BS ISO 18338:2015

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Metallic materials — Torsion test at ambient temperature

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee ISE/101/2, Ductility testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2015

ISBN 978 0 580 80646 9

ICS 77.040.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2015.

Amendments/corrigenda issued since publication

Date	Text affected

BS ISO 18338:2015

INTERNATIONAL STANDARD

ISO 18338

First edition
2015-09-15

Metallic materials — Torsion test at ambient temperature

Matériaux métalliques — Essai de torsion à température ambiante

Reference number
ISO 18338:2015(E)

Contents

Page

Foreword

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The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 2, *Ductility testing*.

Metallic materials — Torsion test at ambient temperature

1 Scope

This International Standard specifies the method for torsion test at room temperature of metallic materials. The tests are conducted at room temperature to determine torsional properties.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 377, *Steel and steel products — Location and preparation of samples and test pieces for mechanical testing*

ISO 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing*

ASTM E2624, *Standard Practice for Torque Calibration of Testing Machines and Devices*

DIN 51309, *Materials testing machines — Calibration of static torque measuring devices*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
troptometer gauge length
L_e
length of the parallel reduced section of the test piece for measurement of angle of twist by means of a troptometer

3.2
torque
T
moment of couple that generates or tends to generate rotation or torsion

3.3
maximum torque
T_m
for materials displaying discontinuous yielding, highest torque that the test piece withstands during the test after the yielding period, or for materials displaying no discontinuous yielding, highest torque that the test piece withstands during the test

3.4
angle of twist
ϕ
angle of relative rotation measured between two planes normal to the test-piece's longitudinal axial over the gauge length

Note 1 to entry: See Figure 1.

3.5
shear angle
ψ
angle due to shearing displacement at surface of test piece along the gauge length

Note 1 to entry: See Figure 1.

3.6
shear stress
τ
any moment during the test, torque, T, divided by the original polar section modulus, W_p

3.7
shearing displacement
ΔL
arc length swept out by the cylinder or major tube radius moving through the angle of twist, also being equivalent to the gauge length sweeping through the shear angle

Note 1 to entry: See Figure 1.

3.8
shear strain
γ
based on the gauge length, the increase of the shearing displacement, ΔL, at any moment during the test, expressed as a percentage of the gauge length L_e, or is equal to the tangent of the shear angle, ψ

3.9
slope
m_G
slope of the linear, elastic portion of the shear stress-shear strain curve

3.10
torsional proof strength, plastic torsion
τ_p
shear stress at which the plastic component of shear strain, due to torsion at the test piece outer surface, is equal to a specified percentage

Note 1 to entry: A suffix is added to the subscript to indicate the prescribed percentage, e.g. $\tau_{p0,35}$.

3.11
torsional yield strength
when the metallic material exhibits a yield phenomenon, shear stress corresponding to the point reached during the torsion test at which plastic deformation occurs without any increase in the torque

3.11.1
upper torsional yield strength
τ_{eH}
maximum value of shear stress prior to the first decrease in torque when the discontinuous yielding occurs

3.11.2
lower torsional yield strength
τ_{eL}
lowest value of shear stress during discontinuous yielding, ignoring any initial transient effects

3.12
torsional strength
τ_m
shear stress corresponding to the maximum torque, T_m

3.13
maximum plastic shear strain
γ_{max}
maximum plastic shear strain component at the outer surface when total separation of the test piece occurs

3.14
reference torsional proof strength, plastic torsion
τ_{rp}
shear stress at the outer surface of a test piece, calculated according to Nadai's expression, when cross-section of the test piece is in partly plastic torsion and attained the proof plastic shear strain

Note 1 to entry: A suffix is added to the subscript to indicate the prescribed percentage, e.g. $\tau_{rp0,35}$.

3.15
reference torsional strength
τ_{rm}
maximum shear stress is calculated according to the Nadai's expression for fractured test piece

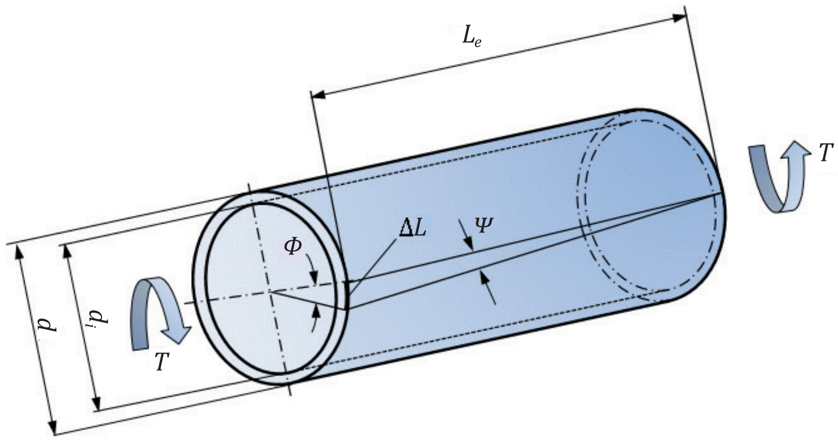


Figure 1 — Basic symbols for torsion test

4 Symbols and designations

Symbols and corresponding designations are given in Table 1 and Figure 1 or elsewhere in this International Standard where they appear.

Table 1 — Symbols and designations

Symbol	Designation	Unit
	Test piece	
d	original external diameter of a tube or a cylinder test piece parallel length portion	mm
d_i	original internal diameter of the parallel length of a tube test piece	mm
L_c	parallel length	mm
L_e	troptometer gauge length	mm
L_t	total length of the test piece	mm
W_p	original polar section modulus [see Formulae (2) and (3)]	mm^3
	Torque	
T	Torque	N·mm
	Angle of twist – shearing displacement	
ϕ	angle of twist	rad
Ψ	shear angle	rad
ΔL	shearing displacement	mm
	Shear stress – shear strain	
τ	shear stress	MPa[a]
$\Delta\tau$	increment in shear stress	MPa
γ	shear strain	%
$\Delta\gamma$	Increment in shear strain	%
γ_p	specified plastic shear strain	%
$\gamma_{\max}$	maximum plastic shear strain	%
	Yield strength – proof strength – torsional strength	
m_G	slope of elastic portion of the shear stress-shear strain curve[b]	MPa
τ_{eH}	upper torsional yield strength	MPa
τ_{eL}	lower torsional yield strength	MPa
τ_p	torsional proof strength, plastic torsion	MPa
τ_m	torsional strength	MPa
τ_{rp}	reference torsional proof strength, plastic torsion	MPa
τ_{rm}	reference torsional strength	MPa

[a] 1 MPa = 1 Nmm^{-2}.

[b] In the elastic portion of the shear stress-shear strain curve, the value of slope may not necessarily represent the shear modulus of elasticity. The value can closely agree with the value of shear modulus of elasticity if optimal conditions (high resolution of troptometer, high accuracy of torque measuring system, perfect alignment of the test piece, etc.) are used.

5 Principle of test

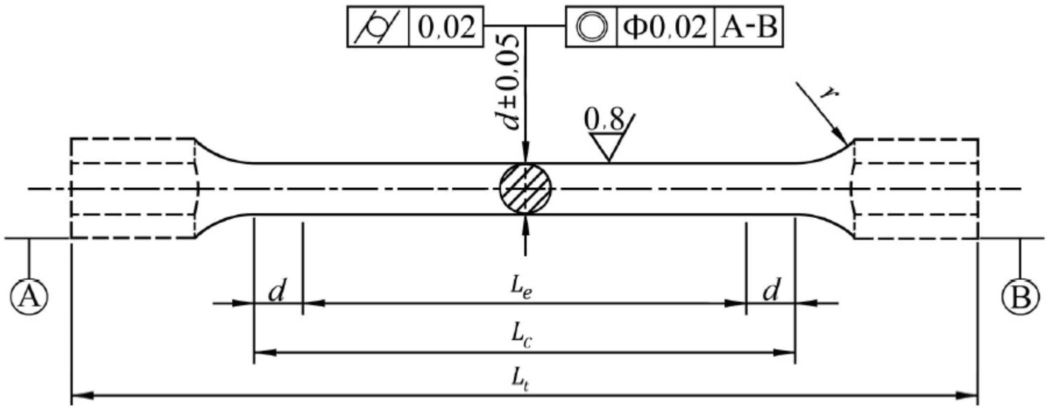
The test piece is subjected to continuously increasing angle of twist, generally to fracture, for the determination of one or more of the mechanical properties such as elastic slope, torsional proof strength, torsional yield strength, torsional strength and maximum plastic shear strain.

6 Test piece

6.1 Shape and dimensions of test pieces

6.1.1 Cylinder test pieces

The shape and dimensions for cylinder test pieces are shown in Figure 2. The shape and size for two ends of the test piece should be in coincidence with the testing machine gripping part. It is recommended that the test pieces be 10 mm diameter, 50 mm or 100 mm gauge length, and 70 mm or 120 mm parallel length. If other test pieces are used, the parallel length should be the sum of gauge length and two times diameter.



Key

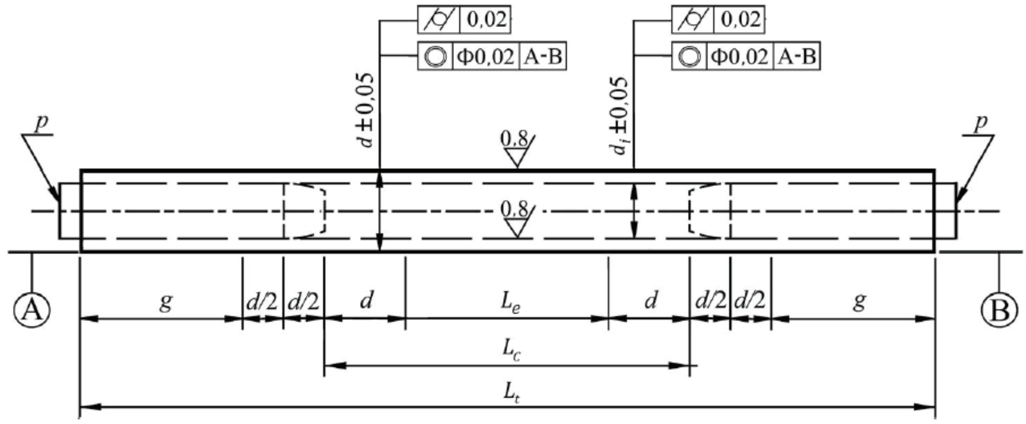
r transition radius

NOTE The shape of the test-piece heads is only given as a guide.

Figure 2 — Cylinder test piece

6.1.2 Tube test pieces

The shape and dimensions for tube test pieces are shown in Figure 3. The parallel length for tube test pieces should be the sum of gauge length and two times external diameter. Tube test pieces should be straight and round, plugged at both ends. The plugged two ends should not be in the parallel length part of tube test pieces. The shape and size for plugs are shown in Figure 4.



Key

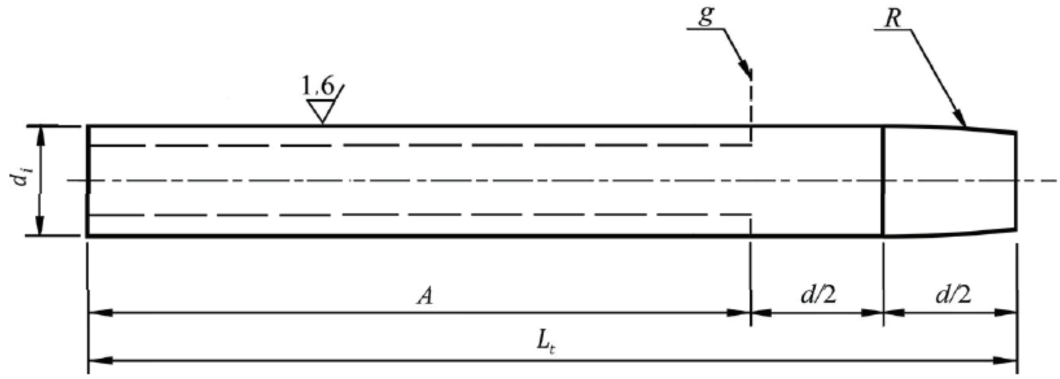
g gripped end

d original external diameter

p plug

d_i original internal diameter

Figure 3 — Tube test piece



Key

g gripped end

R plug transition radius

A parallel and straight part of the plug, here $A \geq 40$ mm

NOTE The diameter of the plug shall have a slight taper from the grip limiting line to the curved section.

Figure 4 — Plugs for tube test pieces

6.1.3 Preparation of test pieces

The test pieces shall be taken and prepared in accordance with the requirement of the relevant International Standards for the different materials. If applicable, the test pieces shall meet the requirement of tensile test pieces specified in ISO 377.

7 Determination of original cross-sectional dimensions

7.1 Cylinder test pieces

The external diameter of the cylinder test piece should be measured at sufficient cross-sections perpendicular to the longitudinal axis in the central region of the parallel length of the test piece. The measuring error of diameter should not exceed ±0,5 %. A minimum of three cross-sections is recommended. The average diameter measured will be used for the calculation of the original polar section modulus, W_p.

7.2 Tube test pieces

The external diameter and internal diameter for tube test pieces should be measured at two ends and on two directions perpendicular to each other, respectively. The measuring error of external diameter and internal diameter should not exceed ±0,5 %.The average external diameter and internal diameter measured will be used for the calculation of the original polar section modulus, W_p.

8 Accuracy of the testing apparatus

8.1 Testing machine

8.1.1 Either one of the gripping parts of the testing machine can freely move along the axial direction during torsion test and the two gripping parts should be in good alignment.

8.1.2 The angle of twist shall be applied continuously on the test piece without shock and vibration.

8.1.3 The indicated torque value of testing machine shall be calibrated periodically for the range of torque used in the determination, and the relative error shall not exceed ±1,0 %.

8.1.4 The torque measuring system shall be calibrated periodically according to ASTM E2624 or DIN 51309.

8.2 Troptometer

8.2.1 The troptometer used here employs an extensometer to measure the linear displacement caused by an angular displacement of the test piece. Troptometers based on other principles or using other types of displacement sensors are acceptable as long as they provide measurements with equivalent accuracies. All kinds of troptometers shouldn't be used for measuring angle of twist unless the below requirements can be satisfied.

8.2.2 The troptometers should be firmly clapped on the test piece and no slip is authorized in the testing procedure. The relative error for troptometers gauge length shall not be bigger than ±1,0 %.

8.2.3 The resolution for indicated angle of twist shall be smaller than or equal to 0,000 17rad. (0,01°).

8.2.4 The relative error for indicated angle of twist shall not be bigger than ±1,0 % [$\phi \leq$ 0,017rad (1°)], it shall be smaller than or equal to ±0,000 17rad (0,01°).

8.2.5 The troptometers shall be calibrated periodically based on ISO 9513.

9 Conditions of testing

9.1 The test is carried out at room temperature between 10 °C and 35 °C, unless otherwise specified. Tests carried out under controlled conditions shall be made at a temperature of 23 °C ± 5 °C.

9.2 Torsion test rate shall be in the range of 0,000 87rad/s to 0,00 87rad/s (0,05°/s to 0,5°/s) until torsional yield strength or torsional proof strength is determined; and it shall be not bigger than 12°/s after those properties are determined.

10 Determination of the properties

10.1 Calculations of shear stress and shear strain

Shear stress shall be calculated from the torque measured in the torsion test, according to Formula (1):

$$\tau = \frac{T}{W_p} \tag{1}$$

For the cylinder test pieces:

$$W_p = \frac{\pi \cdot d^3}{16} \tag{2}$$

For the tube test pieces:

$$W_p = \frac{\pi\left(d^4 - d_i^4\right)}{16d} \tag{3}$$

Shear strain shall be calculated from the angle of twist measured in the torsion test, according to Formula (4):

$$\gamma = \frac{\phi d}{2L_e} \times 100 \tag{4}$$

or from the shear angle measured in the torsion test, according to Formula (5):

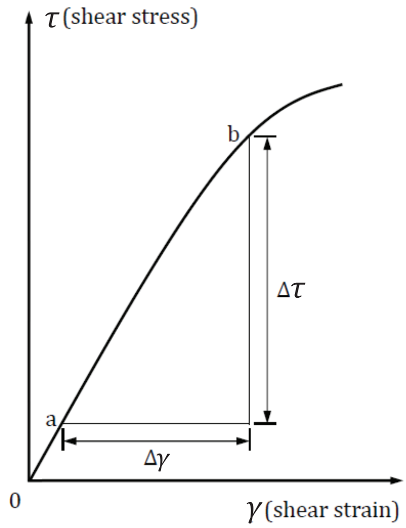
$$\gamma = \tan\psi \times 100 \tag{5}$$

10.2 Determination of the slope of linear portion of shear stress-shear strain curve

10.2.1 From the linear portion of curve, the stress increment and at the same time the corresponding strain increment are obtained (see Figure 5). The slope of the linear portion can be calculated according to Formula (6):

$$m_G = \frac{\Delta\tau}{\Delta\gamma} \tag{6}$$

10.2.2 The parameter may be obtained without plotting the shear stress-shear strain curve by using automatic devices.



Key

a Lower point of the linear portion.

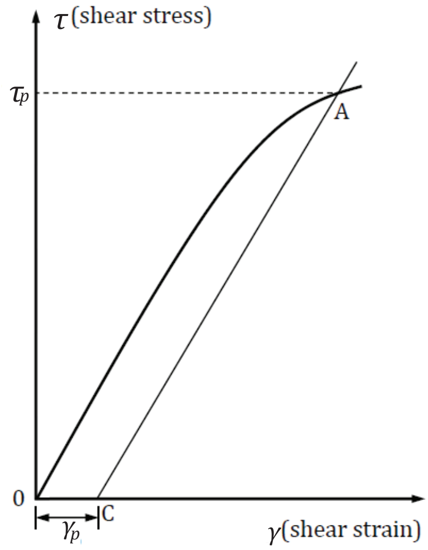
b Upper point (below proportional limit)of the linear portion.

Figure 5 — Determination of the slope of linear portion of $\tau - \gamma$ curve

10.3 Torsional proof strength, plastic torsion

10.3.1 τ_p is determined from the shear stress-shear strain curve by drawing a line parallel to the linear portion of the curve and at a distance from it equivalent to the prescribed plastic shear strain, e.g. γ_p = 0,35 %, see Figure 6. The point at which this line intersects the curve gives the stress τ_p corresponding to the desired proof strength, plastic shear strain, γ_p. Figure 6 shows the nominal torsional proof strength measured by the conventional method. For determining the reference torsional proof strength, see Annex A.

10.3.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.



Key

γ_p prescribed plastic shear strain

τ_p proof strength, plastic torsion

Figure 6 — Determination of the torsional proof strength, τ_p, corresponding to the desired plastic shear strain, γ_p, from the $\tau-\gamma$ curve

10.4 Upper torsional yield strength and the lower torsional yield strength

10.4.1 τ_{eH} is determined as the maximum value of stress prior to the first decrease in stress from the shear stress-shear strain curve; see Figure 7 a).

10.4.2 τ_{eL} is determined as the lowest value of stress during discontinue yielding, ignoring any initial transient effects from the shear stress-shear strain curve; see Figure 7 b).

10.4.3 The properties may be obtained without plotting the shear stress-shear strain curve by using automatic devices.

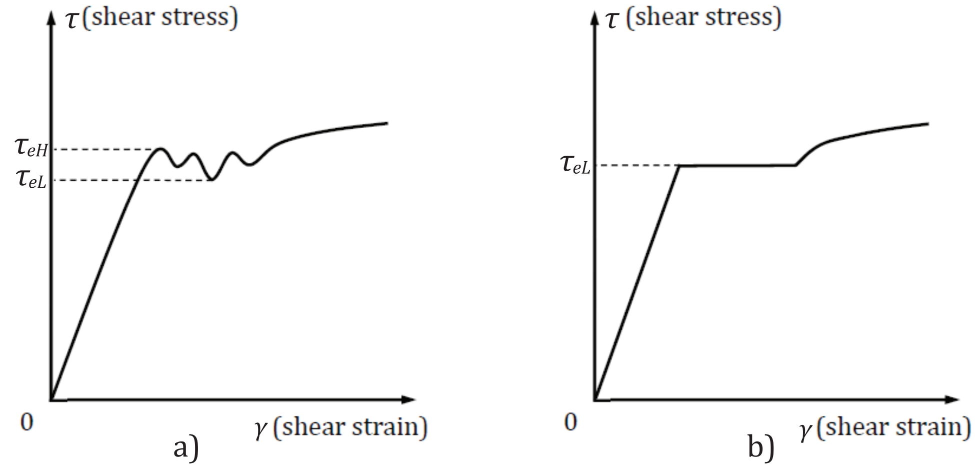


Figure 7 — Determination of the upper torsional yield strength, τ_{eH}, and lower torsional yield strength, τ_{eL}, from the $\tau-\gamma$ curve

10.5 Determination of torsional strength

10.5.1 The test piece is subjected to a continuously increasing angle of twist until fracture. The maximum shear stress is obtained before fracture from the shear stress-shear strain curve; see Figure 8. The figures show the nominal torsional strength measured by the conventional method when fracture occurs at peak load (a) and when some softening occurs after peak load (b). For determining the reference torsional strength, see Annex A.

10.5.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.

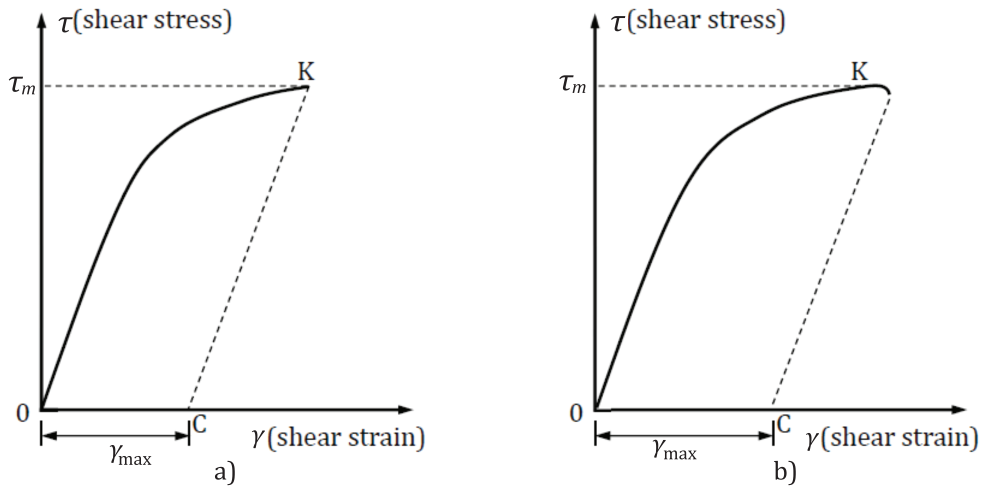


Figure 8 — Maximum shear stress and maximum plastic shear strain component corresponding to the fracture point

10.6 Determination of maximum plastic shear strain

10.6.1 Maximum plastic shear strain is determined from the shear stress-shear strain curve by drawing a line parallel to the linear portion of the curve through the fracture point. The point at which this line intersects the abscissa axis gives the maximum plastic shear strain corresponding to the fracture; see Figure 8.

10.6.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.

11 Test report

The test report shall contain at least the following information unless otherwise agreed by the parties concerned:

a) a reference to this International Standard, i.e. ISO 18338;

b) identification of the test piece;

c) specified material, if known;

d) type of test piece;

e) location and direction of sampling of test pieces, if known;

f) test results.

Annex A
(informative)

Determination of the reference proof strength, plastic torsion and reference torsional strength

A.1 General

For the cylinder and tube test pieces, when the torsion deformation on the cross-section of the test piece is linearly elastic, the torsional stress at the outer surface of the test piece which is calculated according to the classical formulae given in 10.1 is accurate. However, when in partly plastic and fully plastic torsion conditions, the torsional stress calculated by that formula may be an over-estimation of the correct value. Nadai's expression[1][2] is applicable to the calculation of the torsional stress of the test piece in fully elastic, partly plastic and fully plastic torsion conditions. This annex provides a test method based on Nadai's theory to determinate the reference torsional proof strength, plastic torsion, and torsional strength.

A.2 Overview

This annex specifies the method for determination of the reference torsional proof strength, plastic torsion and reference torsional strength.

A.3 Determinations of the reference proof strength, plastic torsion and reference torsional strength

A.3.1 Graphic method to determine the reference proof strength, plastic torsion

A.3.1.1 During torsion test, the shear stress-shear strain (τ — γ) curve is plotted. On the curve, the point A is determined by drawing a line parallel to the linear portion of the curve and at a distance from it equivalent to the prescribed plastic shear strain, e.g. γ_p = 0,35 %. The tangent line A↔τ_I drawn through point A and meets the stress axis with point τ_I; see Figure A.1. Read the shear stress τ_A corresponding to point A and shear stress, τ_I. The reference torsional proof strength, plastic torsion is calculated according to Formulae A.1 and A.2.

For the cylinder test pieces:

$$\tau_{rp} = \frac{1}{4}\left[3\tau_A + \gamma_A \left(\frac{d\tau}{d\gamma}\right)_A\right] = \tau_A - \frac{1}{4}\tau_I \qquad \text{(A.1)}$$

For the tube test pieces:

$$\tau_{rp} = \frac{1}{4}\left[1-\left(\frac{d_i}{d}\right)^4\right]\left\{\frac{3\tau_A}{1-\left(\frac{d_i}{d}\right)^3}+\left[\frac{4}{1-\left(\frac{d_i}{d}\right)^4}-\frac{3}{1-\left(\frac{d_i}{d}\right)^3}\right]\gamma_A\left(\frac{d\tau}{d\gamma}\right)_A\right\}$$

$$=\left[1-\left(\frac{d_i}{d}\right)^4\right]\left\{\frac{\tau_A-\tau_I}{1-\left(\frac{d_i}{d}\right)^4}+\frac{3\tau_I}{4\left[1-\left(\frac{d_i}{d}\right)^3\right]}\right\}$$

$$=\tau_A-\left[\frac{\frac{3}{4}\left(\frac{d_i}{d}\right)^4-\left(\frac{d_i}{d}\right)^3+\frac{1}{4}}{1-\left(\frac{d_i}{d}\right)^3}\right]\tau_I \qquad \text{(A.2)}$$

where

γ_A is the shear strain corresponding to point A.

A.3.1.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.

A.3.2 Determination of the reference torsional strength

A.3.2.1 During torsion test, the shear stress-shear strain (τ — γ) curve is plotted until the test piece fractured. On the curve, the tangent line K↔τ_B is drawn through the maximum shear stress point K and meets the stress axis with point τ_B; see Figure A.2. Read the shear stress τ_K corresponding to point K and shear stress τ_B. The reference torsional strength is calculated by using Formula (A.3) and (A.4).

For the cylinder test pieces:

$$\tau_{rm}=\frac{1}{4}\left[3\tau_K+\gamma_K\left(\frac{d\tau}{d\gamma}\right)_K\right]=\tau_K-\frac{1}{4}\tau_B \qquad \text{(A.3)}$$

For the tube test pieces:

$$\tau_{rm} = \frac{1-\left(\frac{d_i}{d}\right)^4}{4}\left\{\frac{3\tau_K}{1-\left(\frac{d_i}{d}\right)^3}+\left[\frac{4}{1-\left(\frac{d_i}{d}\right)^4}-\frac{3}{1-\left(\frac{d_i}{d}\right)^3}\right]\gamma_K\left(\frac{d\tau}{d\gamma}\right)_K\right\}$$
$$= \tau_K - \left[\frac{\frac{3}{4}\left(\frac{d_i}{d}\right)^4-\left(\frac{d_i}{d}\right)^3+\frac{1}{4}}{1-\left(\frac{d_i}{d}\right)^3}\right]\tau_B \qquad \text{(A.4)}$$

$$\tau_{rm} = \frac{1-\left(\frac{d_i}{d}\right)^4}{4}\left\{\frac{3\tau_K}{1-\left(\frac{d_i}{d}\right)^3}+\left[\frac{4}{1-\left(\frac{d_i}{d}\right)^4}-\frac{3}{1-\left(\frac{d_i}{d}\right)^3}\right]\gamma_K\left(\frac{d\tau}{d\gamma}\right)_K\right\}$$
$$= \tau_K - \left[\frac{\frac{3}{4}\left(\frac{d_i}{d}\right)^4-\left(\frac{d_i}{d}\right)^3+\frac{1}{4}}{1-\left(\frac{d_i}{d}\right)^3}\right]\tau_B \qquad \text{(A.4)}$$

where

γ_K is the shear strain corresponding to the maximum shear stress point K.

A.3.2.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.

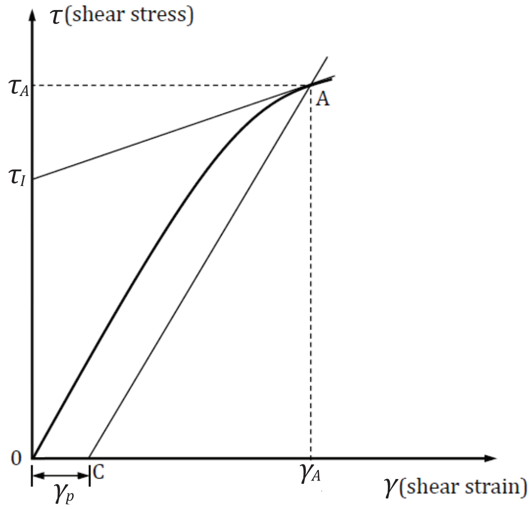


Figure A.1 — Shear stress τ_A and τ_I corresponding to the reference proof strength, plastic torsion

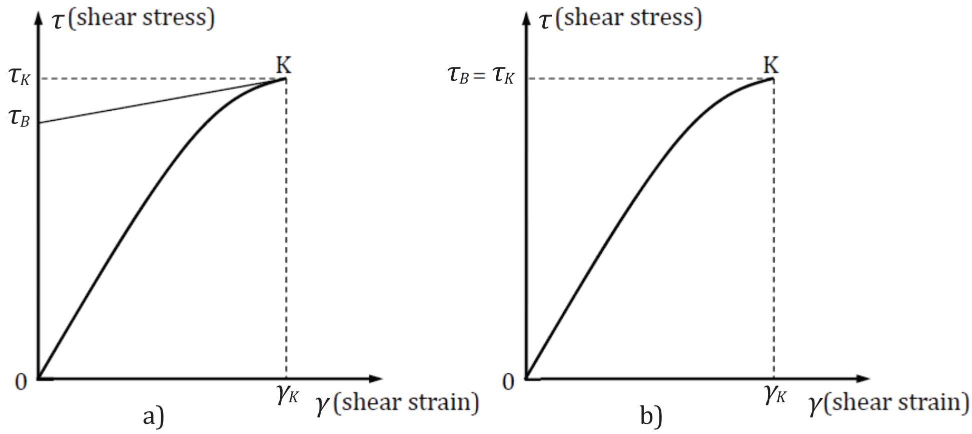


Figure A.2 — Shear stress τ_K and τ_B corresponding to the reference torsional strength

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[1] Nadai A. Theory of Flow and Fracture of Solids. Chapter 21. McGraw-Hill Book Co, New York, Second Edition, 1950

[2] Brown M.W. Torsional Stresses in Tubular Specimens, Journal of Strain analysis, **Vol. 13**, No. 1, 1978, pp. 23-28.

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