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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

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Item 6 (c) of the provisional agenda
Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: portable Tanks

Introduction of a requirement to provide an equivalent level of safety for the shell of a fibre reinforced plastics portable tank (Chapter 6.9) to that currently required for a metallic portable tank (Chapter 6.7)

Submitted by the International Tank Container Organisation (ITCO)*

Introduction

1. This document explains that the provisions in Chapter 6.9 for fibre reinforced plastics (FRP) portable tanks omit a requirement to demonstrate an equivalent level of safety for the shell material when compared to the resilience required to be demonstrated in a given metallic shell material used in the construction of Chapter 6.7 on portable tanks. Calculation and laboratory testing methods are discussed to promote further consideration on how this equivalence may be readily achieved. An amendment is therefore proposed to Chapter 6.9 to incorporate an equivalent specific resilience requirement for each portable tank instruction. This amendment creates an equivalent level of safety to that already demonstrated by metallic portable tanks constructed to the same portable tank instructions in Chapter 6.7.

2. Regulatory provisions in paragraph 6.7.2.4 “Minimum shell thickness” for the design of metallic portable tank shells for the transport of dangerous goods require that the manufacturer calculates a minimum design thickness of the shell based upon the following three design criteria and proposed material properties.

(a) “Operating pressure including dynamic pressure” resulting from transport motion,

(b) “Test pressure”, and

(c) “Minimum equivalent thickness” for the material of construction when compared to a reference steel thickness (which has ultimate tensile stress of 370 N/mm^2 and elongation at failure of 27 %).

* A/75/6 (Sect.20), para. 20.51

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3. Chapter 6.9 for FRP portable tanks provides requirements for the first two criteria (a) and (b) above but is silent on the third criteria.

4. The third criteria (c) above is explained in paragraphs 6.7.2.4.2. to 10 and columns (10) and (11) of Table A of Chapter 3.2. It is a fundamental specific resilience requirement regulating an equivalent level of safety between different materials of shell construction using a criterion which determines the containment of dangerous goods in impact incidents up to certain energy threshold.

Method of calculating an equivalent level of safety for FRP shells

5. A research document "Forschungsbericht 203", published by the German Federal Institute for Materials Research and Testing (BAM) in 1994 sets out that the specific energy absorbed (work done) in the penetration of a tank shell is proportional to the shell thickness multiplied by the material ultimate tensile stress multiplied by its elongation at failure:

$$W \propto e \times R_e \times A$$

Where:

W= work done in penetration of shell

e = thickness of metallic wall

R_e = Ultimate Tensile Stress of metal

A = Elongation to failure

6. On 16 February 2001, the Government of Germany updated this analysis by publishing TRANS/WP.15/AC.1/2001/3, entitled "Adequate equivalent minimum wall thickness formula" which provided a fundamental derivation of the now familiar equation relating the properties of the reference steel to that of the proposed shell material as follows:

$$\frac{e_1}{e_0} = \frac{\sqrt[3]{(R_{m0} \times A_0)^2}}{\sqrt[3]{(R_{m1} \times A_1)^2}}$$

Where:

e_0 = thickness of minimum reference steel wall thickness

e_1 = thickness of proposed steel wall thickness

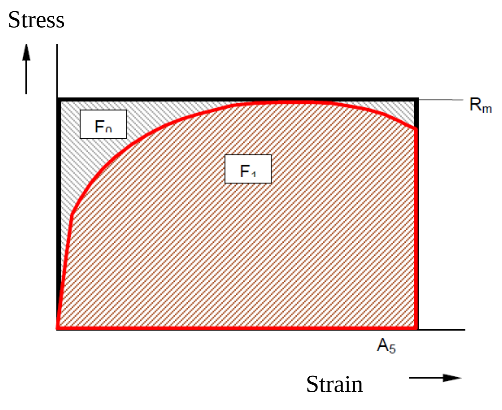
R_{mo} = ultimate tensile stress of reference steel

R_{m1} = ultimate tensile stress of proposed steel

A_o = elongation to failure of reference steel

A_1 = elongation to failure of proposed steel

7. It is explained in the document that the energy absorbed by metallic materials is largely within a range of 89 % to 91 % of the perfect elastic-plastic theory and that the energy absorbed is the area under the graph shown in the figure below.



Area F_0: Strain energy (ideal elastic-plastic behaviour)
Area F_1: Strain energy (real stress-strain curve)

Figure: Ideal and real stress-strain-curves

8. The practical results of this work when applied to regulatory requirements worldwide is that materials selected for use are highly energy absorbent and the containment of dangerous goods in accidents is not unusual (see examples in appendix II).

9. Chapter 6.9 of the UN Model Regulation contains paragraph 6.9.2.4.2, which requires a minimum thickness of the FRP structural layer to be calculated (without reference to the current portable tank equivalent thickness calculation based on 6 mm of reference steel) but with a minimum of at least 3 mm.

10. In calculating this minimum thickness, the materials testing clauses in 6.9.2.7.1 for FRP include requirements to establish the tensile elongation to failure of the resin and its heat distortion temperature, **the thickness of the central wall, tensile strength, elongation at fracture and modulus of elasticity for circumferential and longitudinal directions**, all to be measured using referenced ISO standards.

11. These regulated performance properties provide the means to calculate the strain energy absorption up to the point of failure and hence demonstrate that a proposed thickness has the equivalent level of safety when compared to reference steel. It is noted that the deviation from the perfect elastic-plastic strain profile for a given FRP would need to be established to verify whether the proposed equivalent thickness equation is sufficiently conservative, but this is not thought to be overly burdensome.

Method of measuring an equivalent level of safety for FRP shells

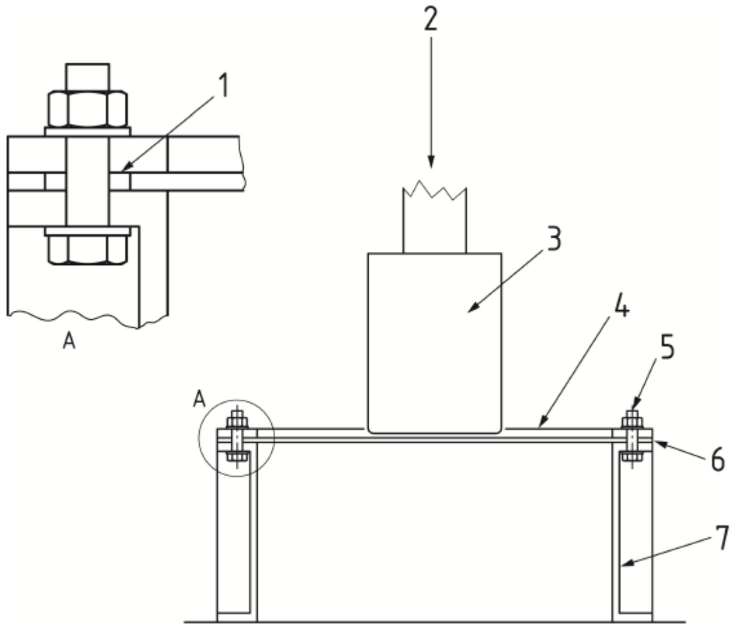
12. As an alternative to using calculation methods to establish a level of resilience, there are established laboratory testing methods available including those currently specified in RID/ADR regulations.

13. The Sub-Committee may wish to consider laboratory testing methods which were originally published by BAM in "Forschungsbericht 203" in 1994, an extract of which is shown in appendix 1 to this document. A current equivalent testing method for FRP materials is regulated in RID 2021.

14. RID 2021 – 6.8.4 Special Provisions TE25 (c) states as follows:

“(c) If protection is provided by a sandwich cover, it shall cover the entire area of the tank ends and shall have a specific energy absorption capacity of at least 22 kJ (corresponding to a wall thickness of 6 mm), which shall be measured in accordance with the method described in annex B to EN standard 13094 "Tanks for the transport of dangerous goods – Metallic tanks with a working pressure not exceeding 0.5 bar – Design and construction".”

15. Standard EN 13094:2015 is a referenced standard in ADR 6.8.2.6 and its annex B is entitled “Method of Measurement of Specific Resilience”. It describes a laboratory test method where a disc of material under test is penetrated quasi statically as shown in the below laboratory scheme.



Key:

1 for non-metallic test plates only – use clamp bolt sleeve

2 test force F

3 test bar

4 clamping ring

5 20 bolts and nuts M12 x 1.75 grade 8.8

6 test plate

7 body

16. This is the type of equipment which established the following table of energy absorption capacities expressed in MJ according to BAM Research paper reproduced below from appendix I to this document.

Metal	e [mm]	W [MJ]	N.f.St. normalized specific resilience based on 6 mm mild steel == 1
Al Mg 4,5 Mn	4.0	4	0.18
	5.2	7	0.32
	7.8	12	0.55
Mild Steel	3.0	10	0.45
	5.0	17	0.77
	6.0	22	1.00
Austenitic Steel	3.0	28	1.27
	3.5	32	1.45

Conclusion

17. It is concluded that both analytical and test methods are available to be applied in the regulations to assess the equivalent level of safety in terms of resilience to impact for a given thickness of FRP portable tank shell. It is also concluded that since it is considered important for metallic materials to be qualified on this basis, then FRP materials should be assessed equally before qualifying for use as portable tanks. Thus the "equivalent thickness" concept could then be applied to regulate minimum equivalent metallic and FRP shell thicknesses which relate to portable tank instructions for "minimum equivalent thicknesses" 6 mm, 8 mm and 10 mm reference steels.

Proposal

18. ITCO therefore proposes that the following amendments to Chapter 6.9 on FRP portable tanks:

In 6.9.2.3.4, omit factor K5 (because this factor only considers tensile strength and not resilience which is a factor of tensile strength and elongation to failure).

In 6.9.2.4 amend the second sub-paragraph as follows (new text is underlined):

"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, this minimum thickness shall not be less than:

(a) that required to obtain a minimum "specific resilience" energy absorbed according to EN 13094:2020 annex B of:

(i) 22 MJ (or equivalent to 6 mm of reference steel) for portable tank instruction T1 to T19,

(ii) 30 MJ (or equivalent to 8mm of reference steel) for portable tank instruction T20,

(iii) 37 MJ (or equivalent to 10 mm of reference steel) for portable tank instruction T21-T22, and

(b) in any case the minimum thickness of the structural layers shall be at least 3 mm."

Justification

19. ITCO wishes to ensure an equivalent level of safety in containment of dangerous liquids in any given portable tank accident, whether on road, rail, sea or during trans-shipment, by ensuring that there is regulatory control over the equivalent specific resilience of FRP materials of construction for use in portable tanks.

Appendix I **[English only]**

Simulation of Accidents for Analysis (Courtesy of BAM Research Report 203)

4 Simulation of accidents

Penetration stresses (specific energy absorption capacity) have been verified as follows /6/:
Plane sample plates corresponding to the actual construction of a tank wall have been submitted to deep-drawing tests by means of a cylindrical pressure stamp.

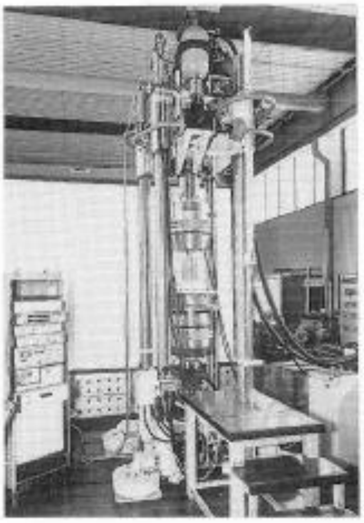


Fig. 1: Test equipment for the determination of the specific energy absorption capacity

The sample plates have been circumferentially fixed to a circular test equipment, so that the tank wall was directly exposed to the stamp.

During the tests, the work load was applied quasi-statically until the sample plate started to crack. The force-displacement-curve was monitored and served to determinate the specific energy absorption capacity for the energy absorption capacity is equal the area below the monitored force-displacement-curve, see fig. 2.

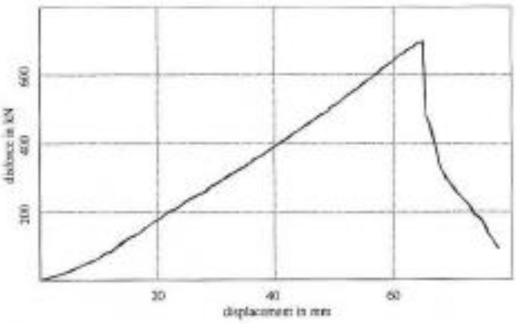


Fig. 2: Force-displacement-curve, schematically; determination of the specific energy absorption capacity

Table 1 shows the monitored data for the specific energy absorption capacity in relationship to material and wall thickness

Table 1: Energy absoption capacities according to BAM-testings

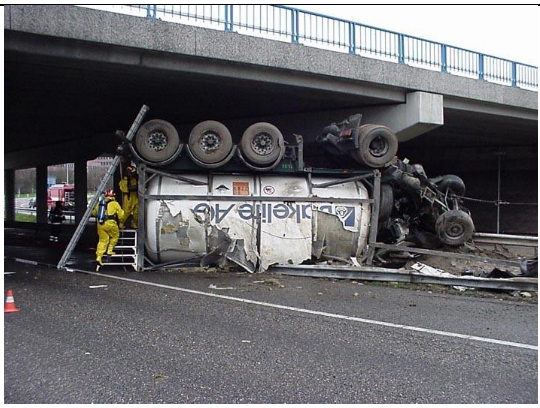
Metal	e [mm]	$W_{spec.}$ [kNm]	N.f.St.
Al Mg 4,5 Mn (Al)	4,0 5,2 6,0 6,5 7,8	4 7 12	0,18 0,32 0,55
Mild Steel (St)	3,0 4,0 4,6 5,0 6,0	10 17 22	0,45 0,77 1,00
Austenitic Steel 1.4571 (Au)	3,0 3,5 3,8 4,5	28 32	1,27 1,45

Appendix II

Portable tank container resilience when subject to high energy accidents

Portable tank container damage following overturn accident: Note the absence of penetrating tears in pressure envelope.

Portable tank container suffered impact in handling accident: Note the minimal protection from ISO frame – energy absorbed without fracture of shell.



Portable tank container suffered serious road traffic accident with overturn. Note the minimal protection from ISO frame – energy absorbed without fracture of shell and contents retained. Fire service personnel pumping dangerous liquid goods from the bottom discharge valve in overturned position before removing the vehicle.