United Nations ST/SG/AC.10/C.3/2017/40

Secretariat

Distr.: General
11 September 2017

Original: English

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

Sub-Committee of Experts on the Transport of Dangerous Goods

Fifty-second session
Geneva, 27 November -6 December 2017
Item 6 (c) of the provisional agenda
Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: portable tanks

Fibre-reinforced plastics portable tanks

Transmitted by the expert from the Russian Federation*

Introduction

1. The multimodal transport of portable tanks (including tank-containers) plays a significant role in the global transport industry. Maritime transport is the key part of it.

2. The world number of tank-containers, according to the latest International Tank Containers Organization (ITCO) report is about 458.200 units. 90% of tank-containers are engaged in chemical and petrochemical products transport.

3. For the moment 100% of the tanks of existing tank-containers certified for multimodal transport are made of metal (mostly steel, aluminium).

4. The International Maritime Organization (IMO) International Maritime Dangerous Goods (IMDG) Code and the United Nations Recommendations on the Transport of Dangerous goods, Model Regulations contain no requirements on other materials for shells of portable tanks suitable for maritime transport, besides steel and aluminium as stipulated above. In the meantime, requirements for fibre-reinforced plastic (FRP) fixed tanks (tank-vehicles), demountable tanks, tank-containers and tank swap bodies are included in the Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) and

* In accordance with the programme of work of the Sub-Committee for 2017-2018 approved by the Committee at its eighth session (see ST/SG/AC.10/C.3/100, paragraph 98 and ST/SG/AC.10/44, paragraph 14).

the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR).

5. However, the innovations in technology of Fibre Reinforced Plastics (FRP) recently allow to replace metal in multimodal tank-container's shells with FRP materials.

6. According to the growing needs of the industry in the Russian Federation a steady growth of volumes of transport of acids, including hydrochloric acid (UN No. 1789), is observed now.

7. Service life of existing tank-containers for aggressive liquids, mostly, is limited to the inner surface protection adequacy while shells manufactured of FRP materials require no additional surface protection against major aggressive environments.

8. Global practice demonstrates higher efficiency of FRP products in areas thought conventional for application of metal materials (space engineering, aircraft industry, shipbuilding, bridge engineering, etc.).

9. Physical and mechanical properties of FRP material structures exceed similar properties of structures made of conventional structural metal materials:

- Specific weight – lower (up to 40%);
- Corrosion resistance – service life has practically no limitations;
- Thermal conductivity – lower as compared to metals (up to 40%, particularly useful to retain the preset product temperatures in the course of transport);
- Capability to produce various features within one FRP material.

10. Advantages of FRP materials:

- Reduced energy consumption of FRP material product manufacture (no casting, forging or welding required);
- Improved serviceability aspects;
- Reduced final product (container) weight, allowing increased cargo weight;
- Increased impact resistance (dampening);
- No special processes are required for cleaning from remaining deleterious substances shipped.

Documents and proposals for consideration by the Sub-Committee

11. Taking into account the changes to the IMDG Code proposed by the Russian Federation to IMO, the corresponding changes to the Model Regulation are also proposed.

12. These change would ensure the harmonization between the Model Regulations and the IMDG Code and would allow the proper implementation of their requirements for all transport modes.

13. The Russian Federation has obtained significant experience in FRP materials, technologies and tests.

14. The expert from the Russian Federation truly believes that it is the right time to amend the Model Regulations with appropriate requirements for design, construction, testing and survey of portable tanks with FRP shells.

15. Noting the above the present document contains proposed amendments to the Model Regulations as follows:

- Annex 1: Proposed amendments to 4.2.5.2.6;
- Annex 2: Proposed amendments to Chapter 6.7; and
- Annex 3: Proposed new Chapter 6.9 "Provisions for the design, construction, inspection and testing of portable tanks with shells made of Fibre-Reinforced Plastics (FPR) intended for the transport of substances of classes or divisions 3, 5.1, 6.1, 6.2, 8 and 9.

Actions requested

16. The expert from the Russian Federation invites the Sub-Committee to consider the issue and amend the Model Regulations accordingly.

Annex 1

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 or divisions 3, 5.1, 6.1, 6.2, 8 and 9.				
Additionally, the requirements of Chapter 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) (see 6.7.2.4)	Pressure relief provisions [a] (see 6.7.2.8)	Bottom opening provisions [b] (see 6.7.2.6)
T1	1,5	See 6.7.2.4.2	Normal	See 6.7.2.6.2
T2	1,5	See 6.7.2.4.2	Normal	See 6.7.2.6.3
T3	2,65	See 6.7.2.4.2	Normal	See 6.7.2.6.2
T4	2,65	See 6.7.2.4.2	Normal	See 6.7.2.6.3
T5	2,65	See 6.7.2.4.2	See 6.7.2.8.3	Not allowed
T6	4	See 6.7.2.4.2	Normal	See 6.7.2.6.2
T7	4	See 6.7.2.4.2	Normal	See 6.7.2.6.3
T8	4	See 6.7.2.4.2	Normal	Not allowed
T9	4	6 mm	Normal	Not allowed
T10	4	6 mm	See 6.7.2.8.3	Not allowed
T11	6	See 6.7.2.4.2	Normal	See 6.7.2.6.3
T12	6	See 6.7.2.4.2	See 6.7.2.8.3	See 6.7.2.6.3
T13	6	6 mm	Normal	Not allowed
T14	6	6 mm	See 6.7.2.8.3	Not allowed
T15	10	See 6.7.2.4.2	Normal	See 6.7.2.6.3
T16	10	See 6.7.2.4.2	See 6.7.2.8.3	See 6.7.2.6.3
T17	10	6 mm	Normal	See 6.7.2.6.3
T18	10	6 mm	See 6.7.2.8.3	See 6.7.2.6.3

T19	10	6 mm	See 6.7.2.8.3	Not allowed
T20	10	8 mm	See 6.7.2.8.3	Not allowed
T21	10	10 mm	Normal	Not allowed
T22	10	10 mm	See 6.7.2.8.3	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 6.9.5.

Annex 2

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:

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.*

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Annex 3

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 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 (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 apply to portable tanks with FRP shells except for those concerning the use of metal materials for the construction of a 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 portable tank to withstand impact, loading and fire conditions. For international transport, alternative arrangement portable tanks with FRP shells shall be approved by the applicable competent authorities.

6.9.2 Definitions, provisions for the design and materials

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 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;

FRP components means reinforcing fibres (filler), plastic binder (matrix), adhesives, and aggregates;

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

Veil means a thin mate, 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 fibres;

Chemically resistant layer means a layers on the inner surface of a FRP shell ensuring protection of the shell against transported chemical substances;

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;

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 and may or may not include end closures;

Vacuum infusion means a FRP construction method of impregnation of dry fillers, preliminary manually or automotive placed under vacuum bag by liquid resin;

Resin transfer moulding means a FRP construction method in airproof moulds using excess pressure for fibre impregnation;

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

Design allowables means statistically determined materials property values derived from test data considering regulation requirements for safety factors applied to FRP shells;

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

Witness-sample means a FRP specimen constructed in parallel to the shell construction if it is not possible to use cut-outs from the shell;

Representative sample means a sample cut out from the shell.

6.9.3 General design and construction provisions

6.9.3.1 Provisions of 6.7.1 and 6.7.2.2 apply to portable tanks with FRP shell, except for 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.

6.9.3.2 The following provisions apply in addition to 6.7.2.2:

6.9.3.2.1 FRP shells shall be designed and constructed by companies, having the Quality Management System recognized by the competent authority and 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.

6.9.3.2.2 FRP shell shall have a rigid 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 in the shell structure in accordance with the provisions stated in this Chapter.

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

6.9.3.2.4 When constructiong 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.

6.9.3.2.5 Shells shall consist of the following three elements:

- Internal chemical resistant liner;
- Structural layer;
- External layer.

6.9.3.2.5.1 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 a FRP liner or a thermoplastic liner.

FRP liners shall consist of:

- 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.

Thermoplastic liners shall consist of thermoplastic sheet material as referred to in 6.9.3.2.6.3, welded together in the required shape, 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.

6.9.3.2.5.2 The structural layer of the shell is the zone specially designed according to 6.7.2.2.12, 6.9.4.2, 6.9.4.4 and 6.9.4.6 to withstand the mechanical stresses. This part normally consists of several fibre-reinforced layers in determined orientations.

6.9.3.2.5.3 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.

6.9.3.2.6 Raw materials and components:

6.9.3.2.6.1 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 shall be at least 20°C higher than the maximum service temperature of the tank, but shall in any case not be lower than 70°C.

6.9.3.2.6.2 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. For the internal surface liner, glass fibres of type C according to ISO 2078:1993 may be used. Thermoplastic veils may only be used for the internal liner when their compatibility with the intended contents has been demonstrated.

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

6.9.3.2.6.4 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.

6.9.3.2.7 FRP shells, their attachments and their service and structural equipment shall be designed to withstand the loads mentioned in 6.7.2.2.12, 6.9.4.2, 6.9.4.4 and 6.9.4.6 without loss of contents (other than quantities of gas escaping through any degassing vents) during the design lifetime.

6.9.3.2.8 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.

6.9.3.2.8.1 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.

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

6.9.3.2.8.3 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.

6.9.3.2.9 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 6.9.8.2.3. Testing may be waived with the agreement of the competent authority, where sufficient proof can be provided by tests with comparable tank designs.

6.9.3.2.10 Fabrication process for FRP shells.

6.9.3.2.10.1 Filament winding, contact moulding and vacuum infusion processes shall be used for fabrication of FRP shells.

6.9.3.2.10.1.1 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 6.9.3.2.6.2 and in the procedure specification shall be used for reinforcement of shells.

6.9.3.2.10.1.2 The resin system shall be one of the resin systems specified in 6.9.3.2.6.1. 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.

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

6.9.3.2.10.2.1 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, 6.9.4.2, 6.9.4.4, 6.9.4.6.

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

6.9.3.2.10.2.3 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.

6.9.3.2.10.2.4 The bandwidth and spacing shall conform to those specified in the qualified procedure specification.

6.9.3.2.10.3 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.

6.9.3.2.10.3.1 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.

6.9.3.2.10.4. Vacuum infusion process. Vacuum infusion process shall be used for fabrication of elliptical or hemispherical end-caps of the shell.

6.9.4 Design criteria

6.9.4.1 FRP shells shall have 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.

6.9.4.2 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 6.9.5.

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

6.9.4.4 For internal design 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 following strength criteria shall be met at any structural layer of a shell:

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

where

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

$F_{22} = \frac{1}{\sigma_2^+ \sigma_2^-};\ F_{33} = \frac{1}{\bar{\sigma}_{12}^2};\ F_{12} = -{}^1/_2 \sqrt{F_{11} F_{22}},$

$\sigma_1^+ = {}^{\sigma_{1в}^+}/_K;\ \sigma_1^- = {}^{\sigma_{1в}^-}/_K;\ \ \sigma_2^+ = {}^{\sigma_{2в}^+}/_K;$

$\sigma_2^- = {}^{\sigma_{2в}^-}/_K;\ \bar{\sigma}_{12в} = {}^{\sigma_{12в}}/_K$

K – safety factor;

$\boldsymbol{\sigma_{11}}$- stress applied along the fibres of a unidirectional FRP layer.

$\boldsymbol{\sigma_{22}}$- stress applied across the fibres of a unidirectional FRP layer.

$\boldsymbol{\sigma_{12}}$- shear applied stress of a unidirectional FRP layer.

$\boldsymbol{\sigma_{1в}^+}$ - ultimate tensile strength of a lamina along the fibres determined by ISO 527-5:2009;

$\boldsymbol{\sigma_{1в}^-}$ - ultimate compressive strength of a lamina along the fibres determined by ISO 14126:1999;

$\boldsymbol{\sigma_{2в}^+}$ - ultimate tensile strength of a lamina across the fibres determined by ISO 527-5:2009;

$\boldsymbol{\sigma_{2в}^-}$ - ultimate compressive strength of a lamina across the fibres determined by ISO 14126:1999;

$\boldsymbol{\sigma_{12в}}$ – ultimate in-plane shear strength determined by ISO 14129:1997.

The tests for determination of strength characteristics $\boldsymbol{\sigma_1^+}$, $\boldsymbol{\sigma_1^-}$, $\boldsymbol{\sigma_2^+}$, $\boldsymbol{\sigma_2^-}$, $\boldsymbol{\bar{\sigma}_{12в}}$ 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.

Other relations for the strength criteria is allowed upon agreement with the competent authority.

The safety factor

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

where:

$\boldsymbol{K_0}$ – 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 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. 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.

K shall have a minimum value of 4 for loads specified in 6.7.2.2.12, 6.9.4.4 and 6.9.4.6.

6.9.4.5 At any of the stresses as defined in 6.7.2.2.12 and 6.9.4.4, 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.

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

6.9.4.7 The overlay laminates used in the joints, including the end joints, 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, 6.9.4.2, 6.9.4.4 and 6.9.4.6. In order to avoid concentrations of stresses in the overlay lamination, the applied tapper 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:

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

where:

$\boldsymbol{\tau_R}$ - is the bending shear strength according to EN ISO 14125:1998 (three points method) 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;

$\boldsymbol{K}$ – safety factor determined as per 6.9.4.4;

$\boldsymbol{K}$ – 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.

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

6.9.4.8 Openings in the 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, 6.9.4.2, 6.9.4.4 and 6.9.4.6 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.

For the design of flanges and pipework attached to the shell, handling forces and the fastening of bolts shall also be taken into account.

6.9.4.9 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, joints of the shell to the container frame, areas of manholes, valves and pressure relief devices.

6.9.5 Minimum wall thickness of shells

6.9.5.1 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 6.9.4.4.

6.9.5.2 Minimum thickness of the FRP shell structural layers shall be determined according to 6.9.4.4, however, in any case the minimum thickness of the structural layers shall be at least 6 mm.

6.9.6 Equipment components for portable tanks with FRP shell.

6.9.6.1 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.

6.9.7 Design approval

6.9.7.1 Design approval of portable FRP tanks shall be as per the provision of 6.7.2.18.

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

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

6.9.7.2.1.1 Results of the material tests used for FRP shell fabrication in accordance with 6.9.8.2.1 provisions;

6.9.7.2.1.2. Results of the ball drop test according to EN 976-1:1997, No. 6.6 and provisions of 6.9.8.2.2;

6.9.7.2.3 Results the fire resistance test in accordance with provisions of 6.9.8.2.3.

6.9.8.1 Inspection and testing of portable FRP tanks shall be carried out as per provisions of 6.7.2.19.

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

6.9.8.2.1 Material testing:

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

6.9.8.2.1.2 Representative samples. Prior to testing all coatings shall be removed from the samples. If representative samples cut off from the shell is impossible the witness 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 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;

(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 interlaminate shear strength of the joints, to be measured by testing representative samples in the tensile test according to EN ISO 14130:1997.

6.9.8.2.1.3 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 (6.9.4.4).

6.9.8.2.1.4 The chemical compatibility of the shell with the substances to be transported 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) Upon agreement with the competent authority other methods of chemical compatibility verification may be used.

6.9.8.2.2 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.

6.9.8.2.3 Fire resistance test.

6.9.8.2.3.1 The prototype 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. 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.

6.9.9 Marking

6.9.9.1 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).

6.9.9.2 The information required in 6.7.2.20.1 (f)(i) shall be "Shell material-Fibre-reinforced Plastic" and the reference number of the FRP shell technical specification;

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

6.9.9.4 The requirements of 6.7.2.20.2 apply to portable tank with a FRP shell.