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CHAPTER 6.8

ADEQUATE EQUIVALENT MINIMUM WALL THICKNESS FORMULA

Transmitted by the Government of Germany*

The secretariat has received from the Central Office for International Carriage by Rail (OCTI) the proposal reproduced below.

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Introduction

The question of replacing as inadequate the equivalent thickness formula (cube root formula) in present Appendices B.1a and B.1b of ADR, marginals 21x 127 (3) and (4) and in present Appendices X and XI of RID, marginals 1.2.8.3 and 1.2.8.4, by an adequate alternative equivalent thickness formula in keeping with the laws of mechanics, was considered in detail at several sessions of the Working Party on the Transport of Dangerous Goods (WP.15) and at meetings of working groups and ad hoc groups convened by WP.15. A summary of the discussions and their results was presented by Germany at the sixty-sixth session of WP.15. Since the interest shown up to that time varied with the participants in the various meetings, Germany submitted a proposal in document TRANS/WP.15/1999/49 which was discussed in detail at the sixty-seventh session. However, no representative vote was achieved because of the complex and detailed justification of the proposal. WP.15 therefore decided to convene a new "tanks" working group in which experts from interested countries would collaborate. The meeting of this working group took place in Berlin on 11 and 12 January 2000. The report of the meeting can be found in document TRANS/WP.15/2000/10.

After a detailed in-depth discussion, the participants decided by a broad consensus to replace the present cube root formula by the adequate equivalent thickness formula proposed (alternative formula) (TRANS/WP.15/1999/49); the existing detailed substantiated justification, however, would have to be reduced to the strictly necessary in order to permit a decision on the proposal at the sixty-eighth session of WP.15. In order to follow the working group's recommendation, Germany drafted an amended document containing an identical version of the proposal itself, but with the justification amended in the light of the working group's discussion (see document TRANS/WP.15/2000/10). The amended document was again considered in detail at the sixty-eighth session of WP.15 by an ad hoc working group of experts and submitted to WP.15 with a recommendation for approval.

WP.15 took a majority decision to follow the recommendation. For reasons of competence, the decision could only cover requirements for tank-vehicles, demountable tanks and battery-vehicles, and present Appendix B.1a of ADR, since the rules for Appendix B.1b (tank-containers), which are harmonized with the provisions of Appendix X of RID, must be discussed and decided by the Joint Meeting. The German proposal was therefore adapted to the restructured ADR and meanwhile reworded; in the new ADR format, it will be added to or replace in the left hand column the provisions for tank-vehicles. In material terms, from the point of view of provisions for tank-containers, there is no modification of the adequate equivalent thickness formula (alternative formula) with regard to the provisions for tank-vehicles adopted by WP.15. It is therefore now proposed that the equivalence formula (alternative formula) should also figure in the RID/ADR provisions for tank-containers.

Proposal

1. Replace the present formula in the "new" 6.8.2.1.18 by:

$$e_1 = \frac{464 \cdot e_0}{\sqrt[3]{\left(Rm_1 \cdot A_1\right)^2}}$$

2. Replace the present formula in footnote 4 of the “new” 6.8.2.1.18 by:

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

3. In the right hand column of the “new” 6.8.2.1.19 add a third subparagraph in accordance with document INF.24 submitted to the RID/ADR Joint Meeting of 13 to 24 March 2000 to read:

> “The thickness of the walls, ends and cover-plates of tanks fitted with a protection against damage within the meaning of 6.8.2.1.20 shall correspond at least to the values given in the following table.”

4. The table at the end of the “new” 6.8.2.1.19 according to document INF.24 submitted to the RID/ADR Joint Meeting of 13 to 24 March 2000 applies to both columns (therefore over the whole width).

5. Add a last sentence to the “new” 6.8.2.1.16 to read:

> “These minimum values may not, however, be exceeded when the formula contained in 6.8.2.1.18 is applied.”

6. The transitional measures must be adapted so that the tanks constructed to date can still be used.

Justification

In function

- of the diameter of the tank,
- of the fact that protection is provided against damage through lateral impact or overturning,
- of the dangerous goods to be carried (dangerous goods in powdery or granular form, or in the form of liquid or gas),

the thickness of the tank walls in accordance with 6.8.2.1.18 and 19 will be subject to certain minimum requirements in relation with the choice of a specific metallic material (mild steel, or reference mild steel).

The minimum thickness requirements of 3 mm, 4 mm, 5 mm or 6 mm referred to in the marginals in question must therefore be understood as a combination of material and wall thickness criteria. Even when a metal other than mild steel has to be used, the relevant basic requirement (e.g. a wall thickness of 6 mm with regard to reference mild steel) must be met in terms of type and size. This is why the wall thickness of a tank, in a metal other than reference mild steel, must be determined in terms of the significant properties of the material and the reference mild steel, on the basis of the prescribed basic wall thickness (e.g. 6 mm).

In other terms:

The properties of tank walls in the case of tanks composed of different metallic materials must be compared with each other. If the tank wall whose thickness is to be determined and which is made of a metal other than reference mild steel has the same significant properties as a basic tank wall (e.g. with a thickness of 6 mm), made of reference mild steel, the requirements of 6.8.2.1.18 and 19 must be adequately met.

The significant properties of tank walls in the sense referred to above are taken to be the deformation capability or the strain energy that can be sustained until mechanical stress causes the failure of the tank walls. These properties can be determined simply, in a reproducible and comparable form, with the standardized uniaxial tensile test.

The absorption of strain energy/curves (or stress/strain curves) up to fracture during the tensile test for certain metallic materials enables the sustainable strain energy of the corresponding specimens to be determined by the fact that the surface areas under the curves have been determined. The specimens of different metals are comparable if equal strain energies have to be applied up to fracture during the tensile test. From the values (of the same level) for the (required) strain energy given by the material properties “tensile strength R_{mo} and elongation on fracture A_o” of reference mild steel and by the dimensions of the corresponding specimens, it is possible to determine, for the known properties “minimum tensile strength R_{m1}” and “minimum elongation on fracture under tensile strength A_1” of the materials, the requisite dimensions of the metal chosen, and thus compare, for example, the required wall thickness e_1, of a tank wall made of that metal.

By following these principles it is possible to derive the adequate equivalence formula (alternative formula) proposed for the minimum thickness of tank walls. The details can be found in the annex to this proposal.

Comments

When a metal other than reference mild steel is chosen, the transposition of requirements according to 6.8.2.1.18 and 19 by applying the adequate formula (alternative formula) proposed on the basis of equivalent strain energies that can be sustained up to failure leads to:

- higher figures than at present for minimum wall thicknesses, e.g. if common aluminium alloys are used,

- lower figures than at present for minimum wall thicknesses, e.g. if austenitic steels are used.

If the wall thickness is increased when common aluminium alloys are used, an undesirable increase in the unladen mass of tanks constructed with such materials is obtained. If more modern or more developed aluminium alloys are used, this disadvantage is again offset to a large extent so that, even from a purely economic point of view, no serious objection can be raised to applying the adequate equivalence formula (alternative formula) proposed. In any case, whether wall thicknesses should be greater if common aluminium alloys are used or whether approximately equivalent wall thicknesses to those in current use should be adopted when more developed aluminium alloys are used, the application of the adequate equivalence formula (alternative formula) would seem to be linked to a definite increase in the safety level of aluminium alloy tanks for dangerous goods.

The introduction of lower fixed values for minimum wall thicknesses when different metals are used, would prevent incorrect developments as regards problems of stability, fatigue behaviour, etc.

The consequences for future minimum wall thicknesses of applying the adequate equivalence formula (alternative formula) can be found in tables 1 and 2 (attached).

Applying the adequate formula (alternative formula) results in a correct and satisfactory evaluation of the significant properties of the various materials used in tanks. This is why it is no longer possible to make a special exception for austenitic steels in accordance with 6.8.2.1.16 - the specified minimum values according to materials standards may be exceeded by up to 15% in the case of austenitic steels - when the adequate equivalence formula (alternative formula) is applied.

Further details on the development and derivation of the adequate equivalence formula (alternative formula) can be found in part in the documents already referred to, TRANS/WP.15/R.433 and INF.32 (sixty-second session of WP.15), INF.12 (sixty-sixth session of WP.15), TRANS/WP.15/1999/48 and -/49 (sixty-seventh session of WP.15) and TRANS/WP.15/2000/4 and -/10 (sixty-eighth session of WP.15) and the reports of the sessions in question.

Annex

Derivation of an adequate equivalent minimum wall thickness formula (alternative formula)

If for tensile testing a short proportional specimen is taken, the permanent elongation after fracture shall be measured on a test piece with a circular cross-section in which the gauge length l is five times the diameter d; if test pieces with a rectangular section are used - as is completely normal for determining the properties of sheet metal - the gauge length shall be calculated by the formula

$$l = 5{,}65 \cdot \sqrt{F_0} \qquad (1)$$

where F_0 is the initial cross-section area of the test piece (see 6.8.2.1.12, footnote 1).

The volume V of the cylindrical and the prismatic test pieces should be equal.
Therefore (see fig. 1)

$$V = \frac{\pi}{4} d^2 \cdot l = F_0 \cdot l = b \cdot e \cdot l \qquad (2)$$

and

$$d = \sqrt{\frac{4}{p}} x \sqrt{bxe}$$

where $l = 5 \cdot d$, resulting in

$$l = 5 \cdot \sqrt{\frac{4}{\pi}} \cdot \sqrt{b \cdot e} = 5{,}65 \cdot \sqrt{b \cdot e} \qquad (3)$$

The deformation properties of the specimen (strain energy or energy absorption capacity) can be described as follows:

$$\Delta W = V \cdot \int_0^{\varepsilon} \sigma d\varepsilon \qquad (4)$$

If the metal has ideal elastic-plastic properties (see fig. 2) equation (4) can be transformed into

$$W \quad = V \cdot R_m \cdot A \qquad (5)$$

where

V = volume of the test piece

R_m = tensile strength

A = elongation on fracture under tensile stress

If another metal capable of sustaining the same amount of strain energy as the basic metal is chosen, equation (5) must be transformed as follows:

$$W = V \cdot R_m \cdot A = \text{const.}$$

$$W = V_0 \cdot R_{m0} \cdot A_0 = V_1 \cdot R_{m1} \cdot A_1 \qquad (6)$$

where

Index 0 = reference metal (steel)

Index 1 = metal chosen.

In a next step, equations (2) and (3) are introduced into equation (6) as follows:

$$W = R_{m0} \cdot A_0 \cdot V_0 = R_{m1} \cdot A_1 \cdot V_1$$

$$= R_{m0} \cdot A_0 \cdot b_0 \cdot e_0 \cdot 5{,}65 \cdot \sqrt{b_0 \cdot e_0} \qquad = R_{m1} \cdot A_1 \cdot b_1 \cdot e_1 \cdot 5{,}65 \cdot \sqrt{b_1 \cdot e_1}$$

where $b_0 = b_1$ = const. (as in the case of real tank shells of a given diameter). The result is as follows:

$$R_{m0} \cdot A_0 \cdot \sqrt{e_0^{\,3}} = R_{m1} \cdot A_1 \cdot \sqrt{e_1^{\,3}}$$

$$\sqrt{e_1^{\,3}} = \sqrt{e_0^{\,3}}\ \frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}$$

$$e_1^{\,3} = e_0^{\,3}\left(\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}\right)^2$$

$$e_1 = e_0 \sqrt[3]{\left(\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}\right)^2} \qquad (7)$$

This final equation is the alternative formula.

Comment:

Although in fact metals do not show ideal elastic-plastic behaviour, nevertheless the application of equation (5) is quite correct, because the area ratio (area under a real stress/strain curve (F_1) divided by the area under the ideal elastic-plastic curve (F_0)) for each metal shows nearly always the same value (0.89 to 0.91). Within a range of 2 to 3%, therefore, wall thicknesses calculated according to the alternative formula (equation 7) show only negligible deviations from real area ratio values. This remark may also be made with reference to the application of the present cube root formula.

Formula	Material Wall thickness	Reference mild steel	Aluminium alloy l Mg 4,5 Mn	Aluminium alloy 5186 (Pechiney)	Austenitic steel (1.4541)	Fine grained steel (St E 460)
Cube Root Formula	$e_1 = e_0 \sqrt[3]{\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}}$	4,0	5,12	4,6	3,0 (2,9)	4,1
Alternative Formula	$e_1 = e_0 \sqrt[3]{\left(\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}\right)^2}$	4,0	6,6	5,3	(2,2) (13,0)	4,1
Cube Root Formula	$e_1 = e_0 \sqrt[3]{\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}}$	6,0	7,7	6,9	4,5 (4,3)	6,1
Alternative Formula	$e_1 = e_0 \sqrt[3]{\left(\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}\right)^2}$	6,0	10,0	7,9	3,4	6,1

Table 1: Required wall thickness e_1 [mm] with $e_0 = 4$ or 6 mm with reference to mild steel (R_{m0} = 360 N/mm² and A_0 = 27%), depending on tank material

Material / Property	Reference mild steel	Al Mg 4.5 Mn	Aluminium alloy 5186 (Pechiney)	Austenitic steel (1.4541)	Fine grained steel (St E 460)
R_{m0} [N/mm²]	360	-	-	-	-
A_0 [%]	27	-	-	-	-
R_{m1} [N/mm²]	-	275	275	540	560
A_1 [%]	-	17	24	43	17
$R_{m0} \cdot A_0$	9 990	-	-	-	-
$R_{m1} \cdot A_1$ $((R_{m1} \cdot A_1) + 15\,\%)$	-	4 675	6 600	23 220 (26 700)	9 520

Table 2: Properties of frequently used tank materials

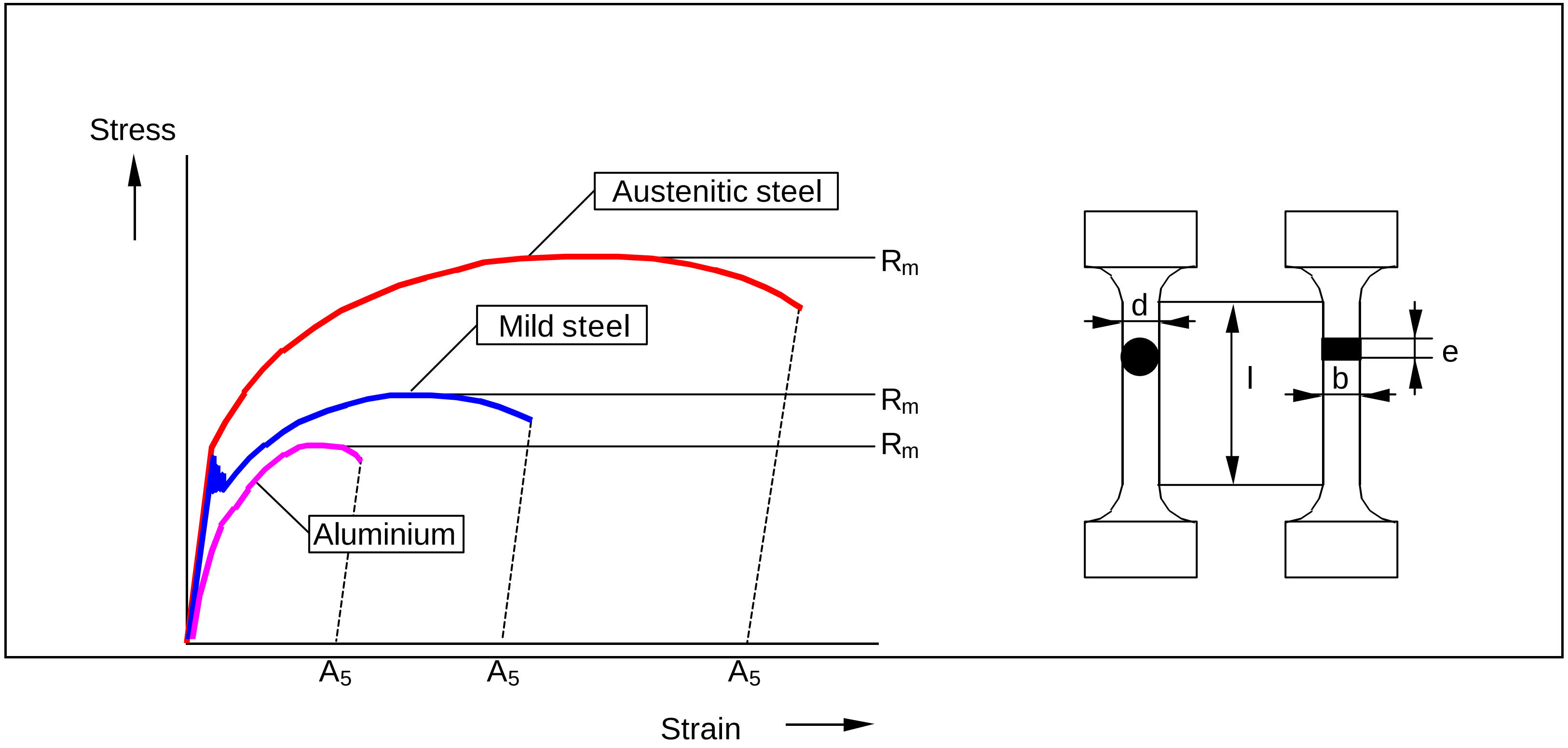
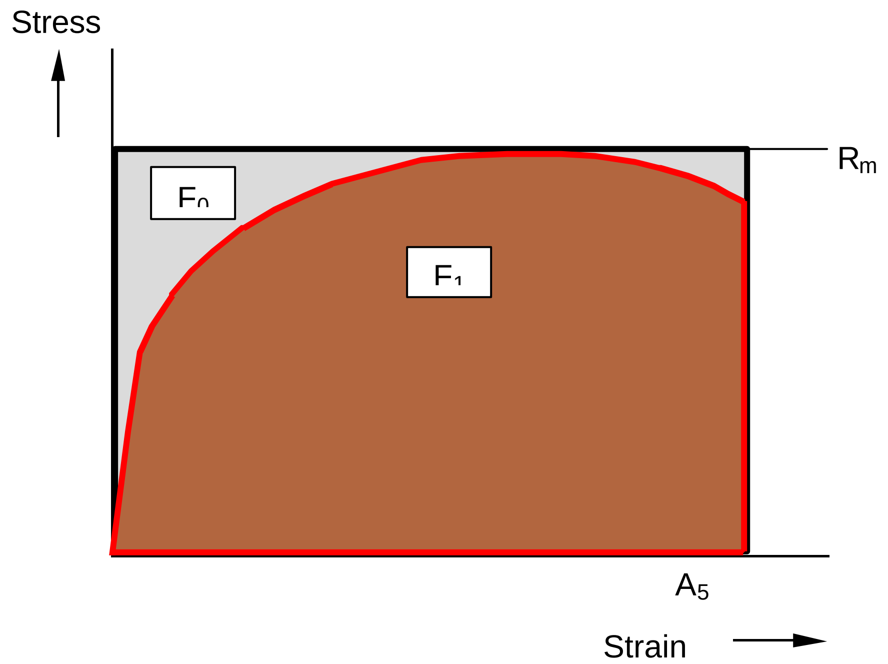


Figure 1: Stress - Strain diagram of typical tank materials



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