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Working Party on the Transport of Dangerous Goods
(Sixty-eighth session, agenda item 4 (a), Geneva, 15-19 May 2000)

Proposal for Amendments to Annexes A and B of ADR

Adequate Equivalence Minimum

Wall Thickness Formula

ADR marginal 21x 127 (3) and (4)

Transmitted by the Government of Germany

Foreword

The matter had been discussed during several sessions of WP.15, Working Group and Ad hoc-Working Group Meetings and the summary of the discussions was given by Germany during the sixty-sixth session of WP.15. Because of different interests of the participants of the several meetings no final agreement could be reached up to then. Therefore, Germany announced during the sixty-sixth WP.15 session to submit a formal proposal on the matter for the sixty-seventh session of WP.15 to ask for a final discussion leading to a decision to change the present marginal 21x 127 (3) and (4).

The proposal submitted in document TRANS/WP.15/1999/49 was discussed during the sixty-seventh session in depth but no representative voting could be achieved because of its complex and complicated justification. Therefore, the decision was taken to discuss the proposal during the meeting of a new-founded Working Group “Tanks” (bringing together experts of interested countries).This meeting was held on 11,12 January 2000, in Berlin (for details see document TRANS/WP.15/2000/4). After a serious and lengthy discussion, the majority of the participants of this meeting was in favour not only of replacing the present cubic-root-formula by the equivalence minimum wall thickness formula (already proposed in document TRANS/WP.15/1999/49), but also of reducing the excessive and detailed justification given in this document to the extent needed to be able to come to a decision during the sixty-eighth session of WP.15.

So, the wording of the proposal itself remains the same as found in document TRANS/WP.15/1999/49, only the justification was changed in the light of the results of the above-mentioned Working Group “Tanks”.

Proposal

1. Replace each of the last sentences of ADR-Marginals

211 127 (3)
211 127 (4)
212 127 (3)
212 127 (4)

by the following text:

“Equivalent thickness” means the thickness obtained by the following formula:

$$e_1 = \frac{456 \cdot e_0}{\sqrt[3]{(Rm_1 \cdot A_1)^2}}$$ 4/

2. Replace footnote 4/ concerning the above mentioned marginals as follows:

4/ This formula is derived from the general formula:

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

where

R_{m0} = 360

A_0 = 27 for the reference mild steel

R_{m1} = minimum tensile strength of the metal chosen, in N/mm^2; and

A_1 = minimum elongation of the metal chosen on fracture under tensile stress, in %

3. Marginals 211 125 (1) and 212 125 (1), consequential amendment

Add the following sentence to the fourth paragraph of the above mentioned marginals (starting with: “When austenitic steels are used....”)

These specified minimum values shall not be exceeded when using the formulas in marginal 211 127 (3) and (4) [212 127 (3) and (4)].

4. Marginal 211 188, consequential amendment

Reword marginal 211 188 as follows:

Fixed tanks (tank vehicles), demountable tanks and battery vehicles constructed before the entry into force of the provisions applicable from [1 January 2001] which do not conform to those provisions but were constructed according to the requirements of ADR in force until that date may still be used.

5. Marginal 212 182, consequential amendment:

Reword marginal 212 182 as follows:

Tank-containers constructed before the entry into force of the provisions applicable from [1 January 2001] which do not conform to those provisions but were constructed according to the requirements of ADR in force until that date may still be used.

Justification

The determination of minimum wall thickness according to the requirements prescribed in marginal 21x 127 (2) results for test and calculation pressures between 4 and 10 bar in wall thicknesses of about 3 up to 5 mm and more related to mild steel. Nevertheless, a sufficient level of safety of the tanks against the effects of internal and external (accidental) loads shall be ensured. This will be done by fulfilling the requirements laid down in the present marginal 21x 127 (3) and (4) respectively by defining absolute minimum thicknesses related to mild steel as follows (marginal 21x 127 (3) e.g.):

"The walls, ends and cover plates of shells, of circular cross-section, not more than 1,80 m in diameter shall be not less than 5 mm thick if of mild steel, or of equivalent thickness if of another metal. Where the diameter is more than 1,80 m the thickness shall be increased to 6 mm except in the case of shells intended for the carriage of powdery or granular substances, if the shell is of mild steel, or to an equivalent thickness if the shell is of another metal. "Equivalent thickness" means the thickness obtained by the following formula:

$$e_1 = \frac{21{,}4 \cdot e_0}{\sqrt[3]{Rm_1 \cdot A_1}}$$ "

These requirements represent the necessary levels of safety of tank shells (i.e. not the fully equipped tank) by the specification of a certain combination of material and wall thicknesses: mild steel of specific properties (reference steel) is combined with wall thicknesses of 6, 5, 4 or 3 mm, depending on the diameter of the tank shell, the substances being transported (liquid/powdery or granular) and the additional protection being applied.

For the use of metallic materials other than the reference steel the above mentioned cubic-root-formula has had to be applied up to now. But the cubic-root-formula does not follow the laws of mechanics: It is inadequate with regard to internal or external loads affected to the tank shell leading to plastic deformation or fracture.

The level of safety of a tank shell is related only to a comparison of

- certain material properties of the reference steel and the value of the basis wall thicknesses,
- certain material properties which result in other wall thicknesses than the basic wall thicknesses if another metal than the reference steel will be used

based on the same value of strain energy up to fracture.

In each case the material properties (i.e. also for different metallic material) will be determined by standardized uniaxial tensile tests. An adequate equivalence minimum wall thickness formula therefore has to be developed on the basis of standardized uniaxial tensile tests, too.

During uniaxial tensile tests the stress-elongation curve and respectively the stress-strain-curve up to the fracture of a specimen of certain dimensions will be recorded. The strain energy up to fracture is equal to the area beneath these curves. Specimens made from different metals are comparable, if equal strain energies have to be applied up to fracture.

The necessary equivalent dimensions (wall thickness e.g.) of the specimen made out of another metal can be determined on the basis of the dimensions (wall thickness e.g.) of the specimen made out of reference steel if the same amount of strain energy up to fracture has to be applied and the material properties of the specimen are known.
Thus, the proposed adequate equivalence minimum wall thickness formula can be derived. Details of the derivation of the proposed formula had been shown already in document TRANS/WP.15/1999/49. To be complete it is attached as an annex to this reworded document.

Additional remarks

The transformation from one material (reference steel) to another related to the same amount of strain energy being absorbed during an uniaxial tensile test (application of the alternative formula i.e.) results in

- higher figures concerning minimum wall thicknesses if common aluminium alloys are used,
- lower figures concerning minimum wall thicknesses if austenitic steels are used.

But the use of advanced aluminium alloys will result in figures for minimum wall thicknesses which will lead to masses of tank shells like those in service now a days. Therefore, no serious justification even from an economical point of view against the application of an adequate alternative formula can be found.

On the other hand, an increase of the safety level of tank shells, made of aluminium alloys can be stated if the alternative formula will be applied.

The consequences of the application of the proposed alternative formula concerning minimum wall thicknesses are shown in tables 1 and 2.

By applying the alternative formula the properties of each material are evaluated in a correct and sufficient manner. So, the special requirement for austenitic steels in marginal 21x 125 (1) - specified minimum figures concerning the properties of austenitic steels may be exceeded up to 15 % - is invalid for its application in future marginal 21x 127 (3) and (4).

Further details concerning the background of the derivation of the alternative formula and the results of previous discussions are shown in the documents TRANS/WP.15/R.433 and INF. 32 (sixty-second session), INF. 13 (sixty-sixth session) and TRANS/WP.15/1999/48 and -/49 (sixty-seventh session).

Annex

Derivation of an adequate equivalence 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 specimen (test piece) of circular cross-section in which the gauge length l is five times the diameter d; if test pieces of rectangular section are used - which 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-sectional area of the test piece (see also marginal 21x 125, footnote 1).

The volume V of the cylindrical and the prismatic specimen 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 $d = \sqrt{\frac{4}{\pi}} \cdot \sqrt{b \cdot e}$

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 (deformation work resp. 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

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

where

V = Volume of the specimen

R_m = tensile strength

A = Elongation on fracture under tensile stress

If another metal which shall be able to absorb the same amount of deformation work (strain energy) like the basic metal, is chosen, equation (5) has to 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 = metal (steel) of reference,

Index 1 = metal chosen.

In a next step equations (2) and (3) will be introduced in equation (6) like 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. (like it is for real tank shells of a given diameter e.g.), so the following result will be reached:

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

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

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

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

So, the derivation of the alternative formula is complete.

A final remark:

Although metals do not show ideal elastic-plastic behaviour, really, nevertheless the application of equation (5) is quite correct, because the area ratio (area under a realistic 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 amount (0.89 to 0.91). So, within a range of up to 2 or 3 % the results of the transformation of wall thicknesses following the alternative formula (equation 7) show negligible deviations to realistic area ratios. This remark has to be made on the application of the present cubic root formula, as well.

Formula	Material/Wall thickness	Reference mild steel	Al Mg 4,5 Mn	Aluminium alloy 5186 (Pechiney)	Austenitic steel (1.4541)	Fine grained steel (St E 460)
Cubic 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)	4,0
Alternative Formula	$e_1 = e_0 \sqrt[3]{\left(\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}\right)^2}$	4,0	6,5	5,2	2,2	4,1
Cubic Root Formula	$e_1 = e_0 \sqrt[3]{\frac{R_{m0} \cdot A_0}{R_{m1} \cdot A_1}}$	6,0	7,7	6,8	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	9,8	7,8	3,4	6,1

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

Property \ Material	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
$R_{m0} \cdot A_0$	9720	-	-	-	-
$R_{m1} \cdot A_1$ $((R_{m1} \cdot A_1) + 15\,\%)$	-	4675	6600	23220 (26700)	9520

Table 2: Material properties of frequently used tank materials

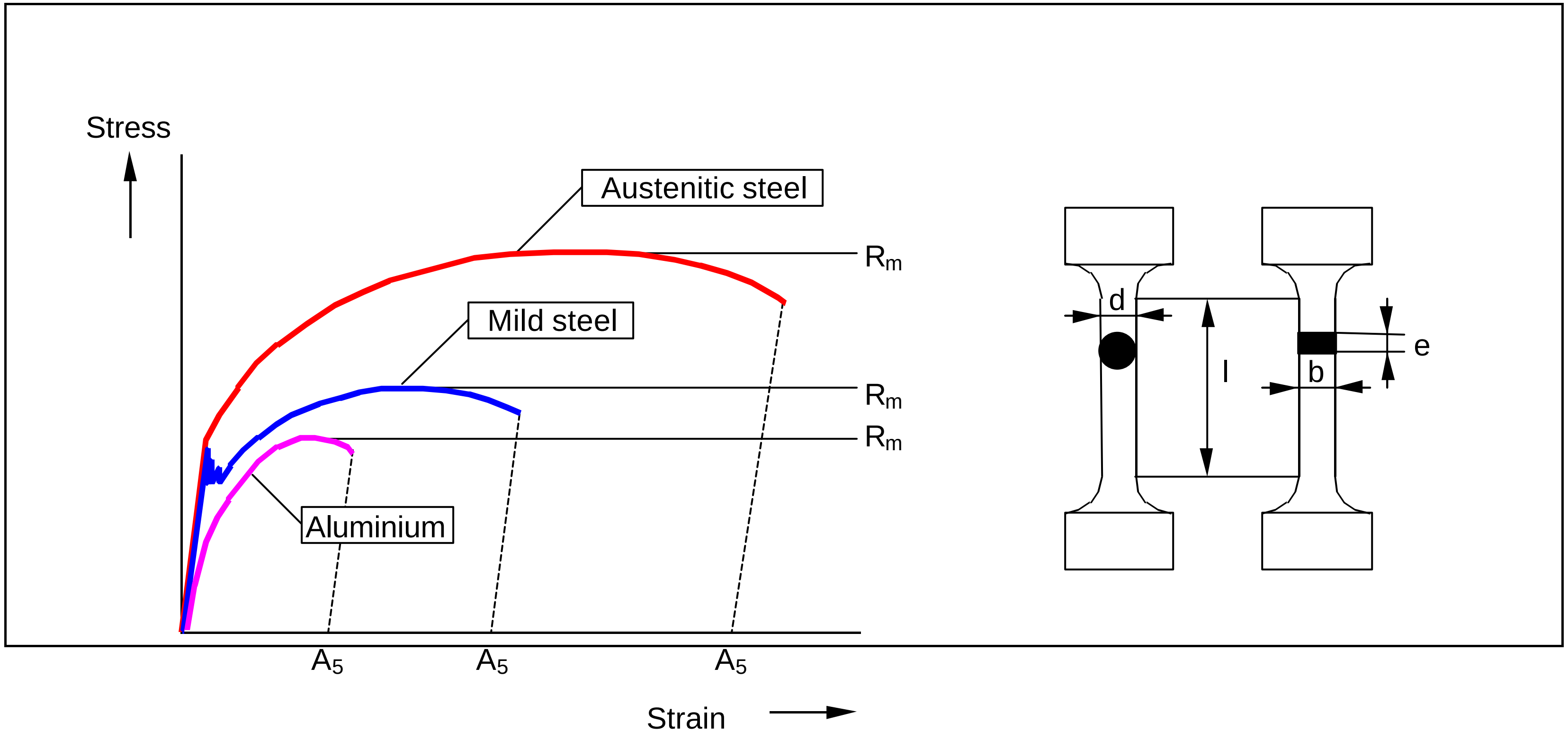
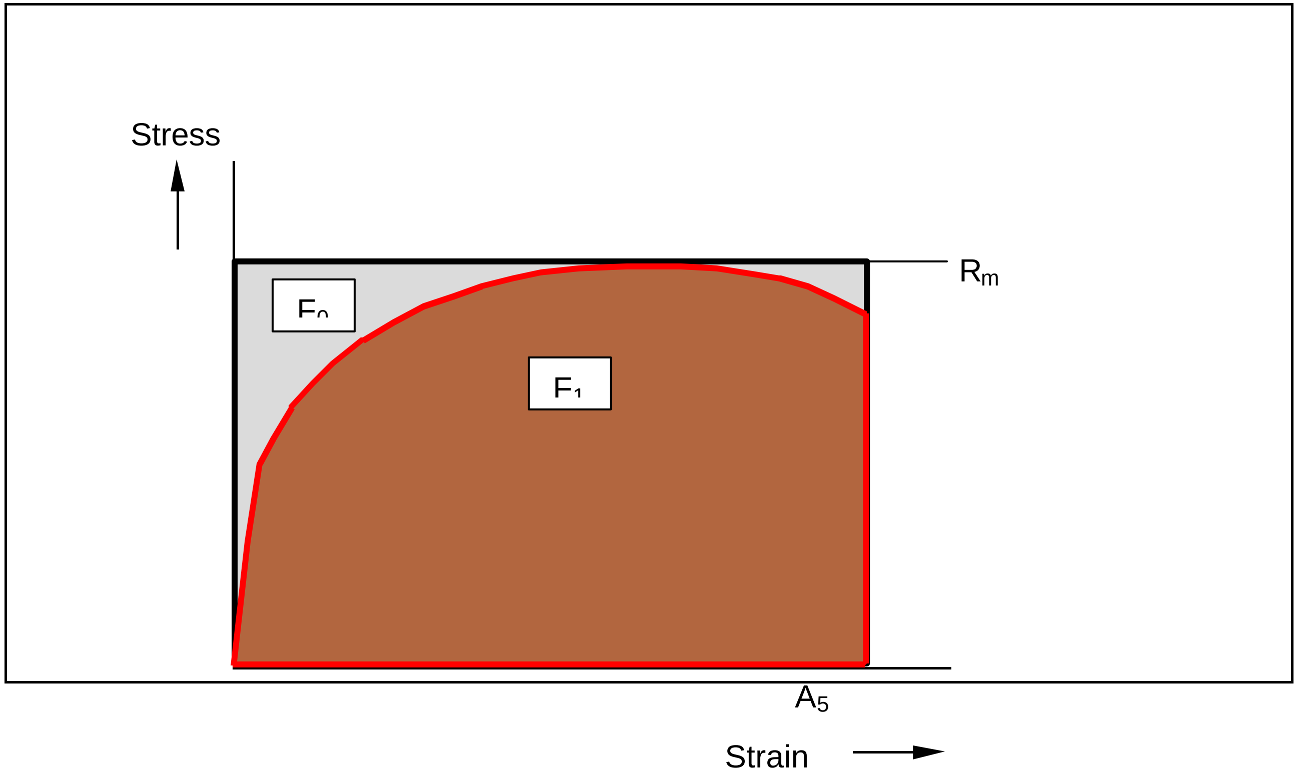


Figure 1: **Stress - strain diagram of typical tank materials**

(diagrammatic view)



Area F_0: Deformation work (Ideal elastic-plastic behaviour)
Area F_1: Deformation work (Realistic stress-strain-curve)

Figure 2: Ideal and realistic stress-strain-curves
(diagrammatic view)