Economic Commission for Europe

Inland Transport Committee

Working Party on the Transport of Dangerous Goods

Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods **25 February 2021**

Bern, 15-19 March 2021

Item 2 of the provisional agenda

Tanks

Tanks: Adoption of the UN Model Regulations on fibre-reinforced plastics portable tanks into RID/ADR

Transmitted by the International Tank Container Organisation (ITCO)

Summary

Executive summary:	This paper explains that the provisions on fibre-reinforced plastics (FRP) portable tanks proposed for adoption by RID/ADR omits the requirement to demonstrate an equivalent level of safety when compared to the resilience of a given thickness of reference steel. Calculation and testing methods are discussed to promote further consideration on how this equivalence may be assessed.
Action to be taken:	To defer the adoption of the Model Regulations on FRP portable tank until an equivalent level of safety to metallic portable tanks is adequately provided for in the provisions.
Related document:	ECE/TRANS/WP.15/AC.1/2021/5 transmitted by the Government of France.

Establishment of an “equivalent level of safety” for FRP portable tanks when compared to metallic portable tanks

1. Introduction

1. Regulatory provisions 6.7.2.4 for design of portable tank metallic shells for the transport of dangerous goods require that the manufacturer establishes a minimum design thickness of the shell based upon the following design criteria and proposed material properties:

- “Test Pressure” (Calculation Pressure),
- “Operating Pressure”,
- “Operating Pressure including Dynamic Pressure” resulting from transport motion,
- “Minimum Equivalent Thickness” when compared to a reference steel thickness (which has ultimate tensile stress of 370 N/mm^2 and elongation at failure of 27%)

2. Paper UN/SCETDG/57/INF.43 produced by the informal working group on FRP portable tanks and adopted by the Sub-Committee of Experts on the Transport of Dangerous

Goods at its December 2020 meeting (57th session, see report ST/SG/AC.10/C.3/114) provides requirements for the first three bullets but is silent on the fourth bullet.

3. The fourth bullet is a fundamental resilience requirement regulating an equivalent level of safety between competing products using a criterion which determines the containment of dangerous goods in impact incidents up to certain energy threshold.

2. Calculating an equivalent level of safety for FRP Shells

4. A research document "Forschungsbericht 203", published by 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.

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

5. 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

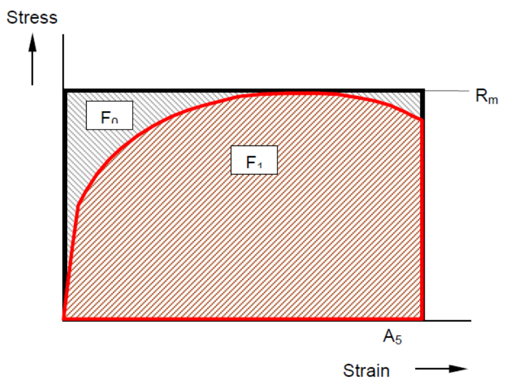
R_{mo} = Ultimate Tensile Stress of reference steel

R_{m1} = Ultimate Tensile Stress of proposed steel

A_o = Elongation to failure of reference steel

A_1 = Elongation to failure of proposed steel

6. It is explained in this paper 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 below.



Area F_0: Strain energy (Ideal elastic-plastic behaviour)
Area F_1: Strain energy (Real stress-strain-curve)

Figure 2: ideal and real stress-strain-curves

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

8. The proposed regulation for FRP shells (UN/SCETDG/57/INF.43), from the informal working group on FRP contains clause 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. 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. 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 a deviation from the perfect elastic-plastic strain profile for FRP would need to be established to verify whether the proposed equivalent thickness equation is sufficiently conservative, but this is not thought to be burdensome.

3. Method of measuring an equivalent level of safety for FRP shells

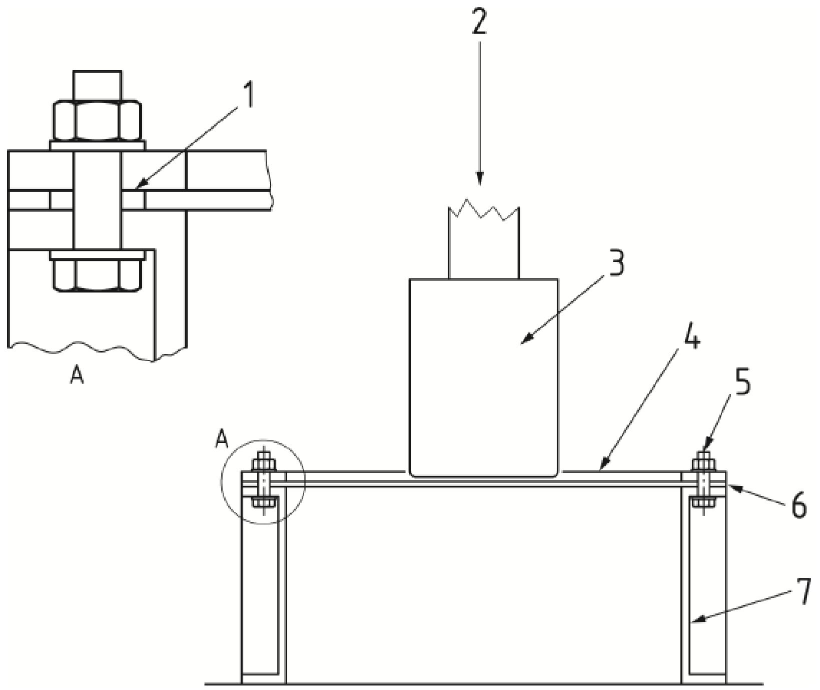
9. In addition to using calculation methods to establish a level of resilience there are established laboratory testing methods available including those currently specified in RID/ADR regulations.

10. The FRP working group may wish to consider laboratory testing methods which were originally published in 1994by BAM in "Forschungsbericht 203", an extract of which is shown in Appendix 1 to this paper. A current equivalent testing method for FRP materials is regulated in RID 2021 as follows.

RID 2021 – 6.8.4 Special Provisions TE25 c) states

"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"."

11. Standard EN 13094:2015 is referenced in ADR 6.8.2.6 and its Annex B is entitled "Method of Measurement of Specific Resilience." This 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 (see Figure B.5)

2 test force F

3 test bar (Figure B.3)

4 clamping ring (Figure B.2)

5 20 bolts and nuts M 12 × 1,75 grade 8.8

6 test plate (Figure B.4)

7 body (Figure B.1)

4. Conclusion

12. It is concluded that both analytical and testing methods are available to be applied in the regulation 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 in portable tanks. Thus the "equivalent thickness" calculation should then be applied to regulate minimum equivalent metallic and FRP shell thicknesses which relate to portable tank instructions for "minimum", 6 mm, 8 mm and 10 mm reference steels.

5. Proposal

13. ITCO proposes that the Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods agrees to defer a final decision to adopt the current FRP portable tank text proposed in the report of the informal working group on fibre-reinforced plastics (FRP) portable tanks (UN/SCETDG/57/INF.43) until these matters are further considered by the Sub-Committee.

6. Justification

14. ITCO is concerned to ensure that an absence of regulatory control over the equivalent resilience of FRP materials of construction for use in portable tanks does not result in a reduction in the level of safe containment of dangerous liquids in any given portable tank accident.

15. This concern is enhanced by the prospect in the proposed regulation of an increase in the range of approved substances beyond the restrictions currently imposed by RID/ADR Chapter 4.4 on FRP but to include significantly higher hazard substances.

16. It should also be recognised that portable tanks are not restricted to land transit but are utilised worldwide on road, rail, sea, and for trans-shipment between all modes. As such they have an enhanced potential for challenging events.

Appendix I

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.

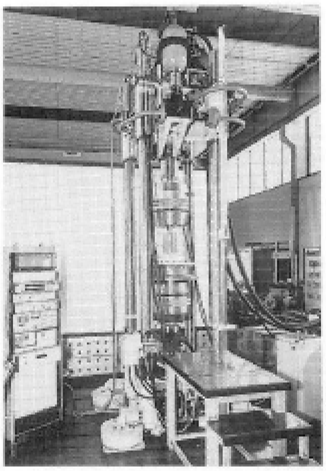


Fig. 1:
Test equipment for the determination of the specific energy absorption capacity

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.

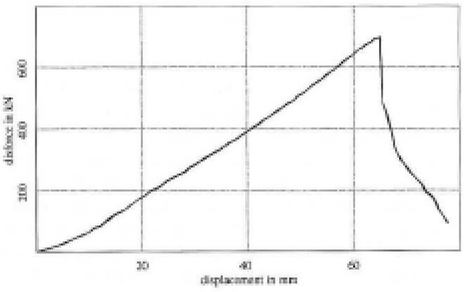


Fig. 2:
Force-displacement-curve, schematically; determination of the specific energy absorption capacity

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

Table 1:
Energy absorption capacities according to BAM-testings

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

Appendix II

Portable tank container resilience when subject to high energy accidents


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


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


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