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Eurocode 3 : Design of steel structures

Part 1-10 : Material toughness and through-thickness properties

Calcul des structures en acier

Partie 1-10 :

Choix des qualités d'acier vis à vis de la ténacité et des propriétés dans le

Bemessung und Konstruktion von Stahlbauten

Teil 1-10 :

Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung

Stage 49 draft

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Contents

National annex for EN 1993-1-10

This standard gives alternative procedures, values and recommendations with notes indicating where national choices may have to be made. The National Standard implementing EN 1993-1-10 should have a National Annex containing all Nationally Determined Parameters for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-1-10 through clauses:

- 2.2(5)
- 3.1(1)

1 General

1.1 Scope

(1) EN 1993-1-10 contains design guidance for the selection of steel for fracture toughness and for through thickness properties of welded elements where there is a significant risk of lamellar tearing during fabrication.

(2) Section 2 applies to steel grades S 235 to S 690. However section 3 applies to steel grades S 235 to S 460 only.

NOTE EN 1993-1-1 is restricted to steels S235 to S460.

(3) The rules and guidance given in section 2 and 3 assume that the construction will be executed in accordance with EN 1090.

1.2 Normative references

(1) This European Standard incorporates by dated and undated reference provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE The Eurocodes were published as European Prestandards. The following European Standards which are published or in preparation are cited in normative clauses:

EN 1011-2 Welding. Recommendations for welding of metallic materials: Part 2: Arc welding of ferritic steels

EN 1090 Execution of steel structures

EN 1990 Basis of structural design

EN 1991 Actions on structures

EN 1998 Design provisions for earthquake resistance of structures

EN 10025 Hot rolled products of non-alloy structural steels. Technical delivery conditions

EN 10045-1 Metallic materials - Charpy impact test - Part 1: Test method

EN 10113 Hot-rolled products in weldable fine grain structural steels - Part 1: General delivery conditions; Part 2: Delivery conditions for normalized/normalized rolled steels; Part 3: Delivery conditions for thermomechanical rolled steels”

EN 10137 Plates and wide flats made of high yield strength structural steels in the quenched and tempered or precipitation hardened conditions - Part 1: General delivery conditions; Part 2: Delivery conditions for quenched and tempered steels; Part 3: Delivery conditions for precipitation hardened steels

EN 10155 Structural steels with improved atmospheric corrosion resistance - Technical delivery conditions

EN 10160 Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)

EN 10164 Steel products with improved deformation properties perpendicular to the surface of the product - Technical delivery conditions

EN 10210-1 Hot finished structural hollow sections of non-alloy and fine grain structural steels - Part 1: Technical delivery requirements

EN 10219-1 Cold formed welded structural hollow sections of non-alloy and fine grain steels - Part 1: Technical delivery requirements

1.3 Terms and definitions

1.3.1

K_V-value

The K_V (Charpy V-Notch)-value is the impact energy $A_V(T)$ in Joules [J] required to fracture a Charpy V-notch specimen at a given test temperature T. Steel product standards generally specify that test specimens should not fail at an impact energy lower than 27J at a specified test temperature T.

1.3.2

Transition region

The region of the toughness-temperature diagram showing the relationship $A_V(T)$ in which the material toughness decreases with the decrease in temperature and the failure mode changes from ductile to brittle. The temperature values T_{27J} required in the product standards are located in the lower part of this region.

1.3.3

Upper shelf region

The region of the toughness-temperature diagram in which steel elements exhibit elastic-plastic behaviour with ductile modes of failure irrespective of the presence of small flaws and welding discontinuities from fabrication.

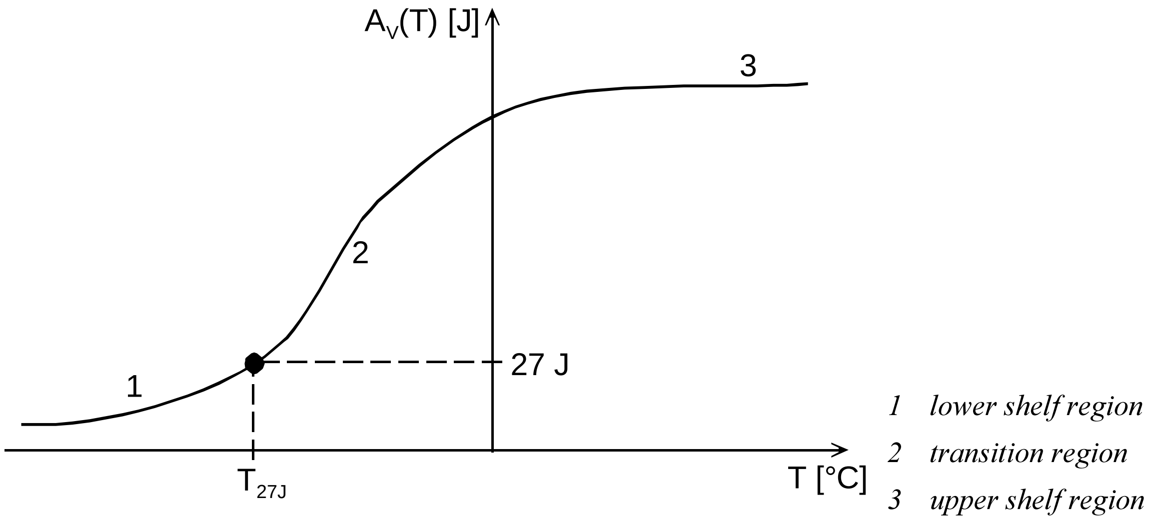


Figure 1.1: Relationship between impact energy and temperature

1.3.4

T_{27J}

Temperature at which a minimum energy A_V will not be less than 27J in a Charpy V-notch impact test.

1.3.5

Z-value

The transverse reduction of area in a tensile test of the through-thickness ductility of a specimen, measured as a percentage.

1.3.6

K_{Ic}-value

The plane strain fracture toughness for linear elastic behaviour measured in $N/mm^{3/2}$.

> **NOTE** The two internationally recognized alternative units for the stress intensity factor K are $N/mm^{3/2}$ and $MPa\sqrt{m}$ (ie $MN/m^{3/2}$) where 1 $N/mm^{3/2}$ = 0,032 $MPa\sqrt{m}$.

1.3.7

Degree of cold forming

Permanent strain from cold forming measured as a percentage.

1.4 Symbols

$A_V(T)$ impact energy in Joule [J] in a test at temperature T with Charpy V notch specimen

Z Z-quality [%]

T temperature [°C]

T_{Ed} reference temperature

δ crack tip opening displacement (CTOD) in mm measured on a small specimen to establish its elastic plastic fracture toughness

J elastic plastic fracture toughness value (J-integral value) in N/mm determined as a line or surface integral that encloses the crack front from one crack surface to the other

K_{Ic} elastic fracture toughness value (stress intensity factor) measured in $N/mm^{3/2}$

ε_{cf} degree of cold forming (DCF) in percent

σ_{Ed} stresses accompanying the reference temperature T_{Ed}

2 Selection of materials for fracture toughness

2.1 General

(1) The guidance given in section 2 should be used for the selection of material for new construction. It is not intended to cover the assessment of materials in service. The rules should be used to select a suitable grade of steel from the European Standards for steel products listed in EN 1993-1-1.

(2) The rules are applicable to tension elements, welded and fatigue stressed elements in which some portion of the stress cycle is tensile.

> **NOTE** For elements not subject to tension, welding or fatigue the rules can be conservative. In such cases evaluation using fracture mechanics may be appropriate, see 2.4. Fracture toughness need not be specified for elements only in compression.

(3) The rules should be applied to the properties of materials specified for the toughness quality in the relevant steel product standard. Material of a less onerous grade should not be used even though test results show compliance with the specified grade.

2.2 Procedure

(1) The steel grade shall be selected taking account of the following:

(i) steel material properties:

- yield strength depending on the material thickness $f_y(t)$
- toughness quality expressed in terms of T_{27J} or T_{40J}

(ii) member characteristics:

- member shape and detail
- stress concentrations according to the details in EN 1993-1-9
- element thickness (t)
- appropriate assumptions for fabrication flaws (e.g. as through-thickness cracks or as semi-elliptical surface cracks)

(iii) design situations:

- design value of lowest member temperature
- maximum stresses from permanent and imposed actions derived from the design condition described in (4) below

- residual stress
- assumptions for crack growth from fatigue loading during an inspection interval (if relevant)
- strain rate $\dot{\varepsilon}$ from accidental actions (if relevant)
- degree of cold forming (ε_{cf}) (if relevant)

(2) The permitted thickness of steel elements for fracture should be obtained from section 2.3 and Table 2.1.

(3) Alternative methods may be used to determine the toughness requirement as follows:

- fracture mechanics method:

  In this method the design value of the toughness requirement should not exceed the design value of the toughness property.

- Numerical evaluation:

  This may be carried out using one or more large scale test specimens. To achieve realistic results, the models should be constructed and loaded in a similar way to the actual structure.

(4) The following design condition should be used:

(i) Actions should be appropriate to the following combination:

$$E_d = E\,\{\,A[T_{Ed}]\ "+"\ \sum G_K\ "+"\ \psi_1\,Q_{K1}\ "+"\ \sum \psi_{2,i}\,Q_{Ki}\,\} \qquad (2.1)$$

where the leading action A is the reference temperature T_{Ed} that influences the toughness of material of the member considered and might also lead to stress from restraint of movement. $\sum G_K$ are the permanent actions, and $\psi_1\,Q_{K1}$ is the frequent value of the variable load and $\psi_{2i}\,Q_{Ki}$ are the quasi-permanent values of the accompanying variable loads, that govern the level of stresses on the material.

(ii) The combinations factor ψ_1 and ψ_2 should be in accordance with EN 1990.

(iii) The maximum applied stress σ_{Ed} should be the nominal stress at the location of the potential fracture initiation. σ_{Ed} should be calculated as for the serviceability limit state taking into account all combinations of permanent and variable actions as defined in the appropriate part of EN 1991.

NOTE 1 The above combination is considered to be equivalent to an accidental combination, because of the assumption of simultaneous occurrence of lowest temperature, flaw size, location of flaw and material property.

NOTE 2 σ_{Ed} may include stresses from restraint of movement from temperature change.

NOTE 3 As the leading action is the reference temperature T_{Ed} the maximum applied stress σ_{Ed} generally will not exceed 75% of the yield strength.

(5) The reference temperature T_{Ed} at the potential fracture location should be determined using the following expression:

$$T_{Ed} = T_{md} + \Delta T_r + \Delta T_\sigma + \Delta T_R + \Delta T_{\dot{\varepsilon}} + \Delta T_{\varepsilon_{cf}} \qquad (2.2)$$

where T_{md} is the lowest air temperature with a specified return period, see EN 1991-1-5

ΔT_r is an adjustment for radiation loss, see EN 1991-1-5

ΔT_σ is the adjustment for stress and yield strength of material, crack imperfection and member shape and dimensions, see 2.4(3)

ΔT_R is a safety allowance, if required, to reflect different reliability levels for different applications

$\Delta T_{\dot{\varepsilon}}$ is the adjustment for a strain rate other than the reference strain rate $\dot{\varepsilon}_0$ (see equation 2.3)

$\Delta T_{\varepsilon_{cf}}$ is the adjustment for the degree of cold forming ε_{cf} (see equation 2.4)

NOTE 1 The safety element ΔT_R to adjust T_{Ed} to other reliability requirements may be given in the National Annex. ΔT_R = 0 °C is recommended, when using the tabulated values according to 2.3.

NOTE 2 In preparing the tabulated values in 2.3 a standard curve has been used for the temperature shift ΔT_σ that envelopes the design values of the stress intensity function [K] from applied stresses σ_{Ed} and residual stresses and includes the Wallin-Sanz-correlation between the stress intensity function [K] and the temperature T. A value of ΔT_σ = 0 °C may be assumed when using the tabulated values according to 2.3.

NOTE 3 The National Annex may give maximum values of the range between T_{Ed} and the test temperature and also the range of σ_{Ed} , to which the validity of values for permissible thicknesses in Table 2.1 may be restricted.

NOTE 4 The application of Table 2.1 may be limited in the National Annex to use of up to S 460 steels.

(6) The reference stresses σ_{Ed} should be determined using an elastic analysis taking into account secondary effects from deformations

2.3 Maximum permitted thickness values

2.3.1 General

(1) Table 2.1 gives the maximum permissible element thickness appropriate to a steel grade, its toughness quality in terms of K_V-value, the reference stress level [σ_{Ed}] and the reference temperature [T_{Ed}].

(2) The tabulated values are based on the following assumptions:

– the values satisfy the reliability requirements of EN 1990 for the general quality of material

– a reference strain rate $\dot{\varepsilon}_0$ = 4×10^{-4}/sec has been used. This covers the dynamic action effects for most transient and persistent design situations. For other strain rates $\dot{\varepsilon}$ (e.g. for impact loads) the tabulated values may be used by reducing T_{Ed} by deducting $\Delta T_{\dot{\varepsilon}}$ given by

$$\Delta T_{\dot{\varepsilon}} = \frac{1440 - f_y(t)}{550} \times \left(\ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)^{1,5} \quad [°C] \tag{2.3}$$

– non cold-formed material with ε_{cf} = 0% has been assumed. To allow for cold forming of non-ageing steels, the tabulated values may be used by adjusting T_{Ed} by deducting $\Delta T_{\varepsilon_{cf}}$ where

$$\Delta T_{\varepsilon_{cf}} = 3 \times \varepsilon_{cf} \quad [°C] \tag{2.4}$$

– the nominal notch toughness values in terms of T_{27J} are based on the following product standards: EN 10025, EN 10113-1 to 3, EN 10137-1 to 3, EN 10155, EN 10210-1, EN 10219-1

For other values the following correlation has been used

$$\begin{aligned} T_{40J} &= T_{27J} + 10\,[°C] \\ T_{30J} &= T_{27J} + 0\,[°C] \end{aligned} \tag{2.5}$$

– for members subject to fatigue all detail categories for nominal stresses in EN 1993-1-9 are covered

NOTE Fatigue has been taken into account by applying a fatigue load to a member with an assumed initial flaw. The damage assumed is one quarter of the full fatigue damage obtained from EN 1993-1-9. This approach permits the evaluation of a minimum number of “safe periods” between in-service inspections when inspections shall be specified for damage tolerance according to EN 1993-

1-9. The required number [n] of in-service inspections is related to the partial factors γ_{Ff} and γ_{Mf} applied in fatigue design according to EN 1993-1-9 by the expression

$$n = \frac{4}{(\gamma_{Ff}\,\gamma_{Mf})^m} - 1 \ ,$$

where m = 5 applies for long life structures such as bridges.

The “safe period” between in-service inspections may also cover the full design life of a structure.

2.3.2 Determination of maximum permissible values of element thickness

(1) Table 2.1 gives the maximum permissible values of element thickness in terms of three stress levels expressed as proportions of the nominal yield strength:

a) $\sigma_{Ed} = 0{,}75\ f_y(t)$ [N/mm²]

b) $\sigma_{Ed} = 0{,}50\ f_y(t)$ [N/mm²] (2.6)

c) $\sigma_{Ed} = 0{,}25\ f_y(t)$ [N/mm²]

where $f_y(t)$ may be determined either from

$$f_y(t) = f_{y,nom} - 0{,}25\frac{t}{t_0} \quad [\mathrm{N/mm^2}]$$

where t is the thickness of the plate in mm

$t_0 = 1$ mm

or taken as R_{eH}-values from the relevant steel standards..

The tabulated values are given in terms of a choice of seven reference temperatures: +10, 0, -10, -20, -30, -40 and -50°C.

Table 2.1: Maximum permissible values of element thickness t in mm

Steel grade	Sub-grade	Charpy energy CVN		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0{,}75\ f_y(t)$							$\sigma_{Ed} = 0{,}50\ f_y(t)$							$\sigma_{Ed} = 0{,}25\ f_y(t)$						
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	15	10	65	55	45	40	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	25	135	110	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
	QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100

NOTE 1 Linear interpolation can be used in applying Table 2.1. Most applications require σ_{Ed} values between $\sigma_{Ed} = 0{,}75\ f_y(t)$ and $\sigma_{Ed} = 0{,}50\ f_y(t)$. $\sigma_{Ed} = 0{,}25\ f_y(t)$ is given for interpolation purposes. Extrapolations beyond the extreme values are not valid.

NOTE 2 For ordering products made of S 690 steels the T_J – values should be specified.

2.4 Evaluation using fracture mechanics

(1) For numerical evaluation using fracture mechanics the toughness requirement and the design toughness property of the materials may be expressed in terms of CTOD values, J-integral values, K_{IC} values, or K_V-values and comparison shall be made using suitable fracture mechanics methods.

(2) The following condition for the reference temperature should be met:

$$T_{Ed} \leq T_{Rd} \qquad (2.7)$$

where T_{Rd} is the temperature at which a safe level of fracture toughness can be relied upon under the conditions being evaluated

(3) The potential failure mechanism should be modelled using a suitable flaw that reduces the net section of the material thus making it more susceptible to failure by fracture of the reduced section. The flaw should meet the following requirements:

– location and the shape should be appropriate for the notch case considered. The fatigue classification tables in EN 1993-1-9 may be used for guidance on appropriate crack positions.

– for members not susceptible to fatigue the size of the flaw should be the maximum likely to have been left uncorrected in inspections carried out to EN 1090. The assumed flaw shall be located at the position of adverse stress concentration.

– for members susceptible to fatigue the size of the flaw should consist of an initial flaw grown by fatigue. The size of the initial crack should be chosen such that it represents the minimum value detectable by the inspection methods used in accordance with EN 1090. The crack growth from fatigue shall be calculated with an appropriate fracture mechanics model using loads experienced during the design safe working life or an inspection interval (as relevant).

(4) If a structural detail cannot be allocated a specific detail category from EN 1993-1-9 or if more rigorous methods are used to obtain results which are more refined than those given in Table 2.1 then a specific verification should be carried out using actual fracture tests on large scale test specimens.

NOTE The numerical evaluation of the test results may be undertaken using the methodology given in Annex D of EN 1990.

3 Selection of materials for through-thickness properties

3.1 General

(1) The choice of quality class should be selected from Table 3.1 depending on the consequences of lamellar tearing.

Table 3.1: Choice of quality class according to EN 10164

Class	Application of guidance
1	All steel products and all thicknesses listed in European standards for all applications
2	Certain steel products and thicknesses listed in European standards and/or certain listed applications

NOTE The National Annex may choose the relevant class. The use of class 1 is recommended.

(2) Depending on the quality class selected from Table 3.1, either:

– through thickness properties for the steel material should be specified from EN 10164, or

– post fabrication inspection should be used to identify whether lamellar tearing has occurred.

(3) The following aspects should be considered in the selection of steel assemblies or connections to safeguard against lamellar tearing:

– the criticality of the location in terms of applied tensile stress and the degree of redundancy.

– the strain in the through-thickness direction in the element to which the connection is made. This strain arises from the shrinkage of the weld metal as it cools. It is greatly increased where free movement is restrained by other portions of the structure.

– the nature of the joint detail, in particular welded cruciform, tee and corner joints. For example, at the point shown in Figure 3.1, the horizontal plate might have poor ductility in the through-thickness direction. Lamellar tearing is most likely to arise if the strain in the joint acts through the thickness of the material, which occurs if the fusion face is roughly parallel to the surface of the material and the induced shrinkage strain is perpendicular to the direction of rolling of the material. The heavier the weld, the greater is the susceptibility.

– chemical properties of transversely stressed material. High sulfur levels in particular, even if significantly below normal steel product standard limits, can increase the lamellar tearing.

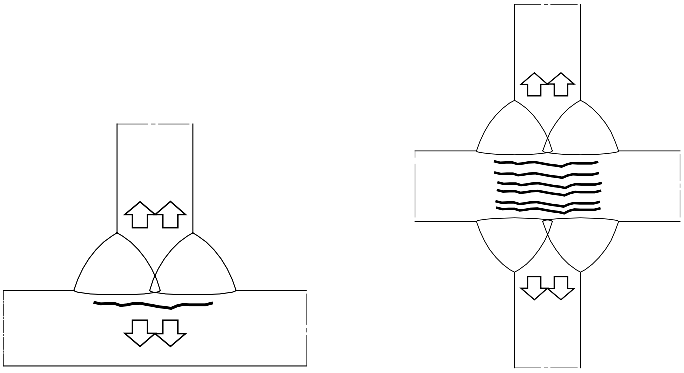


Figure 3.1: Lamellar tearing

(4) The susceptibility of the material should be determined by measuring the through-thickness ductility quality to EN 10164, which is expressed in terms of quality classes identified by Z-values.

NOTE 1 Lamellar tearing is a weld induced flaw in the material which generally becomes evident during ultrasonic inspection. The main risk of tearing is with cruciform, T- and corner joints and with full penetration welds.

NOTE 2 Guidance on the avoidance of lamellar tearing during welding is given in EN 1011-2.

3.2 Procedure

(1) Lamellar tearing may be neglected if the following condition is satisfied:

$$Z_{Ed} \leq Z_{Rd} \quad (3.1)$$

where Z_{Ed} is the required design Z-value resulting from the magnitude of strains from restrained metal shrinkage under the weld beads.

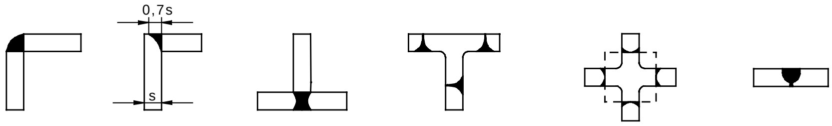
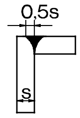
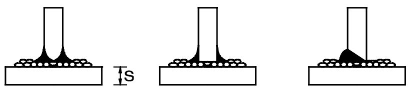
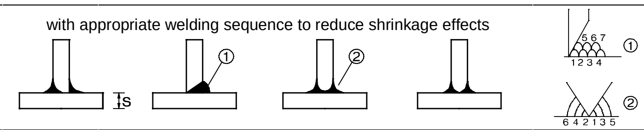
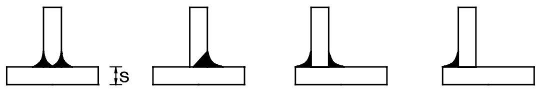
Z_{Rd} is the available design Z-value for the material according to EN 10164.

(2) The required design value Z_{Ed} may be determined using:

$$Z_{Ed} = Z_a + Z_b + Z_c + Z_d + Z_e \quad (3.2)$$

in which Z_a, Z_b, Z_c, Z_d and Z_e are as given in Table 3.2.

Table 3.2: Criteria affecting the target value of Z_{Ed}

a)	Weld depth relevant for straining from metal shrinkage	Effective weld depth a_{eff} (see Figure 3.2) = throat thickn. a of fillet welds		$\mathbf{Z_i}$
		$a_{eff} \leq$ 7mm	a = 5 mm	$\mathbf{Z_a = 0}$
		$7 < a_{eff} \leq 10$mm	a = 7 mm	$\mathbf{Z_a = 3}$
		$10 < a_{eff} \leq 20$mm	a = 14 mm	$\mathbf{Z_a = 6}$
		$20 < a_{eff} \leq 30$mm	a = 21 mm	$\mathbf{Z_a = 9}$
		$30 < a_{eff} \leq 40$mm	a = 28 mm	$\mathbf{Z_a = 12}$
		$40 < a_{eff} \leq 50$mm	a = 35 mm	$\mathbf{Z_a = 15}$
		$50 < a_{eff}$	a > 35 mm	$\mathbf{Z_a = 15}$
b)	Shape and position of welds in T- and cruciform- and corner-connections			$\mathbf{Z_b = -25}$
		corner joints		$\mathbf{Z_b = -10}$
		single run fillet welds $Z_a = 0$ or fillet welds with $Z_a > 1$ with buttering with low strength weld material		$\mathbf{Z_b = -5}$
		multi run fillet welds		$\mathbf{Z_b = 0}$
		partial and full penetration welds		$\mathbf{Z_b = 3}$
		partial and full penetration welds		$\mathbf{Z_b = 5}$
		corner joints		$\mathbf{Z_b = 8}$
c)	Effect of material thickness *s* on restraint to shrinkage	$s \leq 10$mm		$\mathbf{Z_c = 2^*}$
		$10 < s \leq 20$mm		$\mathbf{Z_c = 4^*}$
		$20 < s \leq 30$mm		$\mathbf{Z_c = 6^*}$
		$30 < s \leq 40$mm		$\mathbf{Z_c = 8^*}$
		$40 < s \leq 50$mm		$\mathbf{Z_c = 10^*}$
		$50 < s \leq 60$mm		$\mathbf{Z_c = 12^*}$
		$60 < s \leq 70$mm		$\mathbf{Z_c = 15^*}$
		$70 < s$		$\mathbf{Z_c = 15^*}$
d)	Remote restraint of shrinkage after welding by other portions of the structure	Low restraint:	Free shrinkage possible (e.g. T-joints)	$\mathbf{Z_d = 0}$
		Medium restraint:	Free shrinkage restricted (e.g. diaphragms in box girders)	$\mathbf{Z_d = 3}$
		High restraint:	Free shrinkage not possible (e.g. stringers in orthotropic deck plates)	$\mathbf{Z_d = 5}$
e)	Influence of preheating	Without preheating		$\mathbf{Z_e = 0}$
		Preheating ≥ 100°C		$\mathbf{Z_e = -8}$

* May be reduced by 50% for material stressed, in the through-thickness direction, by compression due to predominantly static loads.

Figure 3.2: Effective weld depth a_{eff} for shrinkage

(3) The appropriate Z_{Rd}-class according to EN 10164 may be obtained by applying a suitable classification.

NOTE For classification see EN 1993-1-1 and EN 1993-2 to EN 1993-6.