Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

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Item 2 (f) of the provisional agenda

Recommendations made by the Sub-Committee on its fifty-first, fifty-second and fifty-third sessions and pending issues: miscellaneous pending issues

Fibre-reinforced plastics (FRP) tanks

Transmitted by the expert from the Germany

1. German experts have elaborated a contribution to the discussion within the informal working group on FRP tanks. The informal working group agreed to use the proposals in the Annexes of the proposal by the Russian Federation (ST/SG/AC.10/C.3/2017/40) as a basis for establishing the requirements to be met by FRP tanks. In revising the draft text, the requirement established by the informal working group to elaborate the new chapter 6.9 required for FRP tanks to complement section 6.7.2 was taken account of. The suitable format of the chapter (final, separate chapter 6.9 or additional provisions in chapter 6.9) should, however, be discussed again.

2. Regarding substance, the following key amendments are proposed:

(a) integration of an additional safety factor for the calculation of wall thicknesses, based on the tank instructions (T code);

(b) requirements as regards the integration of metal components into FRP shells;

(c) enhancement of the calculation methods for wall thickness and joints;

(d) implementation of rules for the calculation as well as inspection and testing of the joints between shell and frame;

(e) extension of the method to verify the chemical resistance for liners and equipment; integration of additional verification methods (spark test) to check the quality of welds for welded thermoplastics liners;

(f) requirements to consider general manufacturing techniques for FRP tanks.

3. The proposals are presented in two annexes. Annex I is a draft text based on the original proposal in document ST/SG/AC.10/C.3/2017/40 with the modifications made by the Russian Federation in red (data file named “Nota ecosos-FRP-eng chapter 6.9 with sections 6.9.1 and 6.9.2 DD 06.07.10.” distributed among the members of the informal working group on 6 July 2018). The amendments proposed by Germany are in blue. The Appendix contains the German proposals for amendments in a table with comments.

Annex I

Proposed amendments to 4.2.5.2.6 of the Model Regulations on the Transport of Dangerous Goods

Amend the portable tank instructions in 4.2.5.2.6 as follows:

(Proposed changes shown in **additions**/~~deletions~~)

4.2.5.2.6. ***Portable tank instructions***

Portable tank instructions specify the requirements applicable to a portable tank when used for the transport of specific substances. Portable tank instructions T1 to T22 specify the applicable minimum test pressure, the minimum shell thickness (in mm reference steel) **or the minimum shell thickness of Fibre-Reinforced Plastics (FRP),** and the pressure relief and bottom-opening provisions.

T1–T22 **PORTABLE TANK INSTRUCTIONS** **T1–T22**

These portable tank instructions apply to liquid and solid substances of class 1 and classes 3 to 9. The general provisions of section 4.2.1 and the requirements of section 6.7.2 shall be met.

The instructions for portable tank with FRP shells apply to liquid substances of classes 3, 5.1, 6.1, 6.2, 8 and 9.

Additionally, the requirements of section 6.9 shall apply to the portable tanks with FRP shells.

Portable tank instructions	Minimum test pressure (bar)	Minimum shell thickness[c] (in mm – reference steel) (see6.7.2.4)	Pressure relief provisions [a] (see 6.7.2.8)	Bottom opening provisions[b] (see6.7.2.6)
T1	1,5	See6.7.2.4.2	Normal	See6.7.2.6.2
T2	1,5	See6.7.2.4.2	Normal	See6.7.2.6.3
T3	2,65	See6.7.2.4.2	Normal	See6.7.2.6.2
T4	2,65	See6.7.2.4.2	Normal	See6.7.2.6.3
T5	2,65	See6.7.2.4.2	See 6.7.2.8.3	Not allowed
T6	4	See6.7.2.4.2	Normal	See6.7.2.6.2
T7	4	See6.7.2.4.2	Normal	See6.7.2.6.3
T8	4	See6.7.2.4.2	Normal	Not allowed
T9	4	6 mm	Normal	Not allowed
T10	4	6 mm	See6.7.2.8.3	Not allowed
T11	6	See6.7.2.4.2	Normal	See6.7.2.6.3
T12	6	See6.7.2.4.2	See6.7.2.8.3	See6.7.2.6.3
T13	6	6 mm	Normal	Not allowed
T14	6	6 mm	See6.7.2.8.3	Not allowed
T15	10	See6.7.2.4.2	Normal	See6.7.2.6.3
T16	10	See6.7.2.4.2	See6.7.2.8.3	See6.7.2.6.3
T17	10	6 mm	Normal	See6.7.2.6.3
T18	10	6 mm	See6.7.2.8.3	See6.7.2.6.3
T19	10	6 mm	See6.7.2.8.3	Not allowed
T20	10	8 mm	See6.7.2.8.3	Not allowed
T21	10	10 mm	Normal	Not allowed
T22	10	10 mm	See6.7.2.8.3	Not allowed

[a] *When the word "Normal" is indicated, all the requirements of 6.7.2.8 apply except for 6.7.2.8.3.*

[b] *When this column indicates "Not allowed" bottom openings are not permitted when the substance to be transported is a liquid (see 6.7.2.6.1). When the substance to be transported is a solid at all temperatures encountered under normal conditions of transport, bottom openings conforming to the requirements of 6.7.2.6.2 are authorized.*

[c] ***For Fibre-Reinforced Plastics (FRP) shells, the minimum thickness shall be determined as per the requirements of 6.9.2.4.***

Annex II

Proposed amendments to the Model Regulations on the Transport of Dangerous Goods, Chapter 6.7
Add a new note at the beginning of Chapter 6.7 to read as follows:
(Proposed changes shown in **additions**/~~deletions~~)

NOTE: *The requirements of this Chapter also apply to portable tanks with shells made of Fibre-Reinforced Plastics (FRP) to the extent indicated in Chapter 6.9.*

Annex III

Proposed new Chapter 6.9 for the Model Regulations on the Transport of Dangerous goods

After the existing Chapter 6.8, add the new Chapter 6.9 as follows:

CHAPTER 6.9

PROVISIONS FOR THE DESIGN, CONSTRUCTION, INSPECTION AND TESTING OF PORTABLE TANKS WITH SHELLS MADE OF FIBRE REINFORCED PLASTICS (FPR) MATERIALS ~~INTENDED FOR THE TRANSPORT OF SUBSTANCES OF CLASSES OR DIVISIONS 3, 5.1, 6.1, 6.2, 8 AND 9~~

6.9.1 _Application and General Provisions

6.9.1.1 The provisions of this Chapter apply to portable tanks with FRP shell intended for the transport of dangerous goods of classes or divisions 3, 5.1, 6.1, 6.2, 8 and 9, section 6.9.2, [as well as non-refrigerated liquefied gases of class 2 with MAWP not exceeding 20.0 bar, section 6.9.3 – (Reserved)], by all modes of transport. In addition to the provisions of this Chapter, unless otherwise specified, the applicable provisions of the International Convention for Safe Containers (CSC) 1972, as amended, shall be fulfilled by any multimodal portable tank with FRP shell which meets the definition of a "container" within the terms of that Convention.

6.9.1.2 The provisions of this Chapter do not apply to portable tanks that are handled in open seas [, nor to portable tanks transported as per portable tank instruction T50 with MAWP over 20.0 bar (provisions of 6.7.3) or T75 (provisions of 6.7.4) nor to multiple-element gas containers (MEGCs) (provisions of 6.7.5).]

6.9.1.3 The provisions of Chapter 4.2~~,~~ and section 6.7.2 [**and section 6.7.3**] apply to ~~portable tanks with FRP shells~~ *FRP portable tank* shells, except for those concerning the use of metal materials for the construction of a ~~portable tank~~ *portable tank* shell and additional requirements stated in this Chapter.

6.9.1.4 In recognition of scientific and technological advances, the technical provisions of this Chapter may be varied by alternative arrangements. These alternative arrangements shall offer a level of safety not less than that given by the provisions of this Chapter with respect to compatibility with substances transported and the ability of the *FRP portable tanks* ~~portable tank~~ to withstand impact, loading and fire conditions. For international transport, alternative arrangement *FRP portable tanks* ~~portable tanks with FRP shells~~ shall be approved by the applicable competent authorities.

6.9.2 Provisions for the design, construction, inspection and testing of portable tanks with shells made of Fibre Reinforced Plastics (FPR) materials intended for the transport of substances of classes 3, 5.1, 6.1, 6.2, 8 and 9

6.9.2.1 Definitions

For the purposes of this section, the definitions of 6.7.2.1 apply except for definitions related to metal materials ("Fine grain steel", "Mild steel" and "Reference steel") for the construction of the shell of a portable tank.

Additionally, the following definitions shall apply to *FRP portable tanks* ~~portable tanks with FRP shell~~:

~~*Fibre Reinforced Plastic (FRP)* means structural material consisting of reinforcing fibres (filler) and plastic binder (matrix) formed directly in the process of tank shell manufacture;~~

Fibre-Reinforced Plastic (FRP) means structural material consisting of fibrous and/or particulate reinforcement contained within a thermoset or thermoplastic polymer (matrix);

FRP ~~*components*~~ *constituents* means ~~reinforcing~~ reinforcement fibres and/or particles ~~(filler)~~, thermoset or thermoplastic polymer (matrix), adhesives, and ~~aggregates~~ additives;

Mat~~e~~ means a fibre reinforcement made of random chopped or twisted fibres bonded together as sheets of various length and thickness;

Veil means a thin mat~~e~~, ~~as usual of 0.18–0.51 mm thickness~~ with high absorbency used in FRP product plies where polymeric matrix surplus fraction content is required (surface evenness, chemical resistance, leakage-proof, etc.);

Roving means a long and narrow bundle of ~~reinforced~~ reinforcement fibres;

~~*Chemically resistant layer*~~ *Liner* means a layer~~s~~ on the inner surface of an FRP shell ~~ensuring protection of the shell against transported~~ preventing contact with the chemical substances being transported;

~~*Liner* means a closed part consisting of a chemically resistant layer and supporting FRP layers;~~

Structural layers means ~~a unidirectional or bidirectional~~ FRP layers of a tank shell designed ~~for taking of operational and testing loads~~ to sustain the design loads;

Fire-protection layer means a layer on the outer surface of a tank shell ensuring its protection against external fire;

~~*FRP shell* means a closed part of cylindrical shape with an interior volume intended for storage and transport of liquid chemical substances~~;

~~*FRP tank* means a tank with FRP shell and service equipment, safety relief devices and other installed equipment;~~

Filament winding means a process for constructing FRP structures in which continuous reinforcements (filament, tape, or other), either previously impregnated with a matrix material or impregnated during winding, are placed over a rotating ~~and removable~~ form or mandrel ~~in a previously prescribed way to meet certain stress conditions~~. Generally, the shape is a surface of revolution which ~~and~~ may ~~or may not~~ include ~~end closures~~ heads;

~~*Vacuum infusion* means an FRP construction method by which of impregnation of dry fillers reinforcement is, preliminary manually or automotive placed under vacuum bag, and impregnated with liquid resin, by application of vacuum pressure;~~

~~*Resin transfer moulding* means an FRP construction method in airproof sealed moulds using excess pressure for fibre impregnation;~~

Resin infusion means an FRP construction method by which dry reinforcement is placed into a matched mould, single sided mould with vacuum bag, or otherwise, and liquid resin is supplied to the part through the use of external applied pressure at the inlet and/or application of full or partial vacuum pressure at the vent.

~~*Contact moulding*~~ *Hand layup* means a process for moulding reinforced plastics in which reinforcement and resin are placed on a mould. Cure either is at room temperature or by heat application using a thermoset resin ~~catalyst promoter~~ system ~~or by heat in an oven, and no additional pressure is used~~;

Design allowables means statistically determined material~~s~~ strength or maximum strain, ~~property values~~ derived from coupon- and/or parallel shell- and/or shell-sample test data, divided by ~~considering regulation requirements for~~ mandated safety factors, applied to ~~FRP shells~~ structural equipment and tank shell;

Coupon-sample means a FRP specimen constructed and tested in accordance with national and / or international standards to determine design allowables;

~~*Witness* *Parallel shell*~~*-sample* means an FRP specimen, which must be representative of the tank shell, ~~constructed in parallel to the shell construction~~ if it is not possible to use cut-outs from the shell itself;

~~*Representative* *Shell*~~*-sample* means a sample cut out from the shell.

6.9.2.2 General design and construction provisions

~~**6.9.2.2.1** Provisions of 6.7.1 and 6.7.2.2 apply to FRP portable tanks with FRP shell, if related to FRP shell except 6.7.2.2.1, 6.7.2.2.2.2, 6.7.2.2.2.3, 6.7.2.2.5, 6.7.2.2.6, 6.7.2.2.9.1, 6.7.2.2.13 (if related to FRP shell), 6.7.2.2.14 and 6.7.2.2.17 related to metal material tank shell design.~~

6.9.2.2.1 Provisions of 6.7.1 and 6.7.2.2 apply to FRP portable tanks. For areas of the shell that are made from FRP, the following provisions of Chapter 6.7 are exempt: 6.7.2.2.1, 6.7.2.2.9.1, 6.7.2.2.13, 6.7.2.2.14 and 6.7.2.2.17.

6.9.2.2.2 The following provisions apply in addition to 6.7.2.2:

6.9.2.2.2.1 FRP shells shall be designed and constructed by companies, having the Quality Management System recognized by the competent authority and as far as applicable in accordance with the provisions of a pressure vessel code, to which the FRP shell is designed, recognized by the competent authority considering national and/or international standards.

6.9.2.2.2.2 FRP shell shall have an ~~rigid~~ appropriate connection with structural elements of the portable tank frame. FRP shell supports and attachments to the frame shell shall cause no ~~dangerous~~ local stress concentrations exceeding the design allowables of ~~in~~ the shell structure in accordance with the provisions stated in this Chapter for all operating and test conditions.

6.9.2.2.2.3 No heating elements are allowed for use for FRP tanks.

~~**6.9.2.2.2.4** When construction FRP shell, components and materials compatible with transported goods in the design temperature range of -40°C to +50°C shall be used.~~

~~For portable FRP tanks handled in more severe climatic conditions the design temperature range shall be agreed with the competent authority.~~

6.9.2.2.2.4 Shells shall be made of suitable materials, which shall be compatible with the substances to be carried in a service temperature range of -40°C to +50°C, unless temperature ranges are specified for specific climactic or operating conditions by the competent authority of the country where the transport operation is being performed.

6.9.2.2.2.5 Shells shall consist of the following three elements:

- Internal ~~chemically resistant~~ liner,
- Structural layer,
- External layer.

6.9.2.2.2.5.1 The internal liner is the inner shell wall zone designed as the primary barrier to provide for the long-term chemical resistance in relation to the substances to be carried, to prevent any dangerous reaction with the contents or the formation of dangerous compounds and any substantial weakening of the structural layer owing to the diffusion of products through the internal liner.

The internal liner may ~~either~~ be an FRP liner, ~~or~~ a thermoplastic liner, or other appropriate coating as agreed with the competent authority.

6.9.2.2.2.5.1.1 FRP liners

FRP liners shall consist of the following two components:

- Surface layer ("gel-coat"): adequate resin rich surface layer, reinforced with a veil, compatible with the resin and contents. This layer shall have a fibre mass content of not more than 30% and have a thickness between 0.25 and 0.60 mm
- Strengthening layer(s): layer or several layers with a minimum thickness of 2 mm, containing a minimum of 900 g/m² of glass mat or chopped fibres with a mass content in glass of not less than 30% unless equivalent safety is demonstrated for a lower glass content.

6.9.2.2.2.5.1.2 Thermoplastic liners

Thermoplastic liners shall ~~consist of thermoplastic sheet material~~ be as referred to in **6.9.2.2.2.6.3**. If the liner consists of thermoplastic sheets, they shall be welded together in the required shape, using a qualified welding procedure and personnel. Furthermore, welded liners shall have a layer of electrically conductive media placed against the non-liquid contact surface of the welds to facilitate spark testing. ~~to which the structural layers are bonded.~~ Durable bonding between liners and the structural layer shall be achieved by the use of an appropriate ~~adhesive~~ method.

6.9.2.2.2.5.2 The structural layer of the shell is the zone specially designed to withstand the design loads according to 6.7.2.2.12, 6.9.2.2.2.2, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** ~~to withstand the mechanical stresses~~. This part normally consists of several fibre-reinforced layers in determined orientations.

6.9.2.2.2.5.3 The external layer is the part of the shell which is directly exposed to the atmosphere. It shall consist of a resin rich layer with a thickness of at least 0.2 mm. ~~For a thickness larger than 0.5 mm, a mat shall be used. This layer shall have a mass content in glass of less than 30% and shall be capable.~~

6.9.2.2.2.6 Raw materials and components:

6.9.2.2.2.6.1 Resins. The processing of the resin mixture shall be carried out in strict compliance with the recommendations of the supplier. This concerns mainly the use of hardeners, initiators and accelerators. These resins can be:

- Unsaturated polyester resins;
- Vinyl ester resins;
- Epoxy resins;
- Phenolic resins.

The heat distortion temperature (HDT) of the resin, determined in accordance with ISO 75-1:~~1993~~2013 and ISO 75-2:2013 shall be at least 20°C higher than the maximum service temperature of the tank as defined in 6.9.2.2.4, but shall in any case not be lower than 70°C.

6.9.2.2.2.6.2 Reinforcement fibres. The reinforcement material of the structural layers shall be a suitable grade of fibres such as glass fibres of type E or ECR according to ISO 2078:1993 + Amendment 1:2015, carbon fibres, and aramid. For the internal surface liner, glass fibres of type C or ECR according to ISO 2078:1993 + Amendment 1:2015 may be used. Thermoplastic veils may only be used for the internal liner when their compatibility with the intended contents has been demonstrated.

6.9.2.2.2.6.3 Thermoplastic liner material. Thermoplastic liners, such as unplastified polyvinyl chloride (PVC-U), polyethylene (PE), polypropylene (PP), polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), etc. may be used as lining materials.

6.9.2.2.2.6.4 Additives. Additives necessary for the treatment of the resin, such as catalysts, accelerators, hardeners and thixotropic substances as well as materials used to improve the tank, such as fillers, colours, pigments etc. shall not cause weakening of the material, taking into account lifetime and temperature expectancy of the design.

6.9.2.2.2.7 FRP shells, their attachments and their service and structural equipment shall be designed to withstand the loads mentioned in 6.7.2.2.12, 6.9.2.2.2.2, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** without loss of contents (other than quantities of gas escaping through any degassing vents) during the design lifetime.

6.9.2.2.2.8 Special requirements for the carriage of substances with a flash-point of not more than 60°C

FRP tanks used for the carriage of flammable liquids of Class 3 with a flash-point of not more than 60°C shall be constructed so as to ensure the elimination of static electricity from the various component parts so as to avoid the accumulation of dangerous charges.

6.9.2.2.2.8.1 The electrical surface resistance of the inside and outside of the shell as established by measurements shall not be higher than 10^9 ohms. This may be achieved by

the use of additives in the resin or interlaminate conducting sheets, such as metal or carbon network.

6.9.2.2.2.8.2 The discharge resistance to earth as established by measurements shall not be higher than 10^7 ohms.

6.9.2.2.2.8.3 All components of the shell shall be electrically connected to each other and to the metal parts of the service and structural equipment of the tank and to the vehicle. The electrical resistance between components and equipment in contact with each other shall not exceed 10 ohms.

6.9.2.2.2.8.4 The electrical surface-resistance and discharge resistance shall be measured initially on each manufactured tank or a specimen of the shell in accordance with the procedure recognized by the competent authority. In the event of damage to the tank shell wall, requiring repair, the electrical resistance shall be re-measured.

6.9.2.2.2.9 The tank shall be designed to withstand, without significant leakage, the effects of a full engulfment in fire for 30 minutes as specified by the test requirements in **6.9.2.7.2.3**. Testing may be waived with the agreement of the competent authority, where sufficient proof can be provided by tests with comparable tank designs.

6.9.2.2.2.10 Fabrication process for FRP shells:

6.9.2.2.2.10.1 Filament winding, ~~contact moulding~~ hand layup and ~~vacuum~~ resin infusion, or other appropriate composite production processes shall be used for fabrication of FRP shells.

6.9.2.2.2.10.1.1 The weight of the fibre reinforcement shall conform to that set forth in the procedure specification with a tolerance of +10% and −0%. One or more of the fibre types specified in **6.9.2.2.2.6.2** and in the procedure specification shall be used for reinforcement of shells.

6.9.2.2.2.10.1.2 The resin system shall be one of the resin systems specified in **6.9.2.2.2.6.1**. No filler, pigment, or dye additions shall be used which will interfere with the natural colour of the resin except as permitted by the procedure specification.

~~**6.9.2.2.2.10.2** Filament winding process. Shell structural layers shall be fabricated by winding of unidirectional impregnated fibre strands.~~

~~**6.9.2.2.2.10.2.1** Specific winding patterns for the continuous fibre strands shall be used as defined in the qualified procedure specification. Any winding pattern which places the filaments in the desired orientation and is designated in the procedure specification may be used. The patterns shall be so arranged that the stressed filaments are aligned to resist the principal stresses which result from internal pressure and other loadings specified in in 6.7.2.2.12, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6**.~~

~~**6.9.2.2.2.10.2.2** Tension on the strands of filaments during the winding operation shall be controlled to assure uniformly stressed filaments in the composite shell.~~

~~**6.9.2.2.2.10.2.3** The speed of winding shall be limited only by the ability to meet the tensioning requirements, to conform to the specified winding pattern, and to assure adequate resin impregnation.~~

~~**6.9.2.2.2.10.2.4** The bandwidth and spacing shall conform to those specified in the qualified procedure specification.~~

~~**6.9.2.2.2.10.3** Contact moulding process. The shell structure shall consist of random short length (25 to 100 mm) fibre filaments and roving (or biaxial fabric, singular or in combination) in a resin matrix.~~

~~**6.9.2.2.2.10.3.1** Flat mats for cylindrical reinforcement shall be laid up as separate layers and overlapped in a staggered pattern. Resin shall be applied to each layer in such a manner as to wet out completely.~~

~~**6.9.2.2.2.10.4** Vacuum infusion process. Vacuum infusion process shall be used for fabrication of elliptical or hemispherical end caps of the shell.~~

6.9.2.3 Design criteria

6.9.2.3.1 FRP shells shall have predominantly ~~a~~ circular cross section and shall be of a design capable of being stress-analysed mathematically or experimentally by resistance strain gauges, or by other methods approved by the competent authority. Examples of areas where it is permitted to deviate from circular cross section include nozzles, flanges, and heads.

6.9.2.3.2 FRP shells shall be designed and constructed to withstand a hydraulic test pressure not less than 1.5 times the design pressure. Specific provisions are laid down stated for certain substances in the applicable portable tank instruction indicated in column 13 of the Dangerous Goods List and described in 4.2.5, or by a portable tank special provision indicated in column 14 of the Dangerous Goods List and described in 4.2.5.3. The minimum wall thickness of the FRP shell shall not be less than that specified in **6.9.2.4**.

6.9.2.3.3 At the specified test pressure the maximum strain in the shell shall not be greater than the elongation at fracture of the resin.

6.9.2.3.4 For internal ~~design~~ test pressure, external design pressure, static loads specified in 6.7.2.2.12 and static gravity loads caused by the contents with the maximum density specified for the design and at maximum filling degree, the membrane design stress σ in the longitudinal and circumferential directions shall not exceed the following value ~~strength criteria shall be met at any structural layer of a shell~~:

$$\sigma = \frac{R_m}{K}$$

where:

R_m = the value of the tensile strength given by taking the mean value of the test results minus twice the standard deviation of the test results. The tests shall be carried out in accordance with the requirement of ISO 527-4:1997 and ISO 527-5:2009, on not less than six samples representative of the design type and construction method;

~~$$F_1\sigma_{11} + F_2\sigma_{22} + F_{11}\sigma_{11}^2 + F_{22}\sigma_{22}^2 + F_{33}\sigma_{12}^2 + 2F_{12}\sigma_{11}\sigma_{22} < 1$$~~

~~where~~

~~$F_1 = \frac{1}{\sigma_1^+} + \frac{1}{\sigma_1^-}$; $F_2 = \frac{1}{\sigma_2^+} + \frac{1}{\sigma_2^-}$; $F_{11} = \frac{1}{\sigma_1^+\sigma_1^-}$;~~

~~$F_{22} = \frac{1}{\sigma_2^+\sigma_2^-}$; $F_{33} = \frac{1}{\sigma_{12}^2}$; $F_{12} = -1/2\sqrt{F_{11}F_{22}}$,~~

~~$\sigma_1^+ = \sigma_{1B}^+/K$; $\sigma_1^- = \sigma_{1B}^-/K$; $\sigma_2^+ = \sigma_{2B}^+/K$;~~

~~$\sigma_2^- = \sigma_{2B}^-/K$; $\bar{\sigma}_{12B} = \sigma_{12B}/K$~~

~~K – safety factor;~~

~~σ_{11} – stress applied along the fibres of a unidirectional FRP layer.~~

~~σ_{22} – stress applied across the fibres of a unidirectional FRP layer.~~

~~σ_{12} – shear applied stress of a unidirectional FRP layer.~~

~~σ_{1B}^+ – ultimate tensile strength of a lamina along the fibres determined by ISO 527-5:2009;~~

~~σ_{1B}^- – ultimate compressive strength of a lamina along the fibres determined by ISO 14126:1999;~~

~~σ_{2B}^+ – ultimate tensile strength of a lamina across the fibres determined by ISO 527-5:2009;~~

~~σ_{2B}^{-} ultimate compressive strength of a lamina across the fibres determined by ISO 14126:1999;~~

~~σ_{12B} ultimate in-plane shear strength determined by ISO 14129:1997.~~

~~The tests for determination of strength characteristics σ_1^+, σ_1^-, σ_2^+, σ_2^-, $\bar{\sigma}_{12B}$ shall be carried out, in accordance with the requirements of the mentioned ISO standards, on not less than six samples representative of the design type and construction method;~~

~~The fibre content, by weight, of the test coupon shall be between 90% and 100% of the minimum fibre content specified for the shell.~~

~~Calculation of the applied stresses σ_{11}, σ_{22} and σ_{12} in any structural layer of a FRP shell shall be carried out by a finite element method.~~

$$K = K_0 \times K_1 \times K_2 \times K_3 \times K_4 \times K_5$$

where:

K shall have a minimum value of 4 ~~for loads specified in 6.7.2.2.12, **6.9.2.3.4 and 6.9.2.3.6**~~.

$\boldsymbol{K_0}$ – a strength factor. For the general design the value for $\boldsymbol{K_0}$ shall be equal to or more than 1.5. ~~For tanks intended for the carriage of substances which require an increased safety level, the~~ The value of $\boldsymbol{K_0}$ shall be multiplied by a factor of two, unless the shell is provided with protection against damage consisting of a complete metal skeleton including longitudinal and transverse structural members;

$\boldsymbol{K_1}$ – a factor related to the deterioration in the material properties due to creep and ageing and as a result of the chemical action of the substances to be carried. It shall be determined by the formula:

$$K_1 = \frac{1}{\alpha\beta}$$

where "α" is the creep factor and "β" is the ageing factor determined in accordance with EN 978:1997 after performance of the test according to EN 977:1997. Alternatively, a conservative value of $\boldsymbol{K_1}$ = 2 may be applied for the purpose of undertaking the numerical validation exercise in 6.9.2.3.4 (this does not remove the need to perform testing to determine α and β). In order to determine α and β the initial deflection shall correspond to 2σ;

$\boldsymbol{K_2}$ – a factor related to the service temperature and the thermal properties of the resin, determined by the following equation, with a minimum value of 1: $\boldsymbol{K_2}$ = 1.25 - 0.0125 (HDT - 70) where HDT is the heat distortion temperature of the resin, in °C;

$\boldsymbol{K_3}$ - a factor related to the fatigue of the material; the value of $\boldsymbol{K_3}$ = 1.75 shall be used unless otherwise agreed with the competent authority. For the dynamic design as outlined in 6.7.2.2.12 the value of $\boldsymbol{K_3}$ = 1.1 shall be used;

$\mathbf{K_4}$ – a factor related to curing and has the following values:
- 1.1 where curing is carried out in accordance with an approved and documented process;
- 1.5 in other cases.

$\mathbf{K_5}$ – a factor related to the portable tank instruction from 4.2.5.2.6:
- 1.0 for T1 to T19;
- 1.33 for T20;
- 1.67 for T21 to T22.

A design validation exercise using numerical analysis and a suitable composite failure criteria is to be undertaken to verify that the plies in the tank shell are below the allowables. Suitable composite failure criteria include, but are not limited to, Tsai-Wu, Tsai-Hill, Hashin, Strain Invariant Failure Theory, Maximum Strain, or Maximum Stress. Other relations for the strength criteria ~~is~~ are allowed upon agreement with the competent

authority. The results of this design validation exercise are to be submitted to the competent authority.

The allowables are to be determined using experiments to derive parameters required by the chosen failure criteria combined with factor of safety K, and the maximum elongation strain criteria prescribed in section 6.9.2.3.5. The analysis of joints is to be undertaken in accordance with the allowables determined under section 6.9.2.3.7. Buckling is to be considered in accordance with 6.9.2.3.7. Design of openings and metallic inclusions is to be considered in accordance with 6.9.2.3.8.

6.9.2.3.5 At any of the stresses as defined in 6.7.2.2.12 and **6.9.2.3.4**, the resulting elongation in any direction shall not exceed 0.2% or one tenth of the elongation at fracture of the resin determined by ISO 527-1:2012, whichever is lower.

6.9.2.3.6 For the external design pressure the minimum safety factor for buckling of the shell shall be not less than 5.

6.9.2.3.7 The adhesive bondlines and/or overlay laminates used in the joints, including the end joints, connection between the equipment and shell, the joints of the surge plates and the partitions with the shell shall be capable of withstanding the loads of 6.7.2.2.12, 6.9.2.2.2.2, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6**. In order to avoid concentrations of stresses in the overlay lamination, the applied taper shall not be steeper than 1:6. The shear strength between the overlay laminate and the tank components to which it is bonded shall not be less than:

$$\tau = \gamma \frac{Q}{l} \leq \frac{\tau_R}{K}$$

where:

$\boldsymbol{\tau_R}$ - is the ~~bending shear~~ interlaminar shear strength according to ~~EN~~ ISO ~~14125:1998 (three points method)~~ 14130:1997 ~~with a minimum of $\boldsymbol{\tau_R}$ = 10 N/mm^2, if no measured values are available~~;

Q – load per unit width of the interconnection;

K – safety factor determined as per **6.9.2.3.4**;

~~***K*** **is the factor calculated in accordance with 6.9.4.4 for the static and dynamic stresses;**~~

l – is the length of the overlay laminate

γ – the notch factor relating average joint stress to peak joint stress at failure initiation location

Other calculation methods for the joints are allowed following approval with the competent authority.

6.9.2.3.8 Metallic flanges and their closures are permitted to be used in FRP shells, under design requirements of 6.7.2. Openings in the FRP shell shall be reinforced to provide at least the same safety factors against the static and dynamic stresses as specified in 6.7.2.2.12, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** as that for the shell itself. The number of openings shall be minimized. The axis ratio of oval-shaped openings shall be not more than 2.

If metallic flanges or componentry are integrated into the FRP shell using bonding, then the characterisation method stated in 6.9.2.3.7 shall apply to the joint between the metal and FRP. If the metallic flanges of componentry are fixed in an alternative fashion, e.g. threaded fastener connections, then the appropriate provisions of the relevant pressure vessel standard shall apply.

6.9.2.3.9 Check calculations of the strength of the shell shall be performed by finite element method simulating the shell layups, joints ~~of the shell layers to each other~~ within FRP shell, joints ~~of~~ between the FRP shell ~~to~~ and the container frame, ~~areas of manholes~~ and openings~~,~~

~~valves and pressure relief devices~~. Treatment of singularities shall be undertaken using an appropriate method according to the applied design code.

6.9.2.4 Minimum wall thickness of shells

6.9.2.4.1 Minimum thickness of the FRP shell ~~walls and end caps~~ shall be confirmed by check calculations of the strength of the shell considering strength requirements given in **6.9.2.3.4**.

6.9.2.4.2 Minimum thickness of the FRP shell structural layers shall be determined according ~~to~~ with **6.9.2.3.4**, however, in any case the minimum thickness of the structural layers shall be at least ~~6~~ 3 mm.

6.9.2.5 Equipment components for portable tanks with FRP shell.

6.9.2.5.1 Service equipment, bottom openings, pressure relief devices, gauging devices, supports, frameworks, lifting and tie-down attachments of portable tanks shall meet the requirements of 6.7.2.5-6.7.2.17**.** If any other metallic features are required to be integrated into the FRP shell, then the provisions of 6.9.2.3.8 shall apply.

6.9.2.6 Design approval

6.9.2.6.1 Design approval of portable FRP tanks shall be as per 6.7.2.18 provisions.

6.9.2.6.2 Additionally the following provisions shall apply to portable FRP tanks:

6.9.2.6.2.1 The prototype test report for the purpose of the design approval shall additionally include the following:

6.9.2.6.2.1.1 Results of the material tests used for FRP shell fabrication in accordance with **6.9.2.7.2.1** provisions;

6.9.2.6.2.1.2 Results of the ball drop test according to ~~EN 976-1:1997, No. 6.6 and~~ the provisions of **6.9.2.7.2.2**[proposal to delete ball drop test from regulation to be discussed with FRP working group];

6.9.2.6.2.1.3 Results the fire resistance test in accordance with provisions of **6.9.2.7.2.3**.

6.9.2.7 Inspection and testing

6.9.2.7.1 Inspection and testing of portable FRP tanks shall be carried out as per provisions of 6.7.2.19. In addition, welded thermoplastic liners shall be spark tested under a suitable standard, after pressure tests performed in accordance with the periodic inspections specified in 6.7.2.19.4.

6.9.2.7.2 Additionally the following provisions shall apply to ~~portable~~ FRP portable tanks:

6.9.2.7.2.1 Material testing:

6.9.2.7.2.1.1 Resins. Resin tensile elongation shall be determined in accordance with ISO 527-2:2012, heat distortion temperature —according to ISO 75-1:2013.

6.9.2.7.2.1.2 ~~Representative~~ Shell samples. Prior to testing all coatings shall be removed from the samples. If ~~representative~~ shell samples ~~cut off from the shell is impossible~~ are not possible ~~the~~ then ~~witness~~ parallel-shell samples may be used. The tests shall cover:

(a) Thickness of the laminates of the central shell wall and the ends;

(b) Mass content and composition of ~~glass~~ composite reinforcement by ISO 1172:1996, orientation and arrangement of reinforcement layers;

(c) Tensile strength, elongation at fracture and modulus of elasticity according to ISO 527-4:1997 or ISO 527-5:2009 for the samples cut off in circumferential and longitudinal directions of the shell. For areas of the FRP shell other than the cylinder, tests shall be performed on representative laminates in accordance with ISO 527-4:1997 or ISO 527-5:2009, to permit evaluation of the suitability of safety factor (K);

(d) Bending ~~strength and~~ deflection established by the bending creep test according to ISO 14125:1998 for a period of 1000 hours using a sample with a minimum width of 50

mm and a support distance of at least 20 times the wall thickness. In addition, the creep factor α and the ageing factor β shall be determined by this test and according to EN 978:1997.

(e) The interlaminar ~~te~~ shear strength of the joints shall be measured by testing representative samples in ~~the tensile test~~ according to ~~EN~~ ISO 14130:1997.

6.9.2.7.2.1.3 Creep factor α and ageing factor β are determined according to EN 978:1997 and EN 977:1998 for subsequent calculation of material deterioration factor K_1 due to creep and ageing (**6.9.2.3.4**).

6.9.2.7.2.1.4 The chemical compatibility of the ~~shell~~ liner and chemical contact surfaces of service equipment with the substances to be carried shall be demonstrated by one of the following methods with the agreement of the competent authority. This demonstration shall account for all aspects of the compatibility of the materials of the shell and its equipment with the substances to be carried, including chemical deterioration of the shell, initiation of critical reactions of the contents and dangerous reactions between both.

(a) In order to establish any deterioration of the shell, representative samples taken from the shell, including any internal liners with welds, shall be subjected to the chemical compatibility test according to EN 977:1997 for a period of 1 000 hours at 50°C. Compared with a virgin sample, the loss of strength and elasticity modulus measured by the bending test according to EN 978:1997 shall not exceed 25%. Cracks, bubbles, pitting effects as well as separation of layers and liners and roughness shall not be acceptable.

(b) Certified and documented data of positive experiences on the compatibility of filling substances in question with the materials of the shell with which they come into contact at given temperatures, times and other relevant service conditions.

(c) Technical data published in relevant literature, standards or other sources, acceptable to the competent authority.

~~(c)~~ (d) Upon agreement with the competent authority other methods of chemical compatibility verification may be used.

6.9.2.7.2.2 Ball drop test as per EN 976-1:1997.

The prototype shall be subjected to the ball drop test according to EN 976-1:1997, No. 6.6. No visible damage inside or outside the tank shall occur.

6.9.2.7.2.3 Fire resistance test.

6.9.2.7.2.3.1 ~~The~~ A representative prototype tank with its service and structural equipment in place and filled to 80% of its maximum capacity with water, shall be exposed to a full engulfment in fire for 30 minutes, caused by an open heating oil pool fire or any other type of fire ~~with the same effect~~ which is able to supply a minimum heat load of 110 kW/m^2 as per the requirement of Section 6.7.2.2.1. For this test, service equipment may be replaced by other items if necessary. The dimensions of the pool shall exceed those of the tank by at least 50 cm to each side and the distance between fuel level and tank shall be between 50 cm and 80 cm. The rest of the tank below liquid level, including openings and closures, shall remain leakproof except for drips.

6.9.2.8 Marking

6.9.2.8.1 The requirements of 6.7.2.20.1 apply to portable tanks with a FRP shell except those of 6.7.2.20.1 (d) (vi) and (f) (ii).

6.9.2.8.2 The information required in 6.7.2.20.1 (f)(i) shall be "Shell structural material: Fibre-reinforced Plastic", the reinforcement fibre e.g. "Reinforcement: E-glass", and resin e.g. "Resin: Vinyl Ester". ~~and the reference number of the FRP shell technical specification~~

~~**6.9.2.8.3** Upon agreement with the customer a metal plate with description of allowable operating damages of the FRP shell may be installed additionally.~~

~~**6.9.2.8.4**~~ **6.9.2.8.3** Requirements of provision 6.7.2.20.2 apply to portable tank with a FRP shell.

6.9.3 Provisions for the design, construction, inspection and testing of portable tanks with shells made of Fibre Reinforced Plastics (FPR) materials intended for the transport of substances of class 2

RESERVED”

Annex IV

Proposed change to UN Model Regulation Chapter 4.2

Section 4.2.1.1:

"This section provides general requirements applicable to the use of portable tanks for the transport of Classes 1, 3, 4, 5, 6, 7, 8 and 9. In addition to these general requirements, portable tanks shall conform to the design, construction, inspection and testing requirements detailed in 6.7.2, and for FRP portable tanks under 6.9.2."

Appendix

List of amendments proposed by Germany with comments

Country	Paragraph	Comment	Proposed text
DE	6.9.1.1	Remove reference to class 2 tanks as this is future work. We propose the deletion of the text highlighted in yellow in the "proposed text" column	The provisions of this Chapter apply to portable tanks with FRP shell intended for the transport of dangerous goods of classes or divisions 3, 5.1, 6.1, 6.2, 8 and 9, **section 6.9.2,** **[as well as non-refrigerated liquefied gases of class 2 with MAWP not exceeding 20.0 bar, section 6.9.3 – (Reserved)]**, by all modes of transport. In addition to the provisions of this Chapter, unless otherwise specified, the applicable provisions of the International Convention for Safe Containers (CSC) 1972, as amended, shall be fulfilled by any multimodal portable tank with FRP shell which meets the definition of a "container" within the terms of that Convention.
DE	6.9.1.2	Remove reference to class 2 tanks as this is future work. We propose the deletion of the text highlighted in yellow in the "proposed text" column	The provisions of this Chapter do not apply to portable tanks that are handled in open seas [, nor to portable tanks transported as per portable tank instruction T50 **with MAWP over 20.0 bar** (provisions of 6.7.3) or T75 (provisions of 6.7.4) nor to multiple-element gas containers (MEGCs) (provisions of 6.7.5).]
DE	6.9.1.3	Remove reference to class 2 tanks as this is future work. We propose the deletion of the text highlighted in yellow in the "proposed text" column. Reference should be made to "FRP portable tank(s)" as this is the formal definition of this structure.	The provisions of Chapter 4.2~~,~~ and section 6.7.2 [**and section 6.7.3**] apply to ~~portable tanks with FRP shells~~ *FRP portable tank* shells, except for those concerning the use of metal materials for the construction of a ~~portable tank~~ *portable tank* shell and additional requirements stated in this Chapter.
DE	6.9.1.4	Reference should be made to "FRP portable tank(s)" as this is the formal definition of this structure.	In recognition of scientific and technological advances, the technical provisions of this Chapter may be varied by alternative arrangements. These alternative arrangements shall offer a level of safety not less than that given by the provisions of this Chapter with respect to compatibility with substances transported and the ability of the *FRP portable tanks* ~~portable tank~~ to withstand impact, loading and fire conditions. For international transport, alternative arrangement *FRP portable tanks* ~~portable tanks with FRP shells~~ shall be approved by the applicable competent authorities.

Country	Paragraph	Comment	Proposed text
DE	6.9.2.1	Required changes to definitions to be in line with the UN Model Regulations. Changes to FRP and FRP process definitions to broaden applicability to all FRP production processes.	For the purposes of this section, the definitions of 6.7.2.1 apply except for definitions related to metal materials ("Fine grain steel", "Mild steel" and "Reference steel") for the construction of the shell of a portable tank. Additionally, the following definitions shall apply to *FRP portable tanks* ~~portable tanks with FRP shell~~: ~~*Fibre-Reinforced Plastic (FRP)* means structural material consisting of reinforcing fibres (filler) and plastic binder (matrix) formed directly in the process of tank shell manufacture;~~ *Fibre-Reinforced Plastic (FRP)* means structural material consisting of fibrous and/or particulate reinforcement contained within a thermoset or thermoplastic polymer (matrix); *FRP* ~~*components*~~ *constituents* means ~~reinforcing~~ reinforcement fibres and/or particles ~~(filler)~~, thermoset or thermoplastic polymer (matrix), adhesives, and ~~aggregates~~ additives; *Mat~~e~~* means a fibre reinforcement made of random chopped or twisted fibres bonded together as sheets of various length and thickness; *Veil* means a thin mat~~e~~, ~~as usual of 0.18-0.51 mm thickness~~ with high absorbency used in FRP product plies where polymeric matrix surplus fraction content is required (surface evenness, chemical resistance, leakage-proof, etc.); *Roving* means a long and narrow bundle of ~~reinforced~~ reinforcement fibres; ~~*Chemically resistant layer*~~ *Liner* means a layer~~s~~ on the inner surface of an FRP shell ~~ensuring protection of the shell against transported~~ preventing contact with the chemical substances being transported; ~~*Liner* means a closed part consisting of a chemically resistant layer and supporting FRP layers;~~ *Structural layers* means ~~a unidirectional or bidirectional~~ FRP layers of a tank shell designed ~~for taking of operational and testing loads~~ to sustain the design loads; *Fire-protection layer* means a layer on the outer surface of a tank shell ensuring its protection against external fire; ~~*FRP shell* means a closed part of cylindrical shape with an interior volume intended for storage and transport of liquid chemical substances~~; ~~*FRP tank* means a tank with FRP shell and service equipment, safety relief devices and other installed equipment;~~ *Filament winding* means a process for constructing FRP structures in which continuous reinforcements (filament, tape, or other), either previously impregnated with a matrix material or impregnated during winding, are placed over a rotating ~~and removable~~ form or mandrel ~~in a previously prescribed way to meet certain stress conditions~~. Generally, the shape is a surface of revolution which ~~and~~ may ~~or may not~~ include ~~end closures~~ heads; ~~*Vacuum infusion* means an FRP construction method by which of impregnation of dry fillers reinforcement is, preliminary manually or automotive placed under vacuum bag, and impregnated with liquid resin, by application of vacuum pressure;~~ ~~*Resin transfer moulding* means an FRP construction method in airproof sealed moulds using excess pressure for fibre impregnation;~~ *Resin infusion* means an FRP construction method by which dry reinforcement is placed into a matched mould, single sided mould with vacuum bag, or otherwise, and liquid resin is supplied to the part through the use of external applied pressure at the inlet and/or application of full or partial vacuum pressure at the vent. ~~*Contact moulding*~~ *Hand layup* means a process for moulding reinforced plastics in which reinforcement and resin are placed on a mould. Cure either is at room temperature or by heat application using a thermoset resin ~~catalyst promoter~~ system ~~or by heat in an oven, and no additional pressure is used~~; *Design allowables* means statistically determined material~~s~~ strength or maximum strain, ~~property values~~ derived from coupon- and/or parallel shell- and/or shell-sample test data, divided by ~~considering regulation requirements for~~ mandated safety factors, applied to ~~FRP shells~~ structural equipment and tank shell; *Coupon-sample* means a FRP specimen constructed and tested in accordance with national and / or international standards to determine design allowables; ~~*Witness Parallel shell*~~*-sample* means an FRP specimen, which must be representative of the tank shell, ~~constructed in parallel to the shell construction~~ if it is not possible to use cut-outs from the shell itself; ~~*Representative Shell*~~*-sample* means a sample cut out from the shell.
DE	6.9.2.2.2.1	Text added based on lack of standards for dangerous goods tank. We have to apply standard for pressure vessels, which may not incorporate sufficient quality	FRP shells shall be designed and constructed by companies, having the Quality Management System recognized by the competent authority and as far as applicable in accordance with the provisions of a pressure vessel code, to which the FRP shell is designed, recognized by the competent authority considering national and/or international standards.

Country	Paragraph	Comment	Proposed text
		management procedures.	
DE	**6.9.2.2.2.2**	The definition of portable tank container according to UN Model Regulations is considered to be a single unit for the purpose of qualification, and so we need to consider the connection between shell and equipment.	FRP shell shall have an ~~rigid~~ appropriate connection with structural elements of the portable tank frame. FRP shell supports and attachments to the frame shell shall cause no ~~dangerous~~ local stress concentrations exceeding the design allowables of ~~in~~ the shell structure in accordance with the provisions stated in this Chapter for all operating and test conditions.
DE	**6.9.2.2.4**	Text changed be in line with UN Model Regulations and ADR. Proposed to include ability for competent authority to permit operation outside of the stated temperature range.	Shells shall be made of suitable materials, which shall be compatible with the substances to be carried in a service temperature range of -40°C to +50°C, unless temperature ranges are specified for specific climactic or operating conditions by the competent authority of the country where the transport operation is being performed.
DE	**6.9.2.2.2.5**	Text changed to be in line with definition of UN Model Regulation.	Shells shall consist of the following three elements: - Internal ~~chemically resistant~~ liner, - Structural layer, - External layer.
DE	**6.9.2.2.2.5.1**	Text changed to permit the use of alternative methods of lining in the form of coating.	The internal liner is the inner shell wall zone designed as the primary barrier to provide for the long-term chemical resistance in relation to the substances to be carried, to prevent any dangerous reaction with the contents or the formation of dangerous compounds and any substantial weakening of the structural layer owing to the diffusion of products through the internal liner. The internal liner may ~~either~~ be an FRP liner, ~~or~~ a thermoplastic liner, or other appropriate coating as agreed with the competent authority.
DE	6.9.2.2.2.5.1.1	Text added to clarify that both components are required in the FRP liner	6.9.2.2.2.5.1.1 FRP liners FRP liners shall consist of the following two components: - Surface layer ("gel-coat"): adequate resin rich surface layer, reinforced with a veil, compatible with the resin and contents. This layer shall have a fibre mass content of not more than 30% and have a thickness between 0.25 and 0.60 mm - Strengthening layer(s): layer or several layers with a minimum thickness of 2 mm, containing a minimum of 900 g/m² of glass mat or chopped fibres with a mass content in glass of not less than 30% unless equivalent safety is demonstrated for a lower glass content.
DE	6.9.2.2.2.5.1.2	Text modified to include need for quality controlled welding processes. In addition, conductive layer to be placed behind welds to permit spark testing.	6.9.2.2.2.5.1.2 Thermoplastic liners Thermoplastic liners shall ~~consist of thermoplastic sheet material~~ be as referred to in **6.9.2.2.2.6.3**. If the liner consists of thermoplastic sheets, they shall be welded together in the required shape, using a qualified welding procedure and personnel. Furthermore, welded liners shall have a layer of electrically conductive media placed against the non-liquid contact surface of the welds to facilitate spark testing. ~~to which the structural layers are bonded.~~ Durable bonding between liners and the structural layer shall be achieved by the use of an appropriate ~~adhesive~~ method.
DE	**6.9.2.2.2.5**.2	Structural layer is also required to be designed in accordance with 6.9.2.2.2.2	The structural layer of the shell is the zone specially designed to withstand the design loads according to 6.7.2.2.12, **6.9.2.2.2.2, 6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** ~~to withstand the mechanical stresses~~. This part normally consists of several fibre-reinforced layers in determined orientations.
DE	**6.9.2.2.2.5**.3	It is not necessary to specify the makeup of the external layer as it is non structural. Text removed.	The external layer is the part of the shell which is directly exposed to the atmosphere. It shall consist of a resin rich layer with a thickness of at least 0.2 mm. ~~For a thickness larger than 0.5 mm, a mat shall be used. This layer shall have a mass content in glass of less than 30% and shall be capable.~~
DE	**6.9.2.2.2.**6.1	Most recent standard date updated, and	**6.9.2.2.2.6.1** Resins. The processing of the resin mixture shall be carried out in strict compliance with the

Country	Paragraph	Comment	Proposed text
		reference to section containing temperature range.	recommendations of the supplier. This concerns mainly the use of hardeners, initiators and accelerators. These resins can be: - Unsaturated polyester resins; - Vinyl ester resins; - Epoxy resins; - Phenolic resins. The heat distortion temperature (HDT) of the resin, determined in accordance with ISO 75-1:~~1993~~2013 and ISO 75-2:2013 shall be at least 20°C higher than the maximum service temperature of the tank as defined in 6.9.2.2.4, but shall in any case not be lower than 70°C.
DE	**6.9.2.2.2.**6.2	Modification to include carbon and aramid fibres, updates to standards.	**6.9.2.2.2.6.2** Reinforcement fibres. The reinforcement material of the structural layers shall be a suitable grade of fibres such as glass fibres of type E or ECR according to ISO 2078:1993 + Amendment 1:2015, carbon fibres, and aramid. For the internal surface liner, glass fibres of type C or ECR according to ISO 2078:1993 + Amendment 1:2015 may be used. Thermoplastic veils may only be used for the internal liner when their compatibility with the intended contents has been demonstrated.
DE	**6.9.2.2.2.**6.3	PE included	Thermoplastic liner material. Thermoplastic liners, such as unplastified polyvinyl chloride (PVC-U), polyethylene (PE), polypropylene (PP), polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), etc. may be used as lining materials.
DE	**6.9.2.2.2.7**	Structural layer is also required to be designed in accordance with 6.9.2.2.2.2	FRP shells, their attachments and their service and structural equipment shall be designed to withstand the loads mentioned in 6.7.2.2.12, **6.9.2.2.2.2, 6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** without loss of contents (other than quantities of gas escaping through any degassing vents) during the design lifetime.
DE	**6.9.2.2.2.**8	Addition of title required to specify that this is only for carriage of substances with a flash-point of not more than 60°C	**6.9.2.2.2.8 Special requirements for the carriage of substances with a flash-point of not more than 60°C**
DE	**6.9.2.2.2.**8.4	Section added based on practice from ADR. Only required for first inspection or after repair	The electrical surface-resistance and discharge resistance shall be measured initially on each manufactured tank or a specimen of the shell in accordance with the procedure recognized by the competent authority. In the event of damage to the tank shell wall, requiring repair, the electrical resistance shall be re-measured.
DE	**6.9.2.2.2.10.**1	Text modified to permit broader range of composite processes to be used for construction. Contact moulding changed to hand layup as it is more conventionally understood terminology.	Filament winding, ~~contact moulding~~ hand layup and ~~vacuum~~ resin infusion, or other appropriate composite production processes shall be used for fabrication of FRP shells.
	6.9.2.2.2.10.2 To 6.9.2.2.2.10.4	These points are related to the individual manufacturing processes, and must be covered under the quality assurance program of the manufacturer, under consideration of the appropriate pressure vessel code. As such, we do not consider this as required information for this regulation.	~~**6.9.2.2.2.10.2** Filament winding process. Shell structural layers shall be fabricated by winding of unidirectional impregnated fibre strands.~~ ~~**6.9.2.2.2.10.2.1** Specific winding patterns for the continuous fibre strands shall be used as defined in the qualified procedure specification. Any winding pattern which places the filaments in the desired orientation and is designated in the procedure specification may be used. The patterns shall be so arranged that the stressed filaments are aligned to resist the principal stresses which result from internal pressure and other loadings specified in in 6.7.2.2.12, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6**.~~ ~~**6.9.2.2.2.10.2.2** Tension on the strands of filaments during the winding operation shall be controlled to assure uniformly stressed filaments in the composite shell.~~ ~~**6.9.2.2.2.10.2.3** The speed of winding shall be limited only by the ability to meet the tensioning requirements, to conform to the specified winding pattern, and to assure adequate resin impregnation.~~ ~~**6.9.2.2.2.10.2.4** The bandwidth and spacing shall conform to those specified in the qualified procedure specification.~~ ~~**6.9.2.2.2.10.3** Contact moulding process. The shell structure shall consist of random short length (25 to 100 mm) fibre filaments and roving (or biaxial fabric, singular or in combination) in a resin matrix.~~ ~~**6.9.2.2.2.10.3.1** Flat mats for cylindrical reinforcement shall be laid up as separate layers and overlapped in a staggered pattern. Resin shall be applied to each layer in such a manner as to wet out completely.~~ ~~**6.9.2.2.2.10.4** Vacuum infusion process. Vacuum infusion process shall be used for fabrication of elliptical or~~

Country	Paragraph	Comment	Proposed text
			~~hemispherical end-caps of the shell.~~
DE	6.9.2.3.1	Text modified to take geometry variations from circular into account.	FRP shells shall have predominantly ~~a~~ circular cross section and shall be of a design capable of being stress-analysed mathematically or experimentally by resistance strain gauges, or by other methods approved by the competent authority. Examples of areas where it is permitted to deviate from circular cross section include nozzles, flanges, and heads.
DE	6.9.2.3.4	Method of evaluation of membrane hoop and axial strength properties included. Requirement to perform ply by ply analysis maintained, but additional instruction added. Additional link to requirement for finite element calculation. New factor of safety, K5, included based on portable tank container instruction (T code), to account for differences in reference thickness.	For internal ~~design~~ test pressure, external design pressure, static loads specified in 6.7.2.2.12 and static gravity loads caused by the contents with the maximum density specified for the design and at maximum filling degree, the membrane design stress σ in the longitudinal and circumferential directions shall not exceed the following value ~~strength criteria shall be met at any structural layer of a shell~~: $\sigma = \frac{R_m}{K}$ where: R_m = the value of the tensile strength given by taking the mean value of the test results minus twice the standard deviation of the test results. The tests shall be carried out in accordance with the requirement of ISO 527-4:1997 and ISO 527-5:2009, on not less than six samples representative of the design type and construction method; ~~$F_1\sigma_{11} + F_2\sigma_{22} + F_{11}\sigma_{11}^2 + F_{22}\sigma_{22}^2 + F_{33}\sigma_{12}^2 + 2F_{12}\sigma_{11}\sigma_{22} < 1$~~ ~~where~~ ~~$F_1 = \frac{1}{\sigma_1^+} + \frac{1}{\sigma_1^-}$; $F_2 = \frac{1}{\sigma_2^+} + \frac{1}{\sigma_2^-}$; $F_{11} = \frac{1}{\sigma_1^+ \sigma_1^-}$;~~ ~~$F_{22} = \frac{1}{\sigma_2^+ \sigma_2^-}$; $F_{33} = \frac{1}{\sigma_{12}^2}$; $F_{12} = -\frac{1}{2}\sqrt{F_{11}F_{22}}$;~~ ~~$\sigma_1^+ = \sigma_{1B}^+ / K$; $\sigma_1^- = \sigma_{1B}^- / K$; $\sigma_2^+ = \sigma_{2B}^+ / K$;~~ ~~$\sigma_2^- = \sigma_{2B}^- / K$; $\bar{\sigma}_{12B} = \bar{\sigma}_{12B} / K$~~ ~~$K$ – safety factor;~~ ~~σ_{11} - stress applied along the fibres of a unidirectional FRP layer.~~ ~~σ_{22} - stress applied across the fibres of a unidirectional FRP layer.~~ ~~σ_{12} - shear applied stress of a unidirectional FRP layer.~~ ~~σ_{1B}^+ - ultimate tensile strength of a lamina along the fibres determined by ISO 527-5:2009;~~ ~~σ_{1B}^- - ultimate compressive strength of a lamina along the fibres determined by ISO 14126:1999;~~ ~~σ_{2B}^+ - ultimate tensile strength of a lamina across the fibres determined by ISO 527-5:2009;~~ ~~σ_{2B}^- - ultimate compressive strength of a lamina across the fibres determined by ISO 14126:1999;~~ ~~σ_{12B} – ultimate in-plane shear strength determined by ISO 14129:1997.~~ ~~The tests for determination of strength characteristics σ_1^+, σ_1^-, σ_2^+, σ_2^-, $\bar{\sigma}_{12B}$ shall be carried out, in accordance with the requirements of the mentioned ISO standards, on not less than six samples representative of the design type and construction method;~~ ~~The fibre content, by weight, of the test coupon shall be between 90% and 100% of the minimum fibre content specified for the shell.~~ ~~Calculation of the applied stresses σ_{11}, σ_{22} and σ_{12} in any structural layer of a FRP shell shall be carried out by a finite element method.~~ $K = K_0 \times K_1 \times K_2 \times K_3 \times K_4 \times K_5$ where: K shall have a minimum value of 4 ~~for loads specified in 6.7.2.2.12,~~ **~~6.9.2.3.4 and 6.9.2.3.6~~**. ***K*0** – a strength factor. For the general design the value for ***K*0** shall be equal to or more than 1.5. ~~For tanks intended for the carriage of substances which require an increased safety level, the~~ The value of ***K*0** shall be multiplied by a factor of two, unless the shell is provided with protection against damage consisting of a complete metal skeleton including

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			longitudinal and transverse structural members; $\boldsymbol{K_1}$ – a factor related to the deterioration in the material properties due to creep and ageing and as a result of the chemical action of the substances to be carried. It shall be determined by the formula: $$K_1 = \frac{1}{\alpha\beta}$$ where "α" is the creep factor and "β" is the ageing factor determined in accordance with EN 978:1997 after performance of the test according to EN 977:1997. Alternatively, a conservative value of $\boldsymbol{K_1}$ = 2 may be applied for the purpose of undertaking the numerical validation exercise in 6.9.2.3.4 (this does not remove the need to perform testing to determine α and β). In order to determine α and β the initial deflection shall correspond to 2σ; $\boldsymbol{K_2}$ – a factor related to the service temperature and the thermal properties of the resin, determined by the following equation, with a minimum value of 1: $\boldsymbol{K_2}$ = 1.25 - 0.0125 (HDT - 70) where HDT is the heat distortion temperature of the resin, in °C; $\boldsymbol{K_3}$ - a factor related to the fatigue of the material; the value of $\boldsymbol{K_3}$ = 1.75 shall be used unless otherwise agreed with the competent authority. For the dynamic design as outlined in 6.7.2.2.12 the value of $\boldsymbol{K_3}$ = 1.1 shall be used; $\mathbf{K_4}$ – a factor related to curing and has the following values: - 1.1 where curing is carried out in accordance with an approved and documented process; - 1.5 in other cases. $\mathbf{K_5}$ – a factor related to the portable tank instruction from 4.2.5.2.6: - 1.0 for T1 to T19; - 1.33 for T20; - 1.67 for T21 to T22. A design validation exercise using numerical analysis and a suitable composite failure criteria is to be undertaken to verify that the plies in the tank shell are below the allowables. Suitable composite failure criteria include, but are not limited to, Tsai-Wu, Tsai-Hill, Hashin, Strain Invariant Failure Theory, Maximum Strain, or Maximum Stress. Other relations for the strength criteria ~~is~~ are allowed upon agreement with the competent authority. The results of this design validation exercise are to be submitted to the competent authority. The allowables are to be determined using experiments to derive parameters required by the chosen failure criteria combined with factor of safety K, and the maximum elongation strain criteria prescribed in section 6.9.2.3.5. The analysis of joints is to be undertaken in accordance with the allowables determined under section 6.9.2.3.7. Buckling is to be considered in accordance with 6.9.2.3.7. Design of openings and metallic inclusions is to be considered in accordance with 6.9.2.3.8.
DE	6.9.2.3.7	Requirement to analyse adhesive bondlines added, including possible connections between the equipment and shell. Notch factor included in equation, to account for differences between average joint stress and peak stress at failure initiation. Minimum permissible value removed for interlaminar shear strength, as measurement is required in all instances. Bending shear under ISO 14125 changed to interlaminar shear under ISO 14130. ISO 14125 was an incorrect measured taken from ADR. In ADR the correct measure was specified in the type testing	The adhesive bondlines and/or overlay laminates used in the joints, including the end joints, connection between the equipment and shell, the joints of the surge plates and the partitions with the shell shall be capable of withstanding the loads of 6.7.2.2.12, **6.9.2.2.2.2, 6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6**. In order to avoid concentrations of stresses in the overlay lamination, the applied taper shall not be steeper than 1:6. The shear strength between the overlay laminate and the tank components to which it is bonded shall not be less than: $$\tau = \gamma \frac{Q}{l} \leq \frac{\tau_R}{K}$$ where: $\boldsymbol{\tau_R}$ - is the ~~bending shear~~ interlaminar shear strength according to ~~EN~~ ISO ~~14125:1998 (three points method)~~ 14130:1997 ~~with a minimum of τ_R = 10 N/mm², if no measured values are available~~; Q – load per unit width of the interconnection; $\boldsymbol{K}$ – safety factor determined as per **6.9.2.3.4**; ~~K – is the factor calculated in accordance with 6.9.4.4 for the static and dynamic stresses;~~ l – is the length of the overlay laminate γ – the notch factor relating average joint stress to peak joint stress at failure initiation location Other calculation methods for the joints are allowed following approval with the competent authority.

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		of materials section as ISO 14130.	
DE	6.9.2.3.8	Provision included for the design and analysis of metallic flanges and their closures.	Metallic flanges and their closures are permitted to be used in FRP shells, under design requirements of 6.7.2. Openings in the FRP shell shall be reinforced to provide at least the same safety factors against the static and dynamic stresses as specified in 6.7.2.2.12, **6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6** as that for the shell itself. The number of openings shall be minimized. The axis ratio of oval-shaped openings shall be not more than 2. If metallic flanges or componentry are integrated into the FRP shell using bonding, then the characterisation method stated in 6.9.2.3.7 shall apply to the joint between the metal and FRP. If the metallic flanges of componentry are fixed in an alternative fashion, e.g. threaded fastener connections, then the appropriate provisions of the relevant pressure vessel standard shall apply.
DE	6.9.2.3.9	Clarification on specific areas requiring finite element analysis. Additional requirement to use suitable method for treatment of numerical singularities include.	Check calculations of the strength of the shell shall be performed by finite element method simulating the shell layups, joints ~~of the shell layers to each other~~ within FRP shell, joints ~~of~~ between the FRP shell ~~to~~ and the container frame, ~~areas of manholes~~ and openings~~, valves and pressure relief devices~~. Treatment of singularities shall be undertaken using an appropriate method according to the applied design code.
DE	6.9.2.4.1	FRP shell means all parts of shell including walls and heads	Minimum thickness of the FRP shell ~~walls and end caps~~ shall be confirmed by check calculations of the strength of the shell considering strength requirements given in **6.9.2.3.4**.
DE	6.9.2.4.2	Minimum wall thickness changed to 3 mm, as 6 mm is conservative.	Minimum thickness of the FRP shell structural layers shall be determined according ~~to~~ with **6.9.2.3.4**, however, in any case the minimum thickness of the structural layers shall be at least ~~6~~ 3 mm.
DE	6.9.2.5.1	Provision included for the design and analysis of metallic service equipment and shell attachments.	Service equipment, bottom openings, pressure relief devices, gauging devices, supports, frameworks, lifting and tie-down attachments of portable tanks shall meet the requirements of **6.7.2.5-6.7.2.17. If any other metallic features are required to be integrated into the FRP shell, then the provisions of 6.9.2.3.8 shall apply.**
DE	6.9.2.6.2.1.2	Reference to exact standard for ball drop test removed as this is specified in the referenced section. Proposal to remove this test from the required testing as it is unlikely to be failed by any materials greater than 3 mm in thickness. It is also not considered representative of wall impact.	Results of the ball drop test according to ~~EN 976-1:1997, No. 6.6 and~~ the provisions of **6.9.2.7.2.2**[proposal to delete ball drop test from regulation to be discussed with FRP working group];
DE	6.9.2.7.1	Implementation of an additional requirement to spark test welded thermoplastic liners.	Inspection and testing of portable FRP tanks shall be carried out as per provisions of 6.7.2.19. In addition, welded thermoplastic liners shall be spark tested under a suitable standard, after pressure tests performed in accordance with the periodic inspections specified in 6.7.2.19.4.
DE	6.9.2.7.2		Additionally the following provisions shall apply to ~~portable~~ FRP portable tanks:
DE	6.9.2.7.2.1.2	Terminology updated. Additional test requirement under (c) to evaluate areas of tank not covered by hoop and axial laminate tests. Text in (d) corrected as this is not a strength test.	~~Representative~~ Shell samples. Prior to testing all coatings shall be removed from the samples. If ~~representative~~ shell samples ~~cut off from the shell is impossible~~ are not possible ~~the~~ then ~~witness~~ parallel-shell samples may be used. The tests shall cover: (a) Thickness of the laminates of the central shell wall and the ends; (b) Mass content and composition of ~~glass~~ composite reinforcement by ISO 1172:1996, orientation and arrangement of reinforcement layers; (c) Tensile strength, elongation at fracture and modulus of elasticity according to ISO 527-4:1997 or ISO 527-5:2009 for the samples cut off in circumferential and longitudinal directions of the shell. For areas of the FRP shell other than the cylinder, tests shall be performed on representative laminates in accordance with ISO 527-4:1997 or ISO 527-5:2009, to permit evaluation of the suitability of safety factor (K); (d) Bending ~~strength and~~ deflection established by the bending creep test according to ISO 14125:1998 for a period of 1000 hours using a sample with a minimum width of 50 mm and a support distance of at least 20 times the wall thickness. In addition, the creep factor α and the ageing factor β shall be determined by this test and according to EN

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			978:1997. (e) The interlaminar ~~te~~ shear strength of the joints shall be measured by testing representative samples in ~~the tensile test~~ according to ~~EN~~ ISO 14130:1997.
DE	6.9.2.7.2.1.4	Requirement to test liner clarified as "shell" is non-descript. Additional requirement to verify chemical compatibility of service equipment added. (b) and (c) added to permit the use of experience and technical data is verification of chemical compatibility.	The chemical compatibility of the ~~shell~~ liner and chemical contact surfaces of service equipment with the substances to be carried shall be demonstrated by one of the following methods with the agreement of the competent authority. This demonstration shall account for all aspects of the compatibility of the materials of the shell and its equipment with the substances to be carried, including chemical deterioration of the shell, initiation of critical reactions of the contents and dangerous reactions between both. (a) In order to establish any deterioration of the shell, representative samples taken from the shell, including any internal liners with welds, shall be subjected to the chemical compatibility test according to EN 977:1997 for a period of 1 000 hours at 50°C. Compared with a virgin sample, the loss of strength and elasticity modulus measured by the bending test according to EN 978:1997 shall not exceed 25%. Cracks, bubbles, pitting effects as well as separation of layers and liners and roughness shall not be acceptable. (b) Certified and documented data of positive experiences on the compatibility of filling substances in question with the materials of the shell with which they come into contact at given temperatures, times and other relevant service conditions. (c) Technical data published in relevant literature, standards or other sources, acceptable to the competent authority. ~~(c)~~ (d) Upon agreement with the competent authority other methods of chemical compatibility verification may be used.
DE	6.9.2.7.2.3.1	Text added to permit the fire test prototype some variation from exact production unit configuration if required by the competent authority. Specification of exact requirement of heat load, as specified in UN Model Regulation section 6.7.2.2.1.	~~The~~ A representative prototype tank with its service and structural equipment in place and filled to 80% of its maximum capacity with water, shall be exposed to a full engulfment in fire for 30 minutes, caused by an open heating oil pool fire or any other type of fire ~~with the same effect~~ which is able to supply a minimum heat load of 110 kW/m^2 as per the requirement of Section 6.7.2.2.1. For this test, service equipment may be replaced by other items if necessary. The dimensions of the pool shall exceed those of the tank by at least 50 cm to each side and the distance between fuel level and tank shall be between 50 cm and 80 cm. The rest of the tank below liquid level, including openings and closures, shall remain leakproof except for drips.
DE	6.9.2.8.2	Information to be specified for the shell structural material to include reinforcement type and resin type. Removal of technical specification, as this is an internal quality assurance reference number of the manufacturer, and this is not necessary for users of the tank to know.	The information required in 6.7.2.20.1 (f)(i) shall be "Shell structural material: Fibre-reinforced Plastic", the reinforcement fibre e.g. "Reinforcement: E-glass", and resin e.g. "Resin: Vinyl Ester". ~~and the reference number of the FRP shell technical specification~~
	6.9.2.8.3	This is inconsistent with the requirements of UN Model Regulations and has been removed.	~~Upon agreement with the customer a metal plate with description of allowable operating damages of the FRP shell may be installed additionally.~~
DE	6.9.3	Title of 6.9.3 added as this is to be reserved for future implementation.	**6.9.3 Provisions for the design, construction, inspection and testing of portable tanks with shells made of Fibre Reinforced Plastics (FPR) materials intended for the transport of substances of class 2** **RESERVED**
DE	4.2.1.1	Text added to include new chapter on FRP portable tanks.	"This section provides general requirements applicable to the use of portable tanks for the transport of Classes 1, 3, 4, 5, 6, 7, 8 and 9. In addition to these general requirements, portable tanks shall conform to the design, construction, inspection and testing requirements detailed in 6.7.2, and for FRP portable tanks, 6.9.2…"