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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-seventh session
Geneva, 29 June-8 July 2020
Item 6 (c) of the provisional agenda
Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: fibre-reinforced plastics (FRP) portable tanks

Working group on fibre-reinforced plastics (FRP) portable tanks

Transmitted by the Chair of the working group[*, **]

Background

1. The Sub-Committee is invited to note that the working group on FRP portable tanks will be meeting in parallel to the plenary session from Monday to Tuesday, 6 and 7 July 2020 in Room IV to continue work on developing requirements for FRP portable tanks.

2. The work to be discussed during this working group meeting will continue based on progress made by correspondence prior to the meeting, but also will be influenced by comments received on the draft regulatory provisions for FRP portable tanks provided in annexes 1 to 3 to this document. It is expected that the group will focus primarily on remaining significant issues and those identified by the Sub-Committee for further work.

3. The working group will report on its work to the plenary through an informal document that also solicits comments on the group's outcomes.

4. Delegates interested in participating in the meeting of the informal working group are invited to announce themselves to the Chair of the working group (steven.webb@dot.gov) and to register online for the fifty-seventh session of the Sub-Committee. Participants in the work of the informal working group should register either as part of a national delegation represented at the Sub-Committee or a non-governmental organisation in consultative status with the Sub-Committee.

[*] 2020 (A/74/6 (Sect.20) and Supplementary, Subprogramme 2)
[**] This document was scheduled for publication after the standard publication date owing to circumstances (CORVID-19) beyond the submitter's control

Introduction

5. The informal working group was formed to develop a UN standard for FRP portable tanks first proposed in ST/SG/AC.10/C.3/2017/40 by the Russian Federation. In the three years since the establishment of the informal working group the group has met in conjunction with each Sub-Committee session and hosted several conference calls and numerous rounds of e-mail correspondence.

6. Annexes 1 to 3 to this document contain draft regulatory text for a UN standard on FRP portable tanks. It is noted that the group is still working to finalize these provisions, and there is still work ongoing on design stress calculations, ensuring the roles of all parties involved (e.g., competent authorities, manufacturers, approval agencies), and quality management systems among other issues.

7. The information provided in the annexes are provided to afford members of the Sub-Committee an opportunity to comment on the draft provisions for UN FRP portable tanks. The informal working group will address remaining issues identified by the group and those raised by the Sub-Committee in a proposal for potential adoption at its session in December 2020.

8. Annexes 1 and 2 contain amendments to existing sections of the Model Regulations and annex 3 contains draft regulatory text for provisions concerning UN FRP portable tanks.

Action Requested

9. The Sub-Committee is invited to review the proposed regulatory text in the annexes and provide comments or questions during the plenary session.

Annex I

Proposed amendments to 4.2.5.3 and 4.2.5.2.6 of the Model Regulations on the Transport of Dangerous Goods

Amend the portable tank special provisions in 4.2.5.3 as follows (proposed changes are shown in **additions**/~~deletions~~):

In 4.2.5.3 on Portable tank special provisions, amend TP32 (a) to read:

"TP32 For UN Nos. 0331, 0332 and 3375, portable tanks may be used subject to the following conditions:"

(a) To avoid unnecessary confinement, each portable tank constructed of metal **or Fibre-Reinforced Plastics** shall be fitted with a pressure-relief device that may be of the reclosing spring-loaded type, a frangible disc or a fusible element. The set to discharge or burst pressure, as applicable, shall not be greater than 2.65 bar for portable tanks with a minimum test pressure greater than 4 bar;"

Amend the portable tank instructions in 4.2.5.2.6 as follows (proposed changes are shown in **additions**/~~deletions~~):

In 4.2.5.2.6 on Portable tank instructions, amend to read:

"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 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 (in mm – reference steel) (see 6.7.2.4)	Minimum shell thickness for FRP….	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	See 6.9.2.4	Normal	See 6.7.2.6.2
T2	1.5	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.3
T3	2.65	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.2
T4	2.65	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.3
T5	2.65	See 6.7.2.4.2	See 6.9.2.4	See 6.7.2.8.3	Not allowed
T6	4	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.2
T7	4	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.3
T8	4	See 6.7.2.4.2	See 6.9.2.4	Normal	Not allowed
T9	4	6 mm	See 6.9.2.4	Normal	Not allowed
T10	4	6 mm	See 6.9.2.4	See 6.7.2.8.3	Not allowed
T11	6	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.3
T12	6	See 6.7.2.4.2	See 6.9.2.4	See 6.7.2.8.3	See 6.7.2.6.3
T13	6	6 mm	See 6.9.2.4	Normal	Not allowed
T14	6	6 mm	See 6.9.2.4	See 6.7.2.8.3	Not allowed
T15	10	See 6.7.2.4.2	See 6.9.2.4	Normal	See 6.7.2.6.3
T16	10	See 6.7.2.4.2	See 6.9.2.4	See 6.7.2.8.3	See 6.7.2.6.3
T17	10	6 mm	See 6.9.2.4	Normal	See 6.7.2.6.3
T18	10	6 mm	See 6.9.2.4	See 6.7.2.8.3	See 6.7.2.6.3
T19	10	6 mm	See 6.9.2.4	See 6.7.2.8.3	Not allowed
T20	10	8 mm	See 6.9.2.4	See 6.7.2.8.3	Not allowed
T21	10	10 mm	See 6.9.2.4	Normal	Not allowed

T22	10	10 mm	See 6.9.2.4	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.

Annex II

Proposed amendments to the Model Regulations on the Transport of Dangerous Goods, Chapter 6.7

Insert 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.*

Annex III

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

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

"CHAPTER 6.9

REQUIREMENTS FOR THE DESIGN, CONSTRUCTION, INSPECTION AND TESTING OF PORTABLE TANKS WITH SHELLS MADE OF FIBRE REINFORCED PLASTICS (FPR) MATERIALS

6.9.1 Application and general requirements

6.9.1.1 The requirements of section 6.9.2 shall apply to portable tanks with an 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 requirements of this Chapter, unless otherwise specified, the applicable requirements 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 requirements of this Chapter do not apply to offshore portable tanks.

6.9.1.3 The provisions of Chapter 4.2, and section 6.7.2 apply to FRP portable tank 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 requirements 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 tank to withstand impact, loading and fire conditions. For international transport, alternative arrangement FRP portable tanks shall be approved by the applicable competent authorities.

6.9.2 Requirements for the design, construction, inspection and testing of FRP portable tanks

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:

External layer means the part of the shell which is directly exposed to the atmosphere;

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

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 or mandrel. Generally, the shape is a surface of revolution and may include heads;

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

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

Glass transition means a reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one;

Glass transition temperature (Tg) means a characteristic value of the temperature range over which the glass transition takes place;

Hand layup means a process for moulding reinforced plastics in which reinforcement and resin are placed on a mould. Cure may be at room temperature or by heat application using a thermoset resin system;

Liner means a layer on the inner surface of a FRP shell preventing contact with the dangerous goods being transported;

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

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. The parallel shell-sample may be flat or curved;

Representative sample means a sample cut out from the shell;

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;

Roving means a long and narrow bundle of fibres;

Structural layer means FRP layers of a tank shell required to sustain the design loads;

Test coupon means a representative FRP specimen constructed and tested in accordance with national and / or international standards to determine design parameters;

Veil means a thin mat with high absorbency used in FRP product plies where polymeric matrix surplus fraction content is required (surface evenness, chemical resistance, leakage-proof, etc.);

6.9.2.2 General design and construction requirements

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, and 6.7.2.2.14. Shells shall be designed and constructed in accordance with the requirements of a pressure vessel code, applicable to FRP materials, recognized by the competent authority.

In addition, the following provisions apply:

6.9.2.2.2 **Manufacturer’s quality system**

6.9.2.2.2.1 The quality system shall contain all the elements, requirements, and provisions adopted by the manufacturer. It shall be documented in a systematic and orderly manner in the form of written policies, procedures, and instructions.

The contents shall in particular include adequate descriptions of:

(a) the organizational structure and responsibilities of personnel with regard to design and product quality;

(b) the design control and design verification techniques, processes, and procedures that will be used when designing the portable tanks;

(c) the relevant manufacturing, quality control, quality assurance and process operation instructions that will be used;

(d) quality records, such as inspection reports, test data and calibration data;

(e) management reviews to ensure the effective operation of the quality system arising from the audits in accordance with 6.2.2.5.3.2;

(f) the process describing how customer requirements are met;

(g) the process for control of documents and their revision;

(h) the means for control of non-conforming portable tanks, purchased components, in-process and final materials; and

(i) training programmes and qualification procedures for relevant personnel.

Under the quality management system, the following minimum requirements shall be met for each FRP portable tank manufactured:

(a) Use of an Inspection and Test Plan (ITP);

(b) Visual inspections;

(c) Verification of fibre orientation and mass fraction by means of documented control process;

(d) Verification of fibre and resin quality and characteristics by means of certificates or other documentation;

(e) Verification of liner quality and characteristics by means of certificates or other documentation;

(f) Verification of degree of cure of resin by direct or indirect means (e.g. Barcol test or differential scanning calorimetry) to be determined in accordance with 6.9.2.7.2.1.1 (i);

(g) Documentation of cure and postcure processes; and

(h) Retention and archiving of cured shell samples for future inspection and shell verification (e.g. from man hole cut out) for a period of 5 years.

6.9.2.2.2.2 Audit of the quality system

The quality system shall be initially assessed to determine whether it meets the requirements in 6.9.2.2.2.1 to the satisfaction of the competent authority.

The manufacturer shall be notified of the results of the audit. The notification shall contain the conclusions of the audit and any corrective actions required.

Periodic audits shall be carried out, to the satisfaction of the competent authority, to ensure that the manufacturer maintains and applies the quality system. Reports of the periodic audits shall be provided to the manufacturer.

6.9.2.2.2.3 Maintenance of the quality system

The manufacturer shall maintain the quality system as approved in order that it remains adequate and efficient.

The manufacturer shall notify the competent authority that approved the quality system of any intended changes. The proposed changes shall be evaluated in order to determine whether the amended quality system will still satisfy the requirements in 6.9.2.2.2.1.

6.9.2.2.3 **FRP Shells**

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

6.9.2.2.4 Shells shall be made of suitable materials, capable of operating within a minimum design temperature range of -40°C to +50°C, unless temperature ranges are specified for specific more severe climatic, operating conditions (e.g. heating elements), by the competent authority of the country where the transport operation is being performed.

6.9.2.2.5 If heating elements are used the temperature of the heating elements shall at no point exceed the maximum design temperature.

The design of the tank container and heating elements shall allow examination of the shell with respect to possible effects of overheating during periodic inspection of the shell with a method applicable to the specific construction of heating elements and shell.

6.9.2.2.6 Shells shall consist of the following functions:

(a) Liner;

(b) Structural layer;

(c) External layer.

Note*: The layers may be combined if all applicable functional criteria are met.*

6.9.2.2.6.1 The internal liner is the inner element of the shell 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. Chemical compatibility shall be verified in accordance with 6.9.2.7.2.1.4.

The internal liner may be an FRP liner, a thermoplastic liner, or a metallic liner.

6.9.2.2.7 FRP liners shall consist of the following two components:

(a) Surface layer ("gel-coat"): adequate resin rich surface layer, reinforced with a veil, compatible with the resin and contents. This layer shall have a maximum fibre mass content of 30% and have a minimum thickness of 0.25 and a maximum thickness of 0.60 mm;

(b) 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.

6.9.2.2.8 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. Durable bonding between liners and the structural layer shall be achieved by the use of an appropriate method.

6.9.2.2.9 Metal liners consist of a layer of metal in order to improve the chemical, thermo-mechanical, electrical characteristics to the FRP tank. The liner shall be manufactured by experienced metal workshops and made of metal materials suitable for forming. The materials shall in principle conform to national or international material standards. For welded liners only a material whose weldability has been fully demonstrated shall be used. When the manufacturing process or the materials make it necessary, the liners shall be suitably heat-treated to guarantee adequate toughness in the weld and in the heat affected zones. In choosing the material, the design temperature range shall be taken into account with respect to risk of brittle fracture, to stress corrosion cracking and to resistance to impact. When fine grain steel is used, the guaranteed value of the yield strength shall be not more than 460 N/mm^2 and the guaranteed value of the upper limit of the tensile strength shall be not more than 725 N/mm^2 according to the material specification. layer shall be achieved by using of an appropriate method.

The metal liner shall satisfy to the provisions 6.7.2.2.2 (a), (b), 6.7.2.2.5, 6.7.2.2.6, 6.7.2.2.13, 6.7.2.2.14 and 6.7.2.3.3.

The metal lining shall be so designed that its leakproofness remains intact, whatever the deformation liable to occur in normal conditions of carriage (see 6.7.2.2.10 and 6.7.2.2.12). All welds subject to full stress level in the shell shall be inspected during the initial test by radiographic, ultrasonic, or another suitable non-destructive test method.

The complete structure comprising the load-sharing liner and the structural layer shall be calculated by finite element calculations. The metal part shall not exceed the values specified in 6.7.2.3.3. The FRP part shall be calculated in accordance with the requirements of 6.9.2.3.4. The metal liner shall be bonded on FRP tank by means allowing the durability of the structure. A structural bonding shall be used between parts. This means a minimum shear resistance of the bonding (τ_b) will be determined according EN 1465:2009 in the service temperature range. A minimum characteristic shear stress of 7 N/mm² shall be required. The FE calculation shall take into account the bonding layer in order to ensure its integrity during thermal and mechanical loads (test pressure, dynamic loads, thermal loads) and during life of the portable tanks. The thermomechanical behavior of the combined metallic and FRP material shall be characterized by thermal and mechanical tests to guarantee the bonding. In the using temperature range, the dynamic loads and pressure test the maximum stress (τ_m) in the joint shall be such as:

$$\tau_m \leq \frac{\tau_b}{K}$$

$\boldsymbol{\tau_b}$ - is the measured shear stress according to EN 1465;

$\boldsymbol{\tau_m}$ - is maximum shear stress calculated;

K shall be determined according 6.9.2.3.4.

6.9.2.2.9.1 The shear resistance of the bonding shall be tested according EN 1465.

6.9.2.2.9.2 The minimum wall thickness of the metal liner shall be 1 mm.

6.9.2.2.10 The structural layer shall be designed to withstand the design loads according to 6.7.2.2.12, 6.9.2.2.3, 6.9.2.3.2, 6.9.2.3.4 and 6.9.2.3.6.

6.9.2.2.11 The external layer of resin or paint shall provide adequate protection of the structural layers of the tank from environmental and service exposure, including to UV radiation and salt fog, and occasional splash exposure to cargoes.

6.9.2.2.12 Resins. The processing of the resin mixture shall be carried out in strict compliance with the recommendations of the supplier. These resins can be:

(a) Unsaturated polyester resins;

(b) Vinyl ester resins;

(c) Epoxy resins;

(d) Phenolic resins.

The resin heat distortion temperature (HDT) or glass transition temperature (Tg), determined in accordance with 6.9.2.7.2.1.1 shall be at least 20 °C higher than the maximum design temperature of the tank as defined in 6.9.2.2.4, but shall in any case not be lower than 70 °C.

6.9.2.2.13 The reinforcement material of the structural layers shall be selected such that they meet the requirements of the structural layer.

For the internal surface liner glass fibres of at a minimum type C or ECR according to ISO 2078:1993 + Amendment 1:2015 shall be used. Thermoplastic veils may only be used for the internal liner when their compatibility with the intended contents has been demonstrated.

6.9.2.2.14 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.

6.9.2.2.15 FRP shells, their attachments and their service and structural equipment shall be designed to withstand the loads mentioned in 6.7.2.2.12, 6.9.2.2.3, 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.

6.9.2.2.16 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.

6.9.2.2.17 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.

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

6.9.2.2.19 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.

6.9.2.2.20 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.

6.9.2.2.21 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.

6.9.2.2.22 Fabrication process for FRP shells:

6.9.2.2.23 Filament winding, hand layup and resin infusion, or other appropriate composite production processes shall be used for fabrication of FRP shells.

6.9.2.2.24 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 6.9.2.2.12 and in the procedure specification shall be used for reinforcement of shells.

6.9.2.25 The resin system shall be one of the resin systems specified in 6.9.2.2.11. 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.

6.9.2.3 Design criteria

6.9.2.3.1 FRP shells 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.

6.9.2.3.2 FRP shells shall be designed and constructed to withstand the test pressure. Specific provisions are laid down stated for certain substances in the applicable portable tank instruction indicated in column 10 of the Dangerous Goods List and described in 4.2.5, or by a portable tank special provision indicated in column 11 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 tensile relative deformation measured in mm/mm in the shell shall not be greater than the elongation at fracture of the resin.

6.9.2.3.4 For internal test pressure, external design pressure specified in 6.7.2.2.10, 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, failure criteria (FC) in the longitudinal direction, circumferential direction, or any ply fibre direction shall not exceed the following value:

$$FC \leq \frac{1}{K}$$

where:

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

where:

K shall have a minimum value of 4;
$\boldsymbol{K_0}$ – a strength factor. For the general design the value for $\boldsymbol{K_0}$ shall be equal to or more than 1.5. 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. 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 6.9.2.7.2.1.2(e) and 6.9.2.7.2.1.2(f), respectively.

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);

$\boldsymbol{K_2}$ – 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. The HDT may be used interchangeably with glass transition temperature, as determined in 6.9.2.7.2.1.1;

$\boldsymbol{K_3}$ - 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 resin curing and has the following values:

(a) 1.0 where curing is carried out in accordance with an approved and documented process, and the quality management system described under 6.9.2.2.2 includes verification of degree of cure for each FRP portable tank using a direct measurement approach, such as differential scanning calorimetry (DSC) determined via ISO 11357-2:2016, as per 6.9.2.7.2.1.2(i);

(b) 1.1 where curing is carried out in accordance with an approved and documented process, and the quality management system described under 6.9.2.2.2 includes verification of degree of cure for each FRP portable tank using an indirect measurement approach as per 6.9.2.7.2.1.2(i), such as Barcol testing via ASTM D2583:2013-03 or EN 59:2016, HDT via ISO 75-1:2013, thermo-mechanical analysis (TMA) via ISO 11359-1:2014, or dynamic thermo-mechanical analysis (DMA) via ISO 6721-11:2019;

(c) 1.5 in other cases.

$\mathbf{K_5}$ – a factor related to the portable tank instruction from 4.2.5.2.6:

(a) 1.0 T1 to T19;

(b) 1.33 for T20;

(c) 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, Yamada-Sun, 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 method and 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, the strength values measured as per 6.9.2.7.2.1.2(c), 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 and the strength values measured as per 6.9.2.7.2.1.2(g). 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 the value indicated in the following table or one tenth of the elongation at fracture of the resin determined by ISO 527-2:2012, whichever is lower.

Type of Resin	**Maximum strain in tension (%)**	**Maximum strain in compression (%)**
Unsaturated polyester or phenolic	0.2	-0.2
Vinylester	0.25	-0.25
Epoxy	0.3	-0.3

6.9.2.3.6 For the external design pressure the minimum safety factor for linear buckling analysis of the shell shall be not less than 3.

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, 6.9.2.2.3, 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:

τ_R - is the interlaminar shear strength according to ISO 14130:1997;

Q – load per unit width of the interconnection;

K – safety factor determined as per 6.9.2.3.4;

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 within FRP shell, joints ~~of~~ between the FRP shell and the container frame, and openings. 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 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 in accordance with 6.9.2.3.4, however, in any case the minimum thickness of the structural layers shall be at least 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 FRP portable tanks shall be as per 6.7.2.18 provisions. The following additional provisions apply to FRP portable tanks.

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

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

6.9.2.6.4 Results of the ball drop test according to provisions of 6.9.2.7.2.1.4;

6.9.2.6.5 Results the fire resistance test in accordance with provisions of 6.9.2.7.2.1.6.

6.9.2.6.6 A service life inspection programme shall be established, which shall be a part of the operation manual, to monitor the condition of the tank at periodic inspections. The inspection programme shall focus on the critical stress locations identified in the design analysis performed under 6.9.2.3.4. The inspection method shall take into account the potential damage mode at the critical stress location (e.g, tensile stress or interlaminate stress). The inspection should be a combination of visual and non-destructive testing (e.g., acoustic emissions, ultrasonic evaluation, thermographic). For heating elements the service life inspection programme shall allow an examination of the shell or their representative locations to take into account the effects of overheating.

6.9.2.6.7 A representative prototype tank shall be subjected to tests as specified below. For this purpose service equipment may be replaced by other items if necessary.

6.9.2.6.7.1 The prototype shall be inspected for compliance with the design type specification. This shall include an internal and external inspection and measurement of the main dimensions.

6.9.2.6.7.2 The prototype, equipped with strain gauges at all locations of high strain, as identified by the design validation exercise in accordance with 6.9.2.3.4, shall be subjected to the following loads and the strain shall be recorded:

(a) Filled with water to the maximum filling degree. The measuring results shall be used to calibrate the design calculations according to 6.9.2.3.4;

(b) Filled with water to the maximum filling degree and subjected to static loads in all three directions mounted by the base corner castings without additional mass applied external to the tank shell. For comparison with the design calculation according to 6.9.2.3.4 the strains recorded shall be extrapolated in relation to the quotient of the accelerations required in 6.7.2.2.12 and measured;

(c) Filled with water and subjected to the specified test pressure. Under this load, the shell shall exhibit no visual damage or leakage.

Under any of these load conditions the stress corresponding to the measured strain level shall not exceed the minimum factor of safety calculated in 6.9.2.3.4.

6.9.2.7.2 Additionally the following provisions shall apply to 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. In addition, at least one measure of the heat distortion temperature (HDT) or glass transition temperature (Tg) of the resin, as described in 6.9.2.7.2.1.2 (f) shall be used.

6.9.2.7.2.1.2 Shell samples. Prior to testing all coatings shall be removed from the samples. If shell samples are not possible then 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 composite reinforcement by ISO 1172:1996 or ISO 14127:2008, as well as 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 circumferential and longitudinal directions of the shell. For areas of the FRP shell, 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). A minimum of 6 specimens per measure of tensile strength shall be used, and the tensile strength shall be taken as the average minus two standard deviations;

(d) Bending deflection and strength shall be established by the three or four point bending test according to ISO 14125:1998 and ISO 14125:1998/Amd1:2011 using a sample with a minimum width of 50 mm and a support distance of at least 20 times the wall thickness. A minimum of 5 specimens shall be used;

(e) Creep factor α shall be determined by taking the average result of at least two specimens of configuration described in 6.9.2.7.2.1.2 (d), subject to creep in three or four point bending at the maximum design temperature nominated under 6.9.2.2.4, for a period of 1000 hours. The following test is to be undertaken for each specimen:

(i) Place specimen into bending apparatus, unloaded, in oven set to maximum design temperature and allow to acclimatise for a period of not less than 60 minutes;

(ii) Load specimen bending in accordance with to ISO 14125:1998 and ISO 14125:1998/Amd 1:2011 at flexural stress equal to the strength determined in 6.9.2.7.2.1.2 (d) divided by four. Maintain mechanical load at maximum design temperature without interruption for not less than 1000 hours.

(iii) Measure the initial deflection 6 minutes after full load application in 6.9.2.7.2.1.2 (e) (ii). Specimen shall remain loaded in test rig.

(iv) Measure the final deflection 1000 hours after full load application in 6.9.2.7.2.1.2 (e) (ii).

(v) Calculate the creep factor α by dividing the initial deflection from 6.9.2.7.2.1.2 (e) (iii) by the final deflection from 6.9.2.7.2.1.2 (e) (iv). The value of creep factor α shall be between 0 and 1.

(f) Ageing factor β shall be determined by taking the average result of at least two specimens of configuration described in 6.9.2.7.2.1.2(d), subject to loading in static three or four point bending in conjunction with immersion in water at the maximum design temperature nominated under 6.9.2.2.4 for a period of 1000 hours. The following test is to be undertaken for each specimen:

(i) Prior to testing or conditioning, specimens shall be dried in an oven at 80°C for a period of 24 hours;

(ii) The specimen shall be loaded in three or four point bending at ambient temperature, in accordance with to ISO 14125:1998 and ISO 14125:1998/Amd 1:2011, at the flexural stress level equal to the strength determined in 6.9.2.7.2.1.2 (d) divided by four. Measure the initial deflection 6 minutes after full load application. Remove specimen from test rig;

(iii) Immerse unloaded specimen in water at the maximum design temperature for a period of not less than 1000 hours without interruption to the water conditioning period. When conditioning period has lapsed, remove specimens, keep damp at ambient temperature, and complete 6.9.2.7.2.1.2 (f) (iv) within 3 days;

(iv) The specimen shall be subject to second round of static loading, in a manner identical to 6.9.2.7.2.1.2 (f) (ii). Measure the final deflection 6 minutes after full load application. Remove specimen from test rig; and

(v) Calculate the ageing factor β by dividing the initial deflection from 6.9.2.7.2.1.2 (f) (ii) by the final deflection from 6.9.2.7.2.1.2 (f) (iv). The value of ageing factor β shall be between 0 and 1.

(g) The interlaminar shear strength of the joints shall be measured by testing representative samples in accordance with ISO 14130:1997;

(h) The efficiency of cure and post-cure processes for laminates are to be determined using one or more of the following methods:

(i) Direct measurement of degree of cure: glass transition temperature (Tg) determined using differential scanning calorimetry (DSC) via ISO 11357-2:2016; or

(ii) Indirect measurement of degree of cure:

- HDT via ISO 75-1:2013
- Tg using thermo-mechanical analysis (TMA) via ISO 11359-1:2014
- Dynamic thermo-mechanical analysis (DMA) via ISO 6721-11:2019
- Barcol testing via ASTM D2583:2013-03 or EN 59:2016.

6.9.2.7.2.1.3 The chemical compatibility of the liner and chemical contact surfaces of service equipment with the substances to be carried shall be demonstrated by one of the following methods. 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 1000 hours at 50 °C or the maximum temperature at which a particular substance is approved for transport. 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.

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

6.9.2.7.2.1.4 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.

6.9.2.7.2.1.5 Fire resistance test.

6.9.2.7.2.1.5.1 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. The fire shall be equivalent to a theoretical fire with a flame temperature of 800 °C, emissivity of 0.9 and to the tank a heat transfer coefficient of 10 W/(m²K) and surface absorptivity of 0.8. A minimum net heat flux of 75 kW/m² shall be calibrated according to ISO 21843:2018. 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 Inspection and testing

6.9.2.8.1 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.

In addition, the initial and periodic inspections shall follow the service life inspection programme per 6.9.2.6.6.

The initial inspection and test shall verify that construction of the tank is made in accordance with the QMS required by 6.9.2.2.2.

Additionally, during inspection of the shell the position of the areas heated by heating elements shall be indicated or marked, be available on design drawings or shall be made visible by a suitable technique (e.g. infrared). Examination of the shell shall take into account the effects of overheating, corrosion, erosion, overpressure and mechanical overloading.

6.9.2.10 Retention of Samples

6.9.2.10.1 Cured shell samples (e.g. from man hole cut out) for each tank manufactured shall be maintained for future inspection and shell verification for a period of 5 years from the date of the initial inspection and test and until successful completion of the required periodic 5-year inspection.

6.9.2.9.11 Marking

6.9.2.11.1 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).

6.9.2.11.2 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”.

6.9.2.11.3 Requirements of provision 6.7.2.20.2 apply to portable tank with a FRP shell.”