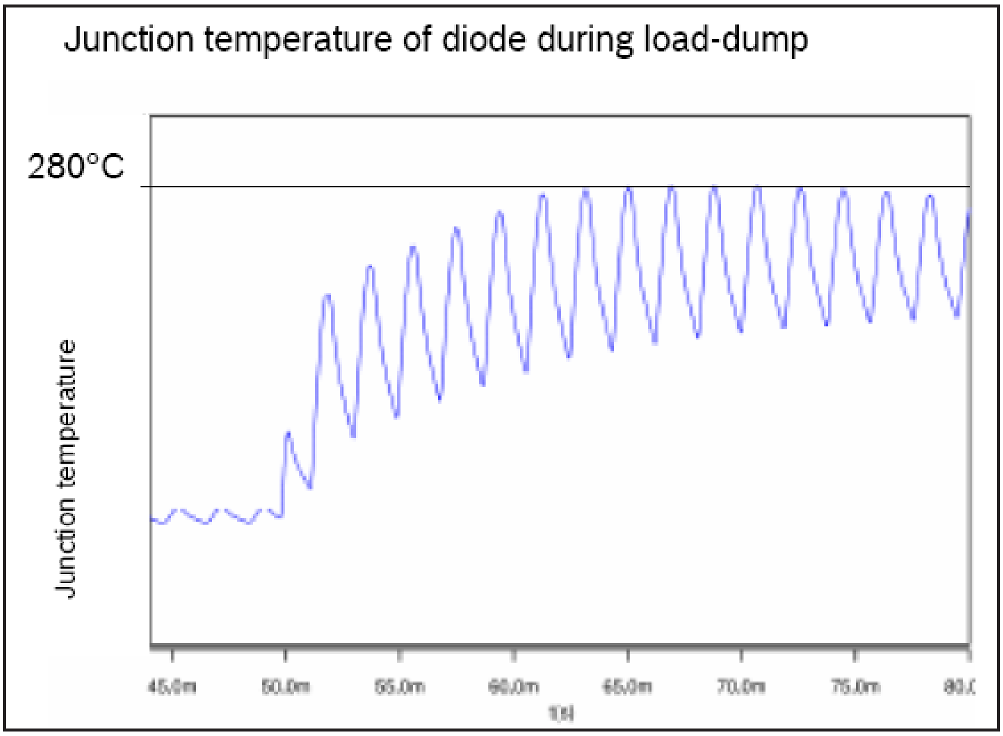


Figure 21 Junction temperature of a diode during load dump

The melting point of the applied solders must be higher than 280°C. The diode will be short-circuited if the melting point of the solder is exceeded (ACEA et al. 2009e).

As a lead-free alternative for generator diodes, low temperature silver sintering is under laboratory scale investigation. First results show problems due to the brittleness of the silver interface. Also the simultaneous connection on both sides of the diode showed to be very difficult. Laboratory solutions are not expected in the near future (ACEA et al. 2009e).

ACEA et al. (2009e) claim that substitution or elimination would require a design change, which is not possible within the given timeframes of ELV Annex II.

4.10.4 Critical review of data and information

The above examples for HMP lead solder uses are just listed, they were not reviewed as the stakeholders did not request them as exemption, but just gave examples of HMP lead solder uses.

Necessity of an exemption for leaded HMP solders

The stakeholders plausibly explain that in several technologies and specific applications, leaded HMP solders cannot yet be substituted. For the same reason, the RoHS Directive exempts the use of lead in high melting point solders (exemption 7a), as long as the lead content is at least 85% (weight). It is hence not contentious that an exemption for leaded HMP solders is required.

Deviation of solder limit from the exemption for leaded HMP solders in the RoHS Directive

Differently from the RoHS Directive, ACEA et al. (2009e) want leaded HMP solders to be exempted starting from 80% of lead content by weight. ACEA et al. (2009e) put forward that, although the lead contents of the different solders used are above 85%, the soldering process will result in some blending of the original solder (HMP solder) alloy with the solder alloy used for component attach (with a lead content of well below 85%). This blending effect may result in regions within the alloy that could fall below 85% lead content.

If this effect actually was to be observed, systematic non-compliance of equipment with the stipulations of the RoHS Directive would be the consequence.

On further request, the ACEA et al. (2009n) explain that the proposed wording of the proposed exemption C(i) for HMP solders is a merger of two exemptions in the current version of the RoHS Directive, namely 7a and 14:

- Current wording of Exemption 14:
  “Lead in solders consisting of more than two elements for the connection between the

pins and the package of microprocessors with a lead content of more than 80% and less than 85% by weight."

- Current wording of exemption 7a:
  "Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead)"

ACEA et al. (2009n) explain that they had intended minimizing the number of application based exemptions.

As exemption 14 of the RoHS Directive is recommended to expire in 2010, the stakeholders agree to align the wording of the requested exemption C (i) with the wording of exemption 7a of the RoHS Directive if the Commission decides to follow the reviewers' recommendation for exemption 14 of the RoHS Directive (Gensch et al. 2009).

The reviewers recommend not to follow the stakeholders' proposal with the 80% lead limit, even in case the Commission would decide to maintain exemption 14 of the RoHS Directive. Exemption 14 is a highly specific exemption limiting the use of 80% lead solders to specific pin grid arrays. Lowering the lead limit down to 80% like in the stakeholders' proposed exemption wording would allow a general use of such solders. The wording of exemption C (i) targets a material specific exemption for such leaded solders, not an application or technology specific one.

Alignment with exemption 7a of the RoHS Directive

Most of the examples of HMP solder uses, which ACEA et al. (2009e) had indicated apply to specific uses of HMP solders in the RoHS Directive as well. The RoHS stakeholders had presented such examples in the last review of the Annex of the RoHS Directive (Gensch et al. 2009). ACEA et al. (2009e) did not provide evidence justifying the requested 80% limit. Granting a different lead limit in the ELV Directive thus technically would not be justified and, as it affects the same industries, might create confusion.

Exemption 7a in the RoHS Directive, in alignment with the Commission's policy and to prevent abuse of the exemption, was recommended to be transferred from a material specific to an application and technology specific exemption. There were cases of abuse of leaded HMP solder materials (Gensch et al. 2009).

It is recommended to follow the same principle for the requested leaded HMP solder exemption in the ELV Directive. Exemptions allow the use of a banned substance if its use is unavoidable according to Art. 4 (2) (b) (ii). Exemptions therefore should be as specific as possible to avoid misuse of banned substances. Exemption 7a of the RoHS Directive is recommended to expire on 30 June 2013 (Gensch et al. 2009). Until then, before the expiry, application and technology specific exemptions for leaded HMP solders must be in place, which industry can apply for once the Annex of the RoHS Directive is amended officially. For the requested HMP solder exemption in the RoHS Directive, the stakeholders ask not to set an expiry date, but a review date instead. Due to the long development cycles, an expiry date would cause troubles in the supply chain. Vehicle manufacturers want to make sure their legal compliance in case the lead HMP solder exemption expires before more specific exemptions are in place. They may thus try to oblige their suppliers to sign certificates stating that they can supply without using lead in HMP solders. The stakeholders report such experiences since Annex II of the ELV Directive was published with an absolute ban of lead from 2011 on.

It is therefore recommended to grant an exemption for HMP solders with 85% of lead by weight or more for now, but to transfer it to an application and technology specific exemption at the same time and in alignment with exemption 7 a of the RoHS Directive, as far as such an alignment is technically justified. Lead containing HMP solders are used in equipment under the RoHS Directive as well as in vehicles for the same technical reasons, in similar applications, and at least in parts the same industries are affected by the HMP solder exemptions. An alignment thus improves the understanding and handling of the exemption.

Like in the RoHS Directive, the ELV stakeholders are not sure whether the listed HMP solder applications actually are complete and cover all applications (ACEA et al. 2009n). A transfer of the material specific to an application and technology specific exemption hence would require a separate stakeholder process.

4.10.5 Final recommendation exemption 8 C (i)

The use of lead in HMP solders is not unavoidable, and Art. 4 (2) (b) (ii) thus would justify an exemption. It is recommended to grant the exemption, but to transfer it later from a material specific exemption to an application and technology specific one, following the example of exemption 7a in the Annex of the RoHS Directive. An alignment with the RoHS Directive makes sense, as the technical background is similar, and as the exemption at least in parts affects the same industries e. g. the component industry.

The proposed wording for exemption C (i) hence is:

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead), review in 2013.*

The review date should enable the review of exemption C (i) together with exemption 7a in the Annex of the RoHS Directive. The 2013 timing for the review is based on the reviewers' recommendation for exemption 7a of the RoHS Directive (Gensch et al. 2009). In case the Commission decides a different expiry or review date for exemption 7a RoHS Directive, the review date for this exemption should be adapted accordingly.