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ISO 18338

Second edition
2021-12

Metallic materials — Torsion test at room temperature

Matériaux métalliques — Essai de torsion à température ambiante

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Foreword

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

This second edition cancels and replaces the first edition (ISO 18338:2015), of which it constitutes a minor revision. The changes are as follows:

— the duplicated part of Formula (A.4) has been deleted;

— minor editorial changes.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Metallic materials — Torsion test at room temperature

1 Scope

This document 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 are referred to in the text in such a way that some or all of their content constitutes requirements of this document. 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 extensometer systems 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.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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

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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
$\tau_{e,H}$
maximum value of shear stress prior to the first decrease in torque when the discontinuous yielding occurs

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3.11.2
lower torsional yield strength
$\tau_{e,L}$
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
$\tau_{r,p}$
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. $\tau_{r,p0,35}$.

3.15
reference torsional strength
$\tau_{r,m}$
maximum shear stress is calculated according to the Nadai's expression for fractured test piece

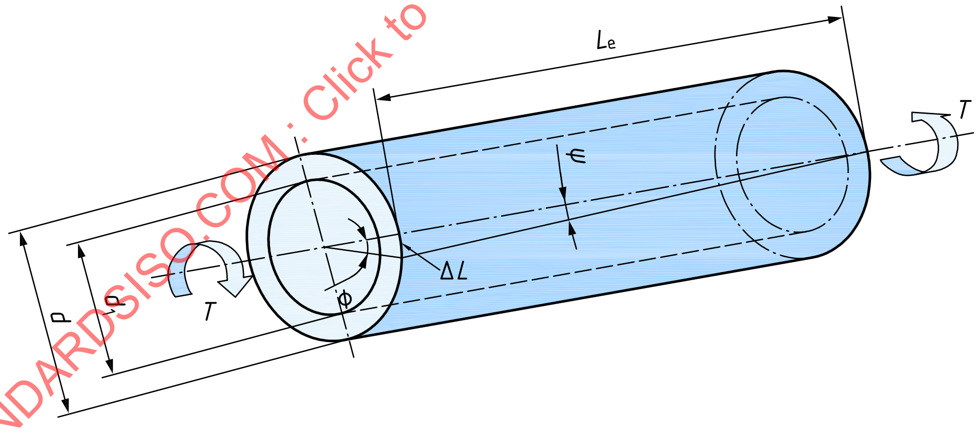

Figure 1 — Basic symbols for torsion test

4 Symbols and designations

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

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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	%
γ_{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
$\tau_{e,H}$	upper torsional yield strength	MPa
$\tau_{e,L}$	lower torsional yield strength	MPa
τ_p	torsional proof strength, plastic torsion	MPa
τ_m	torsional strength	MPa
$\tau_{r,p}$	reference torsional proof strength, plastic torsion	MPa
$\tau_{r,m}$	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.

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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

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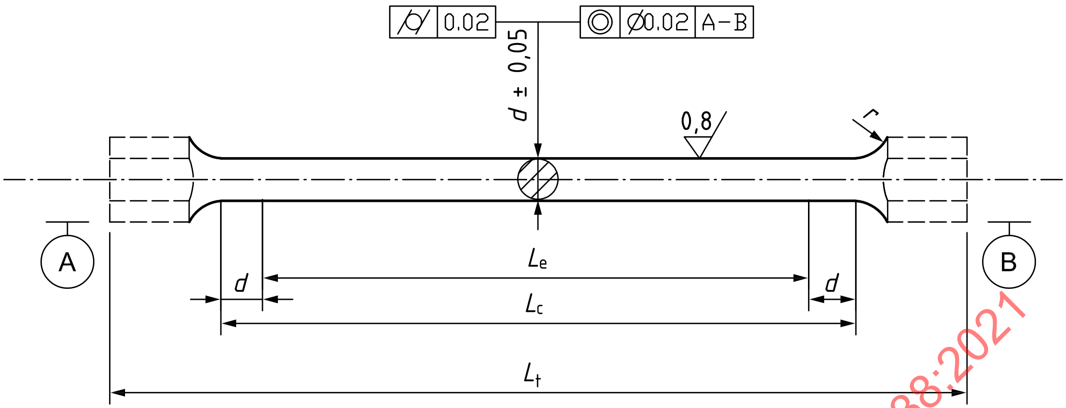
length. If other test pieces are used, the parallel length should be the sum of gauge length and two times diameter.



Key

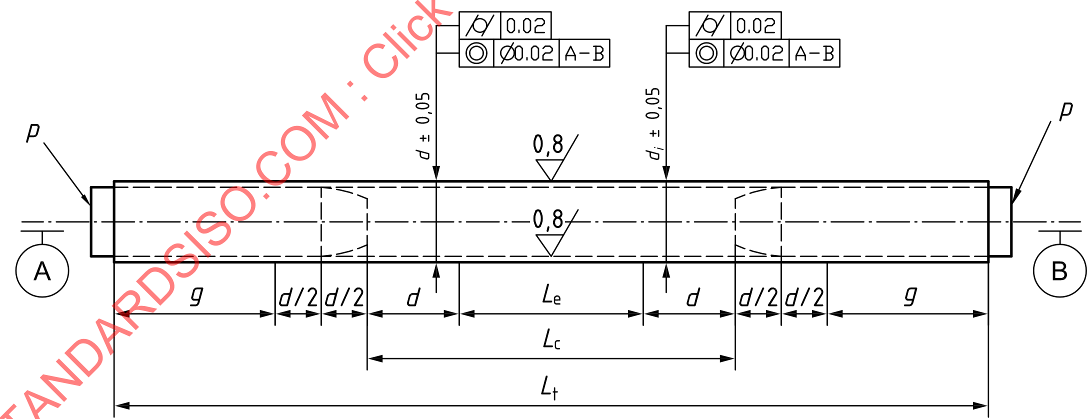
r transition radius

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	*p*	plug
d	original external diameter	d_i	original internal diameter

Figure 3 — Tube test piece

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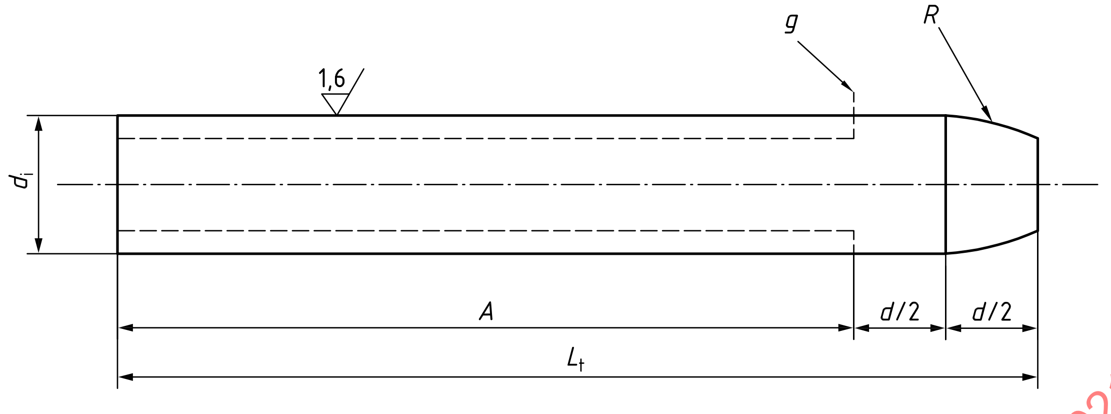

Key

g gripped end

R plug transition radius

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

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

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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.

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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 % [ϕ ≤ 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.

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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):

$$\tau = \frac{T}{W_{\mathrm{p}}} \tag{1}$$

For the cylinder test pieces:

$$W_{\mathrm{p}} = \frac{\pi \cdot d^3}{16} \tag{2}$$

For the tube test pieces:

$$W_{\mathrm{p}} = \frac{\pi\left(d^4 - d_{\mathrm{i}}^4\right)}{16d} \tag{3}$$

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

$$\gamma = \frac{\phi \mathrm{d}}{2L_{\mathrm{e}}} \times 100 \tag{4}$$

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):

$$m_{\mathrm{G}} = \frac{\Delta\tau}{\Delta\gamma} \tag{6}$$

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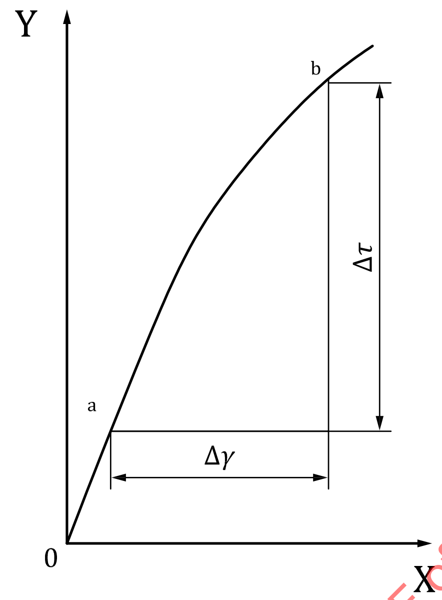
10.2.2 The parameter may be obtained without plotting the shear stress-shear strain curve by using automatic devices.



Key

X τ (shear strain)

Y γ (shear stress)

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.

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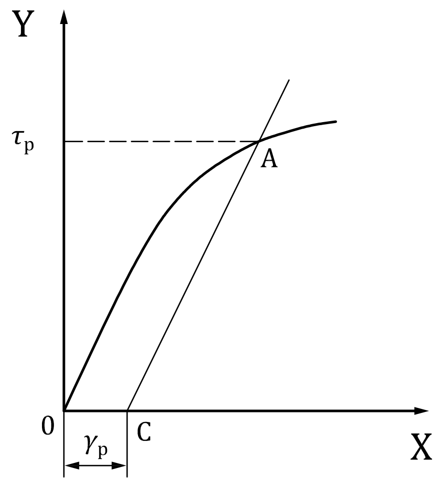
10.3.2 The property may be obtained without plotting the shear stress-shear strain curve by using automatic devices.



Key

X τ (shear strain)

Y γ (shear stress)

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 $\tau_{e,H}$ 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 $\tau_{e,L}$ 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.

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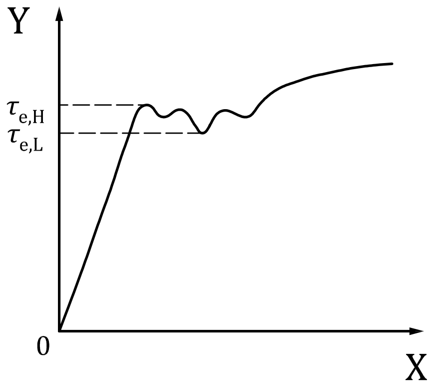
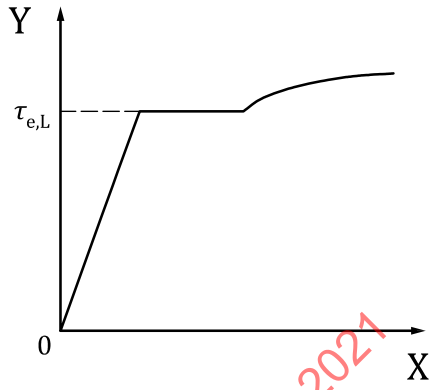


a)



b)

Key

X τ (shear strain)

Y γ (shear stress)

Figure 7 — Determination of the upper torsional yield strength, $\tau_{e,H}$, and lower torsional yield strength, $\tau_{e,L}$, 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.

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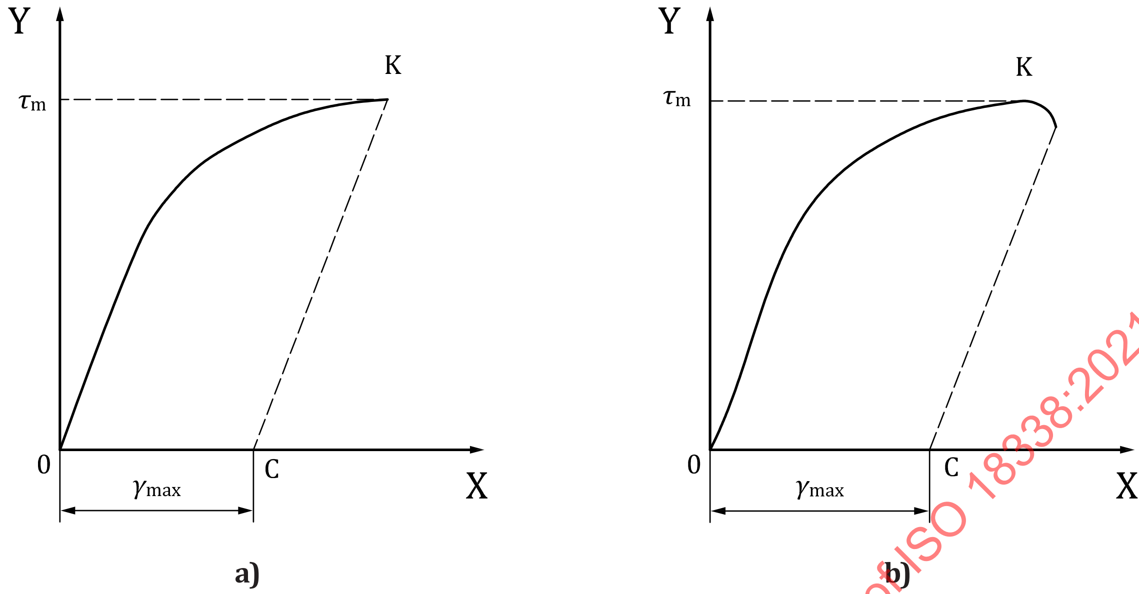

Key

X τ (shear strain)

Y γ (shear stress)

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 document, i.e. ISO 18338:2021;

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.

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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 determine the reference torsional proof strength, plastic torsion, and torsional strength.

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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$\leftrightarrow$$\tau_I$ drawn through point A and meets the stress axis with point τ_I; see Figure A.1. Read the shear stress τ_A

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