Stakeholder Consultation 9th Revision of ELV Annex II Entry 8j

Application for an extended change over period for expiry date of entry 8j in Annex II ELV directive

With this application the automotive industry, represented by their associations ACEA, CLEPA, JAMA, and KAMA, asks for an extended change over period for annex II entry 8j as detailed in this document.

This application is supported by the following associations:

- ACEA, the European Automobile Manufacturers Association, Brussels (transparency registration ID number 0649790813-47)
- JAMA, the Japan Automobile Manufacturers Association, Tokyo / Brussels (transparency registration ID number 71898491009-84)
- KAMA, the Korea Automobile Manufacturers Association, Seoul (transparency registration ID number 72944376512-60)
- CLEPA, the European Association of Automotive Suppliers, Brussels (transparency registration ID number 91408765797-03)

In this section we take reference to the questionnaire from OEKO Institute published on May 29th 2018 as file questionaire_ELV_Ex_8j_Cons-Questionnaire_2018-05-24. We give a short information to every question and reference for details to the following pages, where the questions are answered in detail.

Questionnaire:

1. Please explain whether the use of lead in the application addressed under Exemption 8(j) of the ELV Directive is still unavoidable so that Art. 4(2)(b)(ii) of the ELV Directive would justify the continuation of the exemption. Please take into account the above described background information concerning the result of the last review as far as possible.

   The explanations, why the continuation of this exemption is required, are detailed in the following sections.

   Please be specific with your answer, for example clarify, if applicable, what types of vehicles your answer refers to, i.e., conventional vehicles and various types of hybrid and electric vehicles and which functionalities the exemption still needs to cover.

   Because there are technical, material-based challenges and in addition new safety requirements addressed, this applies for current and future vehicles in general.

2. Please explain the efforts your organisation has undertaken to find and implement the use of lead-free alternatives in the manufacture of laminated glazings for automotive uses.

   The explanations of the industry efforts are detailed in the following sections.

   Please refer to alternatives, which at least reduce the amount of lead applied or eliminate its necessity altogether.

   Please see proposal suggested under document section 10 (Conclusion and Proposal)

3. Please provide a roadmap specifying the necessary steps/achievements in research and development including a time scale for the substitution or elimination of lead in this exemption.

   The generic roadmap situation was outlined in previous consultations yet. So we would like to make reference to them. Further details are given in the following sections.

4. What is the amount of lead that would be contained in laminated glazings of vehicles

   a. placed on the EU market

The figures for the EU Market and the year 2016 have been evaluated end of 2017 for this application. They are detailed under section 1.3. of this submission.

   b. worldwide

There are no worldwide figure available. Evaluation was made for Europe and European legislative demands. For some countries of the world there is no access for external associations to specific data of local production.

in case the exemption remains valid beyond 2019?

As of today, if no new technical progress is made, it is expected that the level is in the same range until the end of the applied extension period.
Further future detailed assumptions are difficult because of competitive / antitrust requirements, which have to be met, and the uncertainty of vehicles sales.

Please provide a substantiated estimate clarifying how you have arrived at the stated result.

For year 2016 the vehicle producers have been asked to provide figures for relevant vehicles put on the EU market in 2016. The answers were sent to a trustee of the association. There the data have been consolidated and aggregated. The approach is detailed in section 1.3.

5. Overall, please let us know whether you agree with the necessity to continue the exemption and sum up your arguments for or against its continuation.

On behalf of the joint industry associations and as detailed in the attached information, e.g. under section 9 and 10, we agree with the necessity and apply to continue the exemption.

Document Contents

0. Scope

With this application the automotive industry, represented by their associations ACEA, CLEPA, JAMA, and KAMA, asks for an extended change over period for annex II entry 8j “soldering of laminated glazing” until 2024. This is due to unexpected, not yet solved technical challenges in implementation of Lead-free soldered solutions for laminated glazing structures. The situation is unfortunately still comparable to that one outlined by industry in the last stakeholder consultations[1]. The technical feasibility to produce in large volumes Lead-free soldered laminated glass components fulfilling the specifications of the car producers is still not proven. Further R&D activities are required until more sustainable and validated substitutes are available.

The critical point is to solder on a non-tempered glass without Lead, as annealed glass is less stress resistant than tempered glass. In addition, use of common Lead-free solder types such as SnAgCu composition causes higher thermomechanical stress. Sufficient safety margin process windows are missed as materials seem to be at their limits.

Further research and development work is needed for enabling full-scale Lead-free soldering to ensure proper component function and long-term reliability in order to provide all car customers with long-term reliable laminated glass components.

In addition the EU Commission has published on 17.05.2018 with proposal COM (2018) 286 on General Safety Regulation new requirements for future type approval.

1. Laminated glass - structure and applications

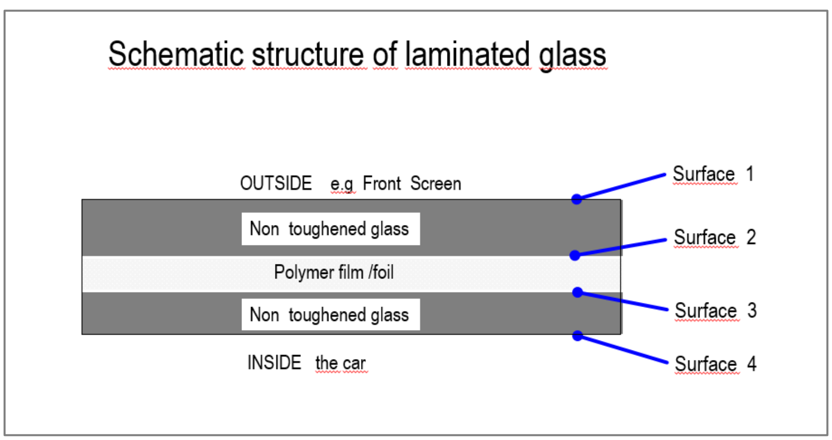

Figure 1: Structure of laminated glazing (term surface in the following text identical to position) (screen wall thickness can be the same or interior screen could be thinner than the exterior one)

Today less than 1/3 of all new registered vehicles have soldered electrical contacts within laminated glazing structures.

[1] Stakeholder submission from ACEA et alt 2011 Sept 9; ACEA Brussels
Stakeholder submission from ACEA et alt 2013 Nov 4; ACEA Brussels

1.1 Production of laminated glass

Laminated glass is produced in several steps.

- Cutting of float glass panes in individual shapes and pretreating (e.g.: edge grinding), application of Lead-free black enamel layer, application of silver prints
- Bending at around 650 to 750°C to achieve individual 3D geometry (different technologies in use)
- Slow cooling to room temperature to minimize residual stress in the glass
- Application of surface 3 or surface 2 electrical contacts
- Preparing laminate consisting of two bended glass panes and an inner layer of a polymer film
- Finishing laminate via autoclave procedure for around 1h at pressure level around 15 bar and temperatures between 120 and 160 °C

Final assembly, if applicable, adding electrical contacts on surface 1 and 4, and final inspection.

1.2 Applications

Typical current uses of Lead-containing solders within laminated glazing structures are:

- Wire heated windscreens applications with wires embedded into/on the foil between the two glass plies
- Coated heated applications
- Others like antenna functions or sensors integration

Applications of entry 8j have been described in our last contribution in detail [2]. As examples two pictures are shown below:

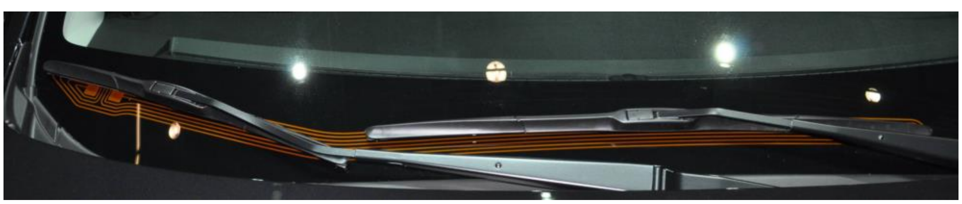

Figure 2: Windscreen wiper heating

[2] https://circabc.europa.eu/webdav/CircaBC/env/ELV%20Exemptions/Library 04.11.2013/acea_clepa_jama_kama_contribution_Ex_8j_comprehensive_ answers_20131104.pdf ; https://circabc.europa.eu/webdav/CircaBC/env/ELV%20Exemptions/Library/acea_clepa_jama_kama_contribution_Ex_8j_further_Input_Public_20131104.pdf

Figure 3: Camera window heating

1.3 Quantities of Lead in solder put on the market via new registered vehicles

For the EU market we see a total quantity of Lead in entry 8j applications in vehicles put on the EU market by new registered vehicles of 2.9 (metric) tons in the year 2016.

Quantity calculation; Europe 2016		
Application group	Use of Lead [kg], rounded	Use of Lead [t], rounded
Wire heated	1240	1,2
Coated heated	1205	1,2
Other /not specified	441	0,4
Total:	2886 kg	2,9 tons

Table 1: Application groups & Lead put on EU market by passenger cars in 2016

Table 1 outlines the total volumes of Lead contained in entry 8j applications in passenger vehicles put on the European market in 2016[3]. The quantities have been requested by ACEA and joint associations and were reported to ACEA as trustee and consolidated. Figures are different from last application because of different designs in use, vehicle volume increase and technical progress e.g. like support functions for recognition of traffic situation. In total we stated a volume of around 2.9 t of Lead used for entry 8j applications in 2016.

End points: During vehicle recycling it is expected that the major part of the applied solder sticks to the contact bridges and is entering the metal recycling routes e.g. for brass or copper

3 http://www.oica.net/category/sales-statistics/ last accessed 19.09.2017. In Europe 15.160.239 passenger vehicles have been sold 2016.

together with other electrical components. The existing technology in the EU for recycling of copper, brass and electrical scrap is able to handle tramp concentrations of Lead.

2. Development of entry 8j

Entry 8j was foreseen by Commission decision to be revised in 2014. With Commission directive 2016/774 (EU) from 2016/05/18 a phase out date for Lead in solders for soldering of laminated glazing was scheduled. According to this decision the exemption today applies only for vehicles type-approved before 1 January 2020 and spare parts for these vehicles.

The stakeholder consultation for revision of entry 8j started in 2013 and therein the automotive industry applied to continue exemption 8j and to review this exemption not before 2017. With Commission directive 2016/774 from May 18 2016 the exemption 8j was scheduled to be terminated for new type approved vehicles by 1.1.2020.

At our opinion the arguments in our previous applications are still valid technical facts and should be taken into account as well. We therefore refer to these and the documentations in databases of the EU and their mandated consultants.

3. Findings of consultant in its last report[4]

The Oeko Institute Freiburg, as by the Commission mandated consultant, released its final report in 2015. In this report also, entry 8j was scrutinized. In its final conclusion on page 111 the consultant states that "In case, specific applications require the continued use of Lead after 2019, the transition period until the end of 2019 is long enough to apply for specific exemptions in due time. ACEA et al. would, however, have to prove that the use of Lead is still unavoidable in these cases in spite of efforts to adapt the design to the requirements of Lead-free soldering, and that the continuation of the exemption is hence justified beyond 2019 for such specific applications."

4. Current situation

Since 1.1.2016 in Europe Annex II entry 8i (Lead in soldering on glass) has expired for new type approved vehicles. Normally for entry 8i applications toughened glass is used which can bear more mechanical stress than non-toughened glass. Even in implementation of Lead-free soldering contacts for toughened glass challenges happened in tests e.g. at high cooling or heating rates or under mechanical load.

A break of the glass may occur due to too high mechanical stress in the area of the soldered contacts. The challenges are not generic, but seem to be oriented to technologies, processes, components (contacts, glass) geometry and individual vehicle. In specific applications

[4] 7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV); Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020; Oeko Institut Freiburg 2015 ; http://ec.europa.eu/environment/waste/elv/pdf/ELV-Exemptions.pdf; and circabc library of the COMM https://circabc.europa.eu/ ; both last accessed 16.Nov. 2017

Indium based solders are under consideration, if specifications of the car producers can be fulfilled. Meeting this material restriction of entry 8i resp. Lead-free soldering of toughened glass is still consuming major parts of the development resources at suppliers and OEMs.

Soldering of laminated glazing is more complicated due to thinner glass and the use of non-toughened glass panes. Additional supplementing information is given under section 6. (Technological Assessment update 2017). With more test experience, more knowledge has been gained on the challenges of fulfilling the specifications of the vehicles producers without entry 8j exemption after 1.1.2020.

Currently an exemption, granted in annex II under entry 8j, enables the use of Lead-based solders for laminated glazing structures. This exemption ends at 1.1.2020 for new EU type approved vehicles.

There are different positions on the difficulty to establish Lead-free solutions. Whereas some glass producers claim to have Lead-free solutions for their product spectrum of laminated glass products available at least on laboratory level, other producers claim for their product spectrum that Lead-free soldered solutions are not able to meet their customer's specifications today in volume production. To cover the demand of laminated glass with electric contacts components the supply of all major suppliers is required.
Challenges in Lead-free soldering of contacts for laminated glass are reported unspecific and up to now no sufficient test results are available to identify clearly the reasons of component failure. Whereas in several cases Lead-free soldering seems to be feasible in laboratory scale on the other hand component and vehicle tests end with negative and disappointing results.

Even if some laboratory solutions and first applications are available today, the transition to industrial solutions is very challenging and will probably not be ready in 2020 for the full laminated application portfolio. Furthermore, laminated glazing is in constant evolution: thinner structures, more and more heating applications being under consideration for future vehicles with even more efficient heating systems, new antenna functions or sensors.

In addition, competitive situation, and confidentiality agreements for new developments sharpen the problem to outline and to report the negative test results. Last but not least it needs to be mentioned that windshields are safety relevant.

In ACEA WG RG (working group recycling) the decision was confirmed to prepare an application for an extended change over period for soldering of laminated glass. For that reason, an industry expert group was mandated to elaborate an application. This expert group was open for inputs by members of all joint associations like CLEPA, VDA, JAMA and KAMA.

To identify the challenges a questionnaire was sent out in spring 2017 to the expert group members. It was asked what technical challenges currently exist for Lead-free solder solutions in comparison to Lead-based solder. The results are summarized below.

Applications assessed as very challenging for Lead-free soldering are:

- Heating functions with high electric current (power) load up to several 10 A
- Clear concern with temperatures > 100 °C for Indium based solders
  - → autoclave procedure process conditions
  - → temp load in use
- Clear concern with thinner glass, (sometimes also for reference Lead)
- As to be expected, curved glass is more demanding than flat glass panes
- High gradients of cooling and heating are seen as challenging
- Transfer from lab solutions to car application more challenging for all Lead-free solders

There is no generic solution and individual vehicle case specific problems are to be considered.

5. Industry activities since 2013

Breaking of the glass is impacted by glass properties, residual stress in the glass, different coefficients of thermal expansion, temperature gradients, connector /connector bridges geometries and connector material, geometry of component, solder type, process parameter like time, heating/cooling profiles and mechanical load to component by vehicle in use. This was also outlined in the last stakeholder contribution of the industry.

Activities still are conducted to:

- Find the appropriate Lead-free solder and wetting supporting media (flux)
- Evaluation, development and testing of modified contacts (materials, geometries)
- Modification trials in glass production processes and parameters.

As a result, it is reported that there are still challenges at elevated temperatures for indium based solders (see also section 6 Technological assessment update 2017)

A revolutionary breakthrough in technology is still missing so the findings of the last revisions are still valid.

<u>Current test results</u>

One industrial stakeholder provided following laboratory stage test results. The laboratory trials were performed on a large variety of connector designs, material composition and process conditions. The main concerns of "Lead-free soldering for laminated" observed on this wide laboratory trial portfolio can be highlighted by two examples:

Test 1 details: on laboratory glass samples with soldered contact on surface 4

Laboratory sample:	10x10 cm
Glass structure:	2.1/PVB/1.6 mm
Siler print on glass:	No black enamel
Connector design:	Heating bridge for high current application > 30 A
Lead-free soldering:	tin-base solder alloy - high melting temperature > 200°C
Observations:	Glass cracks observed sometimes after soldering and before ageing due to stresses induced by lead-free soldering; while the lead allows to reduce the stresses transmitted to the glass substrate → Could generate glass breakages at different steps of its lifetime (stock, transport, mounting, on the road…) and reduce production yield

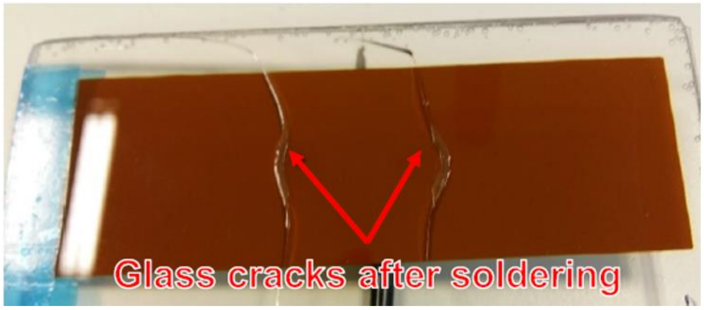

Figure 4: laboratory glass samples with soldered contact on surface

Test 2 details: on laminated backlite with heating grid and soldered contacts on surface 4

Laminated backlite:	Real part
Glass structure:	2.1/PVB/1.6 mm
Siler print on black enamel:	-
Connector design:	Heating bridge for high current application > 30 A
Lead-free soldering:	indium-base alloy with melting temperature > 130°C
2 ageing test of VDA AK2.1:	Thermal cycle test (TC) → -40 to 105°C, 480h, 14V Heat soak test (HSo) → 105°C, 96h, 14V power, 10N load
Observations	Lead-free soldering alloy melting during the ageing test generating a detachment of the connector from the glass → Impossible to survive such high temperature for this kind of low-melting temperature alloys

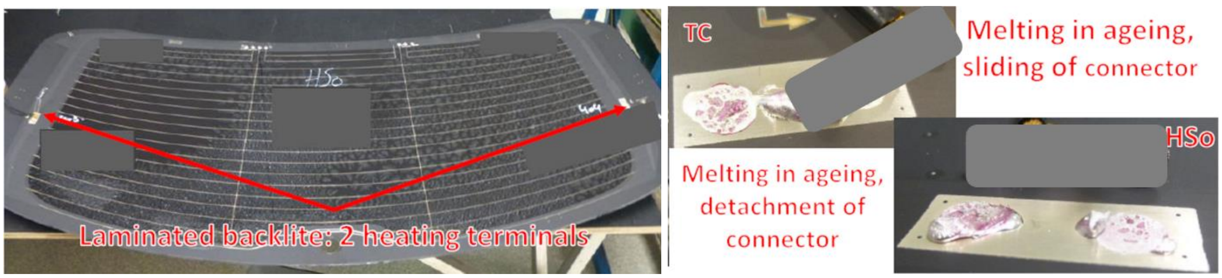

Figure 5: laminated backlite with heating grid and soldered contacts on surface 4

Another stakeholder reported additional experience in Lead-free soldering of laminated glass (figures 6, 7, 8).

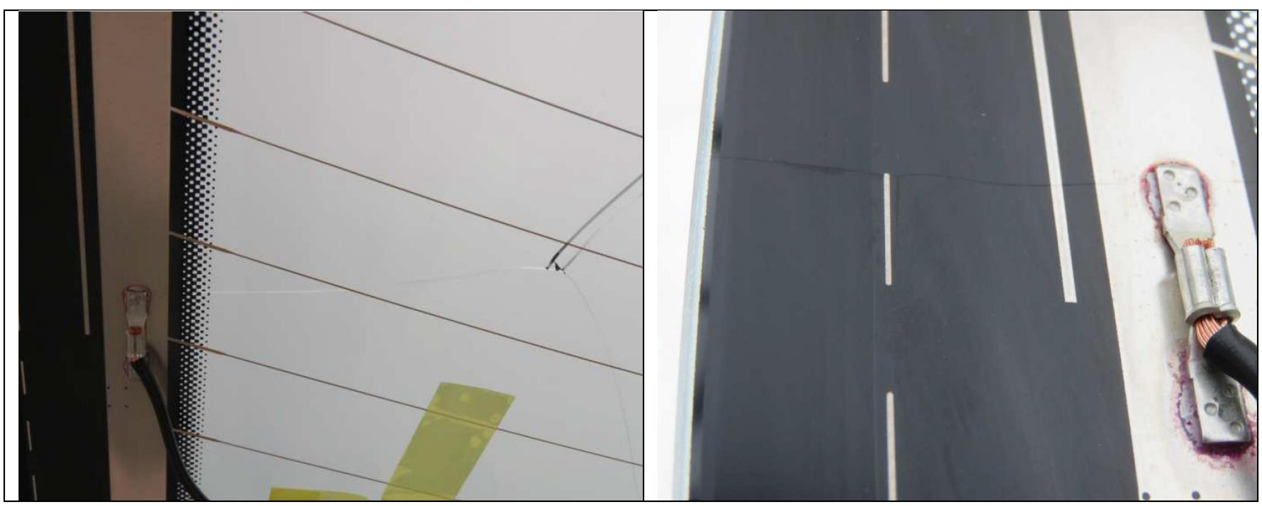

Figure 6 &7: Lead-free soldered backlites (laminated glass) with glass broken.
Break starts at soldered bus bar.

The stakeholder reported cases of glass breaking in rear screen in field with fracture starting from solder Lead-free solder joint. Application was in a vehicle to collect market experience (figures 6, 7, 8). Because of the glass crack problem the Lead-free solder used was changed to Lead-based solder and the problem disappeared.

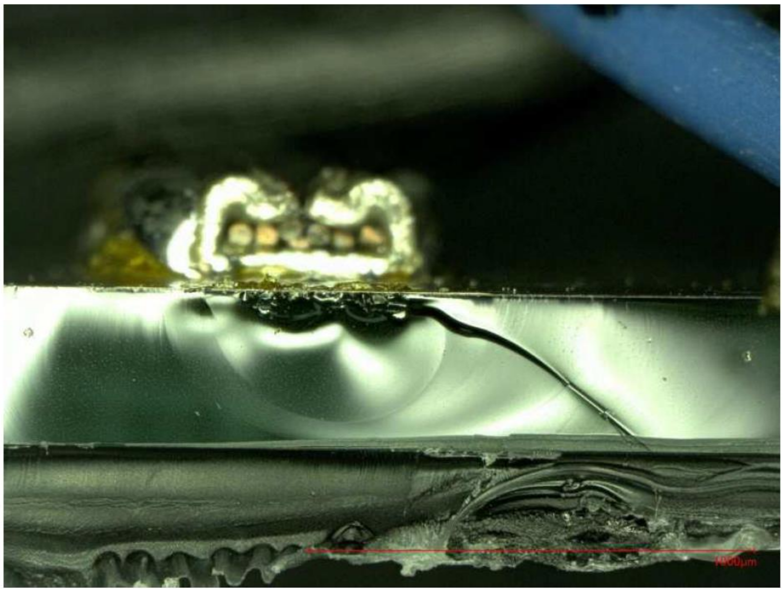

Figure 8: Lead-free soldered backlites with glass broken.
Fracture starts at Lead-free soldered bus bar.

6. Physical and technical parameters

Technological assessment update 2017

In this technological assessment update 2017 it is outlined why Lead-free soldering of laminated glass is much more challenging than soldering of electrical glazing applications of non-laminated toughened glass (→ entry 8i).

– **Annealed glass is mechanical weaker than tempered glass**

In tempered/ "toughened" glass outer surfaces are put under compression stress. Tempered glass is considered to be four to five times stronger than raw glass [6].

For laminated glass annealed glass is in use. According [1] page 6 non-tempered/non-toughened glass can only take 25 to 34 MPa of tensile stress before it fails. The author claims micro-flaws in the surface and micro flaws migrating into and through the glass matrix as reason for that. Further presence of micro bubbles and impurities reduce the acceptable stress level.

The tolerable mechanical strength decreases over time under steady load and in combination with humidity significantly [19] p. 43f.

Flexural strength of bended float glass in center surface and edge area is different. The value in the edge area typically may be weaker by 30 % [19] p. 59.

The tolerable bending stress of tempered glass is 2.5 to 4 x higher than for annealed float glass.

Even semi-toughened glass has reduced mechanical strength (typically ≤ 50%) compared to tempered glass.

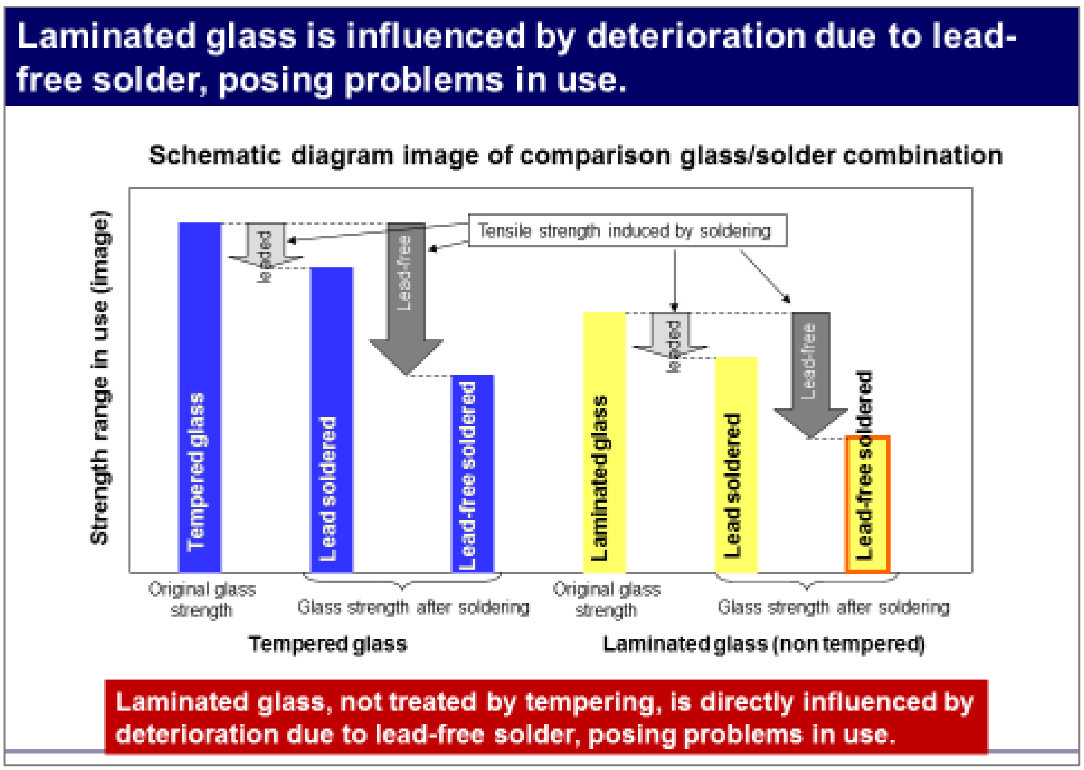

Figure 9: laminated glass challenges (with permission of JAMA)

Figure 9 summarizes the laminated glass situation and compares it with tempered glass.

One OEM recently acquired a new test equipment, enabling -without contact- experimental determination of 3D stress distribution in complete components. The method is based on enhanced laser scattering technology (SCALP). Tests of different laminated screens and soldered with different solder types are scheduled but validated test results are not yet available. This experimental approach is seen as promising to receive real stress figures, which will support further developments. Thermomechanical stress simulation for soldered contacts of laminated screens is very challenging because of numerous even non-linear variants and their sensitivity in the calculation models. The expected experimental data also will support future progress in validation of simulation results. The OEM signalized to share validated test results after their availability.

– **Lead-free solders cause higher CTE mismatch**

  Lead-free solders based on tin as e.g. 95.5Sn/3.8 Ag/0.7Cu have a higher melting point (typically 30 to 40 K) and a higher tensile strength (typically 50 % higher) compared to Lead-based solders. The higher process temperature of tin-based Lead-free solders increases the temperature difference between process temperature and room temperature and increases the resulting CTE mismatch stress level. Figures 10 and 11 are visualizing this.

As an example in table 6.1 parameters for two typical solders are listed.

Property	**Units**	**Sn60Pb40**	**SnAg3.8Cu0.7**	**Source**	
Density	g/mm^3	8.5	7.5	[2]	
Melting point	Deg C	183	217	[2]	
CTE	$x\ 10^{-6}$	23.9	Similar (23.5]	[2]	
Vol change on freezing	%	2.4	Larger (2.7)	[2]	
Specific heat	$J\ kg^{-1}\ K^{-1}$	150	Higher (226)	[2]	
Thermal Conductivity	$W\ m^{-1}\ K^{-1}$	50	Higher (73.2)	[2]	
Young´s Modulus	GPa	30	Higher (48)	[6]	

Table 6.1.: Technical parameters of Lead-based and Lead-free solder.

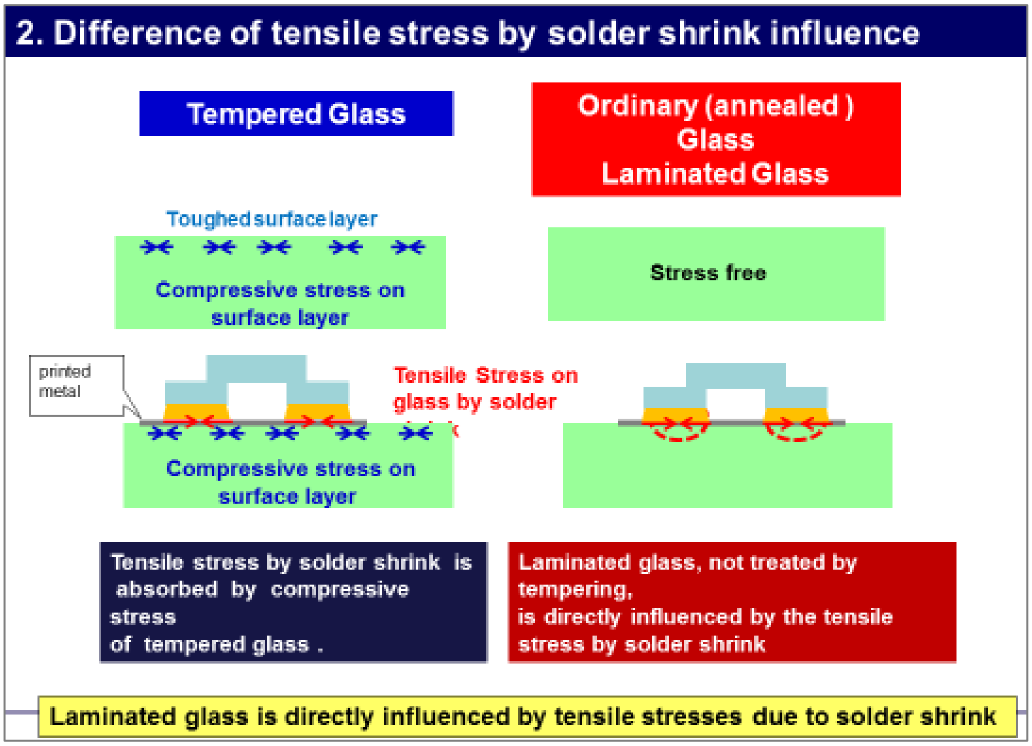

Figure 10: laminated glass challenges (with permission of JAMA)

– **Lead-based solders better can compensate mechanical stress**

As experimental data published in [6] give indication for, Lead-based solders are able to compensate higher mechanical stress levels by plastic deformation at significant lower stress levels compared to Lead-free solders of SnAgCu type. This means that in the case of Lead-based solders mechanical stress is relieved at lower values and SnCuAg type solder can take more mechanical stress before a plastic deformation occurs. The critical break stress level is higher and if this higher mechanical stress impacts to the glass the glass may ”loose” and break. In addition technological aspects have to be considered which means the different behavior of formation of intermetallic phases. Whereas the eutectic Lead-based solders intend to form a fine grain structure, Lead-free SAC solder types intend to form hard intermetallic phases, even in interference with the silver print.

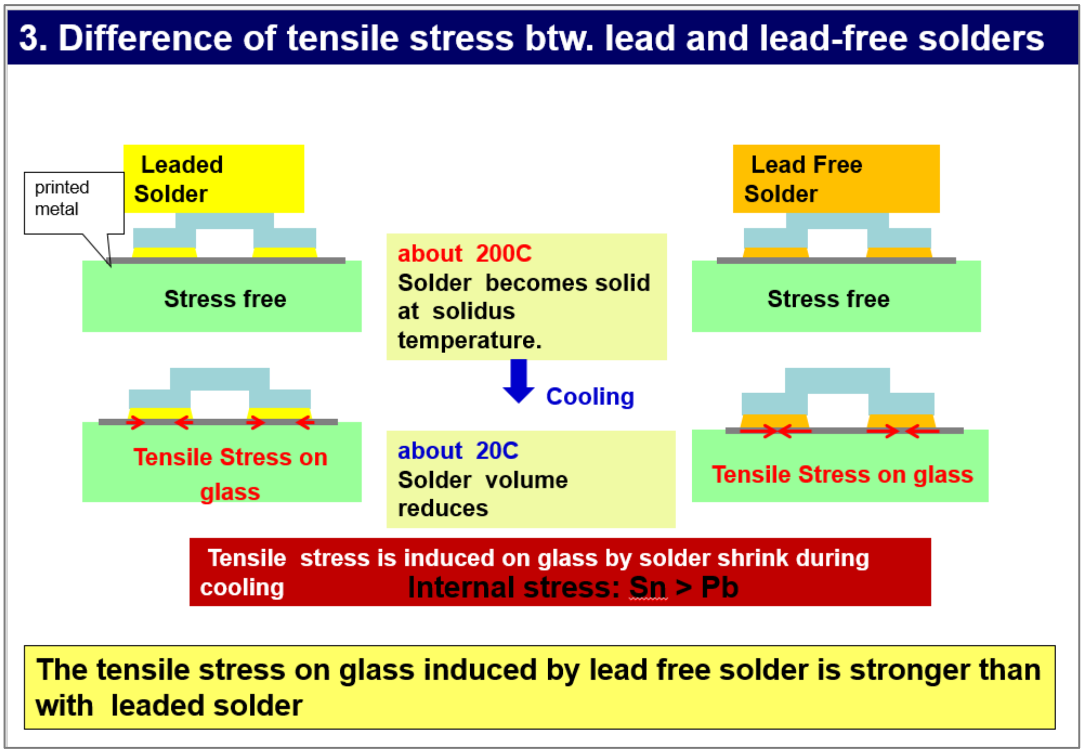

Figure 11: laminated glass challenges for Lead-free solders (with permission of JAMA)

For breaking of the glass there is superposition of CTE mismatch stress between solder and glass, glass residual stress from glass production, additional CTE mismatch of contact bridge and additional mechanical stress from vehicle and its operating conditions like wind load, car body torsion, temperature.

– **Lower temperature cycle window range**

Non toughened glass has a reduced temperature cycle range compared to toughened glass (typically < 50%) [8] p.52. This is especially challenging for the heating functions. Typically small sector heating functions are powered with current up to 10 A and full screen heating function can require current between 20 and 50 A per screen.

– **Thinner glass panes for weight reduction has interference with mechanical parameters**

It easy to understand that a thinner wall size of a material can bear less load than a higher wall size. The wall size of laminated glass panes is normally thinner than that of tempered single side glass.

In order to reduce vehicle weight, during the last 10 years total thickness of laminated glass has been reduced by around 10 % and sometimes even more. If the structure is not symmetrical, it is the inner glass sheet that is thinner and this is in most cases the sheet that has soldered connections on printed products.

Because panel bending stiffness is proportional to glass thickness with cube and moment of inertia proportional 4^{th} power, this has significant impact on the mechanics of a laminated glass structure like torsional stiffness and operating elastic strains.

Especially future E-vehicles may require integrated intelligent electric heating function on thinner glass panes of laminating glazing structures. Weight reduction directly improves the operating distance. A ban of using Lead-based solders for such applications should not block such developments. Details currently are not available for publication for competitive reasons and meeting antitrust rules.

– **Limited potential for Indium based solders**

Known Lead-free Indium-based solders have a low melting temperature. Because of process temperatures for autoclave procedure (typically 120 to 160 °C), soldering with available Lead-free Indium-based solders before autoclave procedure on surface 2 or 3 is not appropriate. So application potential is limited to side 1 or side 4 application, if temperature load demands of the relevant vehicle and its production processes (e.g. paint refurbishing) allows such low melting temperatures. As reported in previous applications temperature load in a specific vehicle can significantly exceed 110 °C under severe climate conditions.

Shearing resistance of In52-Sn48 at 100 °C is only 3.5 MPa [9]. Together with a homologous temperature above 0.7 Indium-based solders are challenging in mechanical properties at elevated temperatures. Indium-based solders are sensitive to corrosion by halides in presence of moisture [10].

In specific cases In- based solders could be used as problem cruncher, if individual vehicle specs /demands package /size /available space can be met.

Indium (CAS 7440-74-6) was registered by industry under REACh recently. There are also some hazard classifications for Indium listed (https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.345) but no harmonized classification yet. There is no data on neurotoxicity and immunotoxicity provided yet and the registration dossier and/or substance is not evaluated yet by authorities.

– **Residual stress from production**

Depending on geometric position within a glass pane, the residual stress figures under unfavorable conditions can reach up to +/-5 MPa and even more than 10 MPa (press bended laminated techniques), depending on thickness and/or bending procedure.

7. Results from literature screening

Especially for Lead-free soldering of laminated automotive glass no publications could be found. But there are actual papers available for soldering of solar panels where Lead-free soldering is outlined as a remaining challenge as well today.

There was great hope that a transferable appropriate solution for Lead-free soldering of solar panels would be available in 2016 as result of funded R&D projects. But this technology transfer could not happen.

For production of solar panels mainly Lead-based solders are still in use, because similar to laminated automotive glazing, thermomechanical stress is seen challenging for alternatives [17, 18].

Nevertheless, a lot of R&D activity in this field is conducted globally and encourages to the assumption that in midterm appropriate Lead-free joining solutions for volume production will become available.

Reference to solar panels

In [4] it is outlined that formation and impact of IMC (Inter metallic compounds) in SnCuAg (95.5Sn-3.8Ag-0.7Cu) solder accelerates degradation of solder joints and product endurance of solar panels. Fatigue failure was seen as dependent on solder joint composition.

The coefficient of thermal expansion (CTE) of the copper ribbon, solder alloy and silver bus-bar are different. The CTE mismatch induce thermo-mechanical stresses in the solder joint during soldering as well as service operations resulting in fatigue and eventual failure

In [12] microstructure and thermal ageing characteristics of solder bonds of crystalline silicon solar cells have been investigated. A low melting point Lead-free solder Sn41Bi57Ag2 and a Lead-containing solder Sn40Pb40 had been in scope. The Sn41Bi57Ag2 solder joints show faster IMC growth. IMC are confirmed to be critical for long term reliability because their brittleness triggers thermomechanical fatigue. SnPb-based solder is characterized as "absorbing easily thermomechanical stress". The high homologous temperature of the Lead-free solder promotes faster IMC growth and by this is assumed to "cause commonly observed reliability problems".

In [4] page 31 Section *Solder Joint Reliability* it is outlined that "The reliability of solder joints can be affected by a variety of application conditions such as vibration, mechanical shock, thermo-mechanical fatigue, thermal aging and humidity (Lechovic et alt., 2009). McCluskey (2010) and Cuddalorepatta et al (2010) reported that the soldered interconnect joint is the most susceptible part of the assembly."

In addition [7] addresses the same issue: "Soldering process: mechanical and thermal coupling of ribbon and solar cell -> different thermal contraction leads to mechanical stresses " → higher thermo-mechanical stress due to higher soldering temperature " and Lead-free soldering is again mentioned as challenge.

Yet in 2009 [13] it was reported that "The aim is to show how to match present soldering equipment for future challenges like thinner cells and leadfree soldering without the need of exchanging the whole soldering process." But as newer publications give evidence, that aim is not reached as of today in general.

8. Aspects of potential substitutes and critical minerals

Conductive glueing

In the course of the last revision of entry 8e within the DA5 [5]project the usability of conductive glueing was assessed. The information in the report shows that conductive glueing is among other criteria restricted to specific cases and have a poor electrical conductivity. Conductive adhesives are based on silver in an organic matrix. Silver tends to migrate under voltage and humidity. Higher power density increases the risk of electro-migration. Above 175 °C the organic based matrix begins to degrade.

An electrical heating function of a laminated glass requires high electric current density application[6]. There is an inevitable compromise between mechanical resistance and conductivity[7]. There are no new developments known for conductive adhesives for high current applications.

These results are valid also for entry 8j applications.

Critical minerals aspects

In 2017 again, as in 2014, the EU Commission has put Indium on the Table of critical raw materials [3]. In 2017 also Bismuth is now listed as critical raw material. Use of critical raw materials should be avoided because of high supply risks.

The life cycle analysis for indium provided in the course of the last application claims the need to reflect overall environmental benefits of substituting Lead in a specific application by Indium.

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[5] OEKO Institut report for 7th Adaption to scientific and technical progress of exemptions; section for entry 8e p. 19 f. (Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020) Oeko Institut Freiburg 2015.
[6] same report, section on entry 8j p.81
[7] same report, section on entry 8j p.81

9. Challenges for future developments

Activities for future automated assisted driving push ideas to integrate sensor and camera functions in windshields or other laminated glazing structures. E-driven vehicles have no waste heat from combustion processes. So as yet outlined above, future vehicle may require even more efficient integrated electric de-icing systems for light weight front screens instead of conventional heating systems with a fan and hot air. The heat generated by the engine is not available anymore for E-vehicles.

There might be an interference between Lead-free soldering of laminated glass components and future technical progress for more safety and for weight reduction targets (thinner glass, function integration). And especially electric vehicles are requiring thinner glazing for weight reduction and higher efficient embedded electrical functions. These two requirements being already challenging today with Lead solders.

Furthermore, with proposal COM (2018) 286 [8] from 17.05.2018 on General Safety Regulation the Commission is mandating integration of advanced safety features that could contribute to reduce further road fatalities and injuries. The integration of intelligent speed assistance, lane-keeping systems, emergency stop signals or attention monitoring systems will also address challenges for implementation of reliable electrical contacts of laminated glass. As of today, it is open, if this can be realized with Lead-free solders, or the use of Lead-containing solders is essential. It is clear that use of Lead-free solder is the default for the new developments.

10. Conclusion and Proposal

The overall thermomechanical stress level for Lead-free soldered laminated glazing structures and sometimes also for Lead-based solder soldered laminated glazing structures is on or above the level for the breaking tension of the glass. A sufficient safety margin to ensure reliable mass production and long-lasting component function is still missing. Further R&D is necessary to enable Lead-free soldering of laminated glass in mass production for all applications. Automotive industry therefore applies to extent the exemption by 4 years until 1.1.2024.

Proposal for a revised entry 8j:

< Materials and components>

- Lead in solders for soldering of laminated glazing, except embedded solder contacts in the intermediate polymer

< Scope and expiry date of the exemption>

- Vehicles type-approved before 1 January 2024 and spare parts for these vehicles

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018PC0286 17.05.2018; Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018

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[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on the 2017 list of Critical Raw Materials for the EU ;13.9.2017 COM(2017) 490 final https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF ; last accessed 2017/09/15

[4] ZARMAI M.T., EKERE, N.N., ODUOZA C. F. & AMALU E. H.*: Effect of Intermetallic compounds on the thermo-mechanical reliability of lead-free solder joints in solar cell assembly;* School of Engineering, Faculty of Science and Engineering, University of Wolverhampton, International Journal of Mechanical Engineering (IJME) ISSN(P): 2319-2240; ISSN(E): 2319-2259 Vol. 4, Issue 6, Oct - Nov 2015, 29-38 © IASET

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[6] WIESE, Steffen: *Verformung und Schädigung von Werkstoffen der Aufbau –und Verbindungstechnik; Das Verhalten im Mikrobereich;* Springer Verlag Heidelberg 2010

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[8] Glas Trösch brochure: N.N. *Glas und Praxis –Kompetentes Bauen und Konstruieren mit Glas*. © Copyright 2012 by Glas Trösch AG, Bützberg;

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[18] http://www.iswa.uni-stuttgart.de/ch/forschung/arbeitsbereich_ch/aktuelle_forschung/pv_schadstoffe.html, last accessed 2017/09/19

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A: Annex technical data solder, materials

Material properties

α	Linear coefficient of thermal expansion
E	Young´s Modulus [N/m²]
σ	Stress [N/m²]
ε	Strain or deformation
ΔT	Temperature difference
l_0	Initial length [m]
Δl	Elongation [m]
$\sigma_{\Delta T}$	Stress due to change in temperature
F	Force [N]
A	Area [m²]

Strain or deformation for an unrestricted expansion

Strain $\varepsilon = (l_0 - l_1) / l_0 = \Delta l / l_0$ (1)

Stress $\sigma = F/A$ (2)

E = F / a * A* (3)

Restricted expansion

Stress $\sigma_{\Delta T} = \varepsilon * E = E * (\Delta T * \alpha)$ (4)

$E = \sigma / (\alpha * \Delta T)$ (5)

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*Contact area busbar typically 3 *5 mm²*

Material properties metals

Metal	CTE 10^{-6} K^{-1}	Source	E-Module [GPa] @RT	Source	ν	Source
Cu	17	Wiese Tab 2.6	119	Wiese Tab 2.6	0,35	Wiese Tab 2.6
Au	14,3	Wiese Tab 2.6	79	Wiese Tab 2.6	0,42	Wiese Tab 2.6
Pb						
(Si)	2,5	Wiese Tab 2.6	148	Wiese Tab 2.6	0,18	Wiese Tab 2.6

RT room temperature

ν Poisson figure

Material properties glass

Property	Values
Density	2,498 ± 1 kg/m^3
Young's modulus	73 ± 1 GN/m^2
Poisson's ratio	0.22 ± 0.01
Specific heat	770 ± 5 J/kg K
Thermal conductivity	1.0 ± 0.1 W/mK
Coefficient of linear thermal expansion (mean value 20 -100 ºC)	77.5 (± 1.0) x 10^{-7} per K

Source: glass producer

Material properties solders

Solder melting points and homologous temperature

Solder alloy	Melting point [°C], T_m	Sources [9]*)	Homologous temperature
5Sn-Pb95	307	Rfcafe.com /NIST	0,51
96,5 Sn-3,0Ag-0,5Cu	219	Rfcafe.com /NIST	0,60
50In-50Pb	209	Rfcafe.com /NIST	0,62
45Sn-55Pb	204	Rfcafe.com /NIST	0,62
55Sn-45Pb	193	Rfcafe.com /NIST	0,64
60Sn-40Pb	186	Rfcafe.com /NIST	0,65
63Sn-Pb37	183	Rfcafe.com /NIST	0,65
62Sn-36Pb-2Ag	179	Rfcafe.com /NIST	0,66
97In-3Ag	143	Rfcafe.com /NIST	0,72
43Sn-57Bi	139	Rfcafe.com /NIST	0,72
48Sn-52In	118	Rfcafe.com /NIST	0,76
In65Sn30Ag4.5Cu0.5	109 -124	Aimalloys	> 0,75

Homologous temperature T_h ($T_h = T/T_m$) at room temperature; creeping under stress is observed at homologous temperatures of at least 0.3 to 0.4. Ordinary calculation principles of material mechanics are limited to homogenous temperatures figures up to 0.4. Above calculation becomes more complex. (see also previous consultations)

[9] *) http://www.rfcafe.com/references/electrical/solder.htm last accessed 18.9.2017 and further solder data from http://www.farnell.com/datasheets/315929.pdf last accessed 18.9.2017 and http://www.aimalloys.com/sites/default/files/in65_alloy_tds.pdf last accessed 18.9.2017 for In alloy

Property	Units	Sn60Pb40	SnAg3.8Cu0.7	Source
Density	g/mm^3	8.5	7.5	[2]
Melting point	Deg C	183	217	[2]
CTE	$x\ 10^{-6}$	23.9	Similar (23.5]	[2]
Vol change on freezing	%	2.4	Larger (2.7)	[2]
Specific heat	$J\ kg^{-1}\ K^{-1}$	150	Higher (226)	[2]
Thermal Conductivity	$W\ m^{-1}\ K^{-1}$	50	Higher (73.2)	[2]
Young´s Modulus	GPa	30	Higher (48)	[6]

Solder	CTE $10^{-6}\ K^{-1}$	Source	E-Module [GPa] @RT	Source	ν	
95,5Sn-3,8Ag-0,7Cu			69,7	Wiese Tab 8.27	0,31	Wiese Tab 8.27
95,5Sn-3,8Ag-0,7Cu			58,0	Wiese Tab 8.26		
96.5Sn-3Ag-0,5 Cu			69,3	Wiese Tab 8.27	0,29	Wiese Tab 8.27
Sn63Pb37	26	Wiese Tab 2.6	29	Wiese Tab 2.6	0,36	Wiese Tab 2.6

Mechanical Properties Solders

source: PhD thesis Lambracht, P.: Materialwissenschaftliche Aspekte bei der Entwicklung bleifreier Lote TU Darmstadt Fachbereich Material-und Geowissenschaften, 2002

Legierung	E-Modul [GPa]	Scherfestigkeit [MPa]	Lit. Referenz
In-48Sn	23,6	10,4	Tab 2.2 S.8
Sn40Pb	39	18	Tab 2.2 S.8
Sn-3,5Ag	50	26,8 ; 36,6	Tab 2.2 S.8

Mechanical Properties Solders

source: Siewert, T. ; Liu,S, ; Smith,D.; Madeni, J.C.; Database for Solder Properties with Emphasis on New Lead-free solders; NIST (National Institute of Standards and Technology) & School of Mines "Properties of Lead-free solders Release 4.0 Colorado Febr. 11 2002

Solder	Melt. point °C	UTS *)	Elongation [%]	Shear strength	Young´s Modulus
Sn-37 Pb	*183*	*31-46*	*35 -176*	*28,4*	*35*
Sn-3,5 Ag	*221*	*55*	*35*	*32,1*	*56*

*) UTS Ultimate Tensile Strength