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Kovinski materiali - Preskusna metoda z uporabo majhnega bata

Metallic materials - Small punch test method

Small punch test für metallische Werkstoffe

Matériaux métalliques - Méthode d’essai de micro-emboutissage

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Metallic materials - Small punch test method

Matériaux métalliques - Méthode d'essai de micro-emboutissage

Metallische Werkstoffe - Small-Punch-Test

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European foreword

This document (EN 10371:2021) has been prepared by Technical Committee CEN/TC 459/SC 1 “Test methods for steel (other than chemical analysis)”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2021, and conflicting national standards shall be withdrawn at the latest by October 2021.

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Introduction

This document describes small punch testing of metallic materials.

While it is recognized that the small punch test technique is not equivalent to uniaxial testing and cannot currently replace uniaxial and fracture mechanics tests with larger specimens, it allows estimation of the values normally obtained using classical standard size uniaxial or fracture mechanics specimens.

The small punch technique is especially useful when only small amounts of material are available as in the case of experimental material batches, or for assessing aging of components where the extraction of classical specimen types would require expensive repairs. Other areas of interest for small punch testing are the characterization of irradiated materials, where small specimens minimize laboratory staff exposure to radiation or the investigation of different zones in welds.

1 Scope

This document specifies the small punch method of testing metallic materials and the estimation of tensile, creep and fracture mechanical material properties from cryogenic up to high temperatures.

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.

EN 60584-1, *Thermocouples - Part 1: EMF specifications and tolerances (IEC 60584 1)*

EN ISO 148-1, *Metallic materials - Charpy pendulum impact test - Part 1: Test method (ISO 148-1)*

EN ISO 204, *Metallic materials - Uniaxial creep testing in tension - Method of test (ISO 204)*

EN ISO 286-2, *Geometrical product specifications (GPS) - ISO code system for tolerances on linear sizes - Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts (ISO 286-2)*

EN ISO 6892-1, *Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1)*

EN ISO 6892-2, *Metallic materials - Tensile testing - Part 2: Method of test at elevated temperature (ISO 6892-2)*

EN ISO 7500-1, *Metallic materials - Calibration and verification of static uniaxial testing machines - Part 1: Tension/compression testing machines - Calibration and verification of the force-measuring system (ISO 7500-1)*

EN ISO 7500-2, *Metallic materials - Verification of static uniaxial testing machines - Part 2: Tension creep testing machines - Verification of the applied force (ISO 7500-2)*

EN ISO 9513, *Metallic materials - Calibration of extensometer systems used in uniaxial testing (ISO 9513)*

ISO 2768-1, *General tolerances - Part 1: Tolerances for linear and angular dimensions without individual tolerance indications*

3 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
punch
single solid rod with a hemispherical tip or a cylindrical rod combined with a ball is used to punch through the centre of the disc shaped test piece

Note 1 to entry: The hemispherical portion of the punch or the ball shall have a sufficient hardness to ensure rigidity so as not to be deformed during the test. Ultra-hard ball-bearing balls can be used for that application. The compliance of the punch will affect the displacement measurement (see 3.5).

3.2
test piece
circular, disc shaped piece of the material under investigation

Note 1 to entry: The testing of other geometries is admissible according to this document if the active part of the specimen has a flat cylindrical shape and the clamped area is equal to or larger than that of the specimens included in this document.

3.3
small punch (SP) test
when the punch tip/ball is pushed through the specimen with constant displacement rate of the cross head, $\dot{w}$ and the force, F is measured as a function of deflection, u / displacement, v

Note 1 to entry: The test can be used for estimating tensile and fracture material properties. If displacement is used, consideration of machine compliance is necessary (Annex A).

3.4
small punch creep (SPC) test
when the punch tip/ball is pushed through the specimen under constant force, F and the deflection, u / displacement, v is measured as a function of time

Note 1 to entry: The test can be used for estimating uniaxial creep properties.

3.5
displacement, v of the punch tip
distance by which the punch tip has moved after initial contact with the specimen surface

3.6
crosshead displacement
w
distance by which the cross head has moved after initial contact of the punch tip with the specimen surface

3.7
deflection
u
distance by which the point at the centre of the specimen on the surface opposite to the point of contact between the punch and the specimen has moved after initial contact of the punch tip with the test piece

3.8
creep-deflection curve
***u*(*t*)**
data record of deflection, u as a function of time, t for a given applied force, F from a small punch creep test

Note 1 to entry: The loading period is part of the creep deflection curve. $t = 0$, $F = 0$ (or F = preload) refers to the point in time when loading is started.

3.9
creep-displacement curve
***v*(*t*)**
data record of displacement, v as a function of time, t for a given applied force, F from a small punch creep test

Note 1 to entry: The loading period is part of the creep displacement curve. t=0, F=0 (or F=preload) refers to the point in time when loading is started.

3.10
force-deflection curve
***F*(*u*)**
record of the force, F required to keep the punch moving at constant crosshead displacement rate, $\dot{w}$ as a function of the deflection

3.11
force-displacement curve
***F*(*v*)**
record of the force, F required to keep the punch moving at constant crosshead displacement rate, $\dot{w}$ as a function of the displacement of the punch tip

Note 1 to entry: If the displacement is not measured at the punch tip, but derived from the displacement of the crosshead or at another point along the force line, the displacement signal needs to be corrected for compliance. For details, refer to Annex A.

3.12
ductile to brittle transition temperature
DBTT
temperature where the fracture behaviour of a given material changes from brittle to ductile as defined in EN ISO 148-1

3.13
small punch ductile to brittle transition temperature
T_{SP}
characteristic temperature at which the fracture behaviour in a small punch test changes from brittle to ductile (Annex E)

3.14
small punch energy
E_{SP}
integral of the force-deflection curve up to the deflection at maximum force, u_m

Note 1 to entry: This energy is used for determining T_{SP}. In the case of pop-ins, the integration is carried out up to the first significant pop-in (Annex E).

Note 2 to entry: Instead of deflection, displacement is allowed to be used.

Note 3 to entry: In the case of ductile materials, failure has not yet occurred when the maximum force, F_m is reached. However, limiting the integration to deflection at maximum force, u_m allows harmonized treatment of ductile and brittle failure.

3.15
normalized small punch energy
E_n
E_{SP} normalized by the maximum force F_m

3.16
upper shelf energy
E_{US}
some materials like ferritic/martensitic steels show a distinct transition of $E_{SP}(T)$ from a lower to a higher level at a given temperature, T_{SP}, the higher level of $E_{SP}(T)$ is called upper shelf energy, E_{US}

3.17
lower shelf energy
E_{LS}
some materials like ferritic/martensitic steels show a distinct transition of $E_{SP}(T)$ from a lower to a higher level at a given temperature, T_{SP}, the lower level of $E_{SP}(T)$ is called lower shelf energy, E_{LS}

3.18
pop-in significant for E_{SP} calculation
event during a SP test where the force in the $F(u)$ or $F(v)$ curves drops quasi instantaneously and rises again

Note 1 to entry: A pop-in is indicative for brittle failure.

Note 2 to entry: For calculating E_{SP}, a significant pop-in is defined as a drop of the force by 10% of the maximum force, F_m in the test at any point (Annex E).

3.19
creep rupture time from uniaxial testing
t_u
time to rupture for a test piece maintained at the specified temperature, T and initial stress, R_0 as defined in EN ISO 204

Note 1 to entry: The symbol t_u in a uniaxial creep test may have as superscript the specified temperature in degrees Celsius and as subscript the initial stress, R_0 in mega pascals.

3.20
creep rupture time from small punch testing
t_r
time to rupture for a test piece maintained at the specified temperature, T and constant force F in a small punch creep test

Note 1 to entry: The symbol t_r in a uniaxial creep test may have as superscript the specified temperature in degrees Celsius and as subscript the force, F in newtons.

3.21
proof strength
R_p
proof strength determined from uniaxial tensile testing as defined in EN ISO 6892-1 and EN ISO 6892-2 or estimated from small punch testing (Annex D)

Note 1 to entry: The symbol is followed by a suffix giving the prescribed percentage of strain, for example $R_{p0,2}$.

3.22
yield strength
R_{eL}, R_{eH}
lower and higher yield strength determined from uniaxial tensile testing as defined in EN ISO 6892-1 and EN ISO 6892-2 or estimated from small punch testing (Annex D)

3.23
tensile strength
$\boldsymbol{R_m}$
stress corresponding to maximum force in uniaxial tensile testing as defined in EN ISO 6892-1 and EN ISO 6892-2 or estimated from small punch testing (Annex C)

3.24
plane strain fracture toughness
$\boldsymbol{K_{Ic}}$
crack-extension resistance under conditions of crack-tip plane-strain, expressed as a critical value of stress intensity factor

3.25
plane strain *J*-integral fracture toughness
$\boldsymbol{J_{Ic}}$
crack-extension resistance under conditions of crack-tip plane strain, expressed as a critical value of *J*-integral, J_{Ic}

3.26
effective fracture strain
$\boldsymbol{\varepsilon_f}$
natural logarithm of the ratio from the initial specimen thickness h_0 and the thickness after testing close to the fracture surface, h_f (Annex H)

4 Symbols and designations

For the purposes of this document, the following symbols and designations apply.

NOTE This list only includes the most pertinent symbols. Less important symbols that are only used in a specific context are not listed.

Symbol	Unit	Designation	Reference
A_{gt}	%	Total uniform elongation of the uniaxial tensile test	Annex C
A, B	mm	Parameters in the tanh fit of $E_n(T)$	Annex E
A_ε, B_ε	-	Parameters in the tanh-fit of $\varepsilon_f(T)$	Annex E
α	-	Transfer factor between T_{SP} and T_{CVN}: $T_{SP} = \alpha\ T_{CVN}$	Annex E
α_ε	-	Transfer factor between $T_{SP,\varepsilon}$ and T_{CVN}: $T_{SP,\varepsilon} = \alpha_\varepsilon\ T_{CVN}$	Annex E
β_{Rm}	-	Correlation factor for estimation of R_m	Annex C
C	K	Parameter in the tanh fit of $E_n(T)$	Annex E
C_ε	K	Parameter in the tanh-fit of $\varepsilon_f(T)$	Annex E
C_P	mm/N	Compliance of punch and push rod	Annex A
d	mm	Diameter of the punch tip	Clause 6
D	mm	Diameter of the receiving hole (lower die)	Clause 6
DBTT	°C, K	Ductile to brittle transition temperature	Annex E

Symbol	Unit	Designation	Reference
D_S	mm	Diameter of the test piece	Clause 5
E_{LS}	mJ	Lower shelf energy	Annex E
EMF	-	Electromotive force	Annex B
E_n	mm	E_{SP} normalised by F_m	Annex E
E_{SP}	mJ	Small punch energy	Annex E
E_{US}	mJ	Upper shelf energy	Annex E
E_{LS}	mJ	Lower shelf energy	Annex E
E_Y	GPa	Young's modulus	Annex A
ε_f	-	Effective fracture strain $\varepsilon_f = \ln(h_0/h_f)$	Annex E
ε_{LS}	-	Effective fracture strain in the lower shelf	Annex E
$\dot{\varepsilon}_{min}$	1/h	Estimated uniaxial minimum strain rate corresponding to minimum deflection rate in a SPC test	Annex G
ε_{US}	-	Effective fracture strain in the upper shelf	Annex E
F	N	Force applied to the specimen	Clause 7, Clause 8
F_e	N	Elastic-plastic transition force in a small punch test	Clause 7, Annex D
F_m	N	Maximum of F during the test	Annex C, Annex E
F_i	N	Force at deflection u_i or displacement v_i, used for estimating R_m	Annex C
h	mm	Thickness of the test piece	Clause 5
h_0	mm	Initial thickness of the test piece (at the beginning of the test)	Clause 5
h_f	mm	Final thickness of the test piece adjacent to the fracture area	Annex E, Annex H
J_{Ic}	N/mm	Plane strain J-integral fracture toughness	Annex F
K_{Ic}	MPa $m^{0,5}$	Plane strain fracture toughness	Annex F
L	mm	Length of the chamfer in the receiving hole	Clause 6
Ψ	N/MPa	Force to stress ratio in SPC	Annex G
r	mm	Radius of the punch tip	Clause 6
R	mm	Radius of the receiving hole (lower die)	Clause 6
R_0	MPa	Initial stress in a uniaxial creep test	Annex G

Symbol	**Unit**	**Designation**	**Reference**
R_a	µm	Surface roughness (of the test piece)	Clause 5
R_m	MPa	Ultimate tensile strength	Annex C
R_p	MPa	Proof strength	Annex D
σ	MPa	Equivalent stress	Annex G
T	°C, K	Test temperature	Clause 6, Clause 7, Clause 8, Annex B
T_{CVN}	°C, K	Charpy transition temperature defined at 50 % of upper shelf energy (see EN ISO 148-1)	Annex E
t_r	h	Rupture time of SPC test	Annex G
T_{SP}	°C, K	Ductile to brittle transition temperature as determined from SP testing	Annex E
$T_{SP,\varepsilon}$	°C, K	T_{SP} determined from fracture strain	Annex E
t_u	h	Rupture time in uniaxial creep testing	Annex G
u	mm	Deflection of the specimen	Clause 7, Clause 8
u_e	mm	Deflection at F_e	Annex D
u_i	mm	Characteristic deflection used for estimating R_m	Annex C
u_m	mm	Deflection at F_m	Annex C, Annex E
u_{min}	mm	Deflection at minimum deflection rate $\dot{u}_{min}$ in a SPC test	Annex G
$\dot{u}$	mm/h	Deflection rate	Annex G
$\dot{u}_{min}$	mm/h	Minimum deflection rate in a SPC test	Annex G
u_{p1}	mm	Deflection at first significant pop-in	Annex E
v	mm	Displacement of the ball/punch tip	Clause 7, Clause 8
v_i	mm	Characteristic displacement used for estimating R_m	Annex C
v_{p1}	mm	Displacement at first significant pop-in	Annex E
v_r	mm	Displacement at rupture	Annex G
w	mm	Displacement of the crosshead	Annex A

5 Test piece

5.1 General

The test pieces that should be used are circular discs with a diameter of D_S = 8 mm and an initial thickness of h_0 = 0,5 mm. The use of other specimen shapes is admissible according to this document provided the thickness and surface finish requirements are met and they can be properly clamped.

The use of smaller test pieces (D_S = 3 mm, h_0 = 0,25 mm) is also admissible according to this document. This allows the use of specimens adapted to the size of a TEM specimen holder.

For obtaining macroscopic material properties a representative volume element shall be contained in the specimen thickness. The specimen should contain at least 5 grains in thickness cross-section, but some exceptions can be accepted for coarse-grain, directionally solidified or single crystal materials.

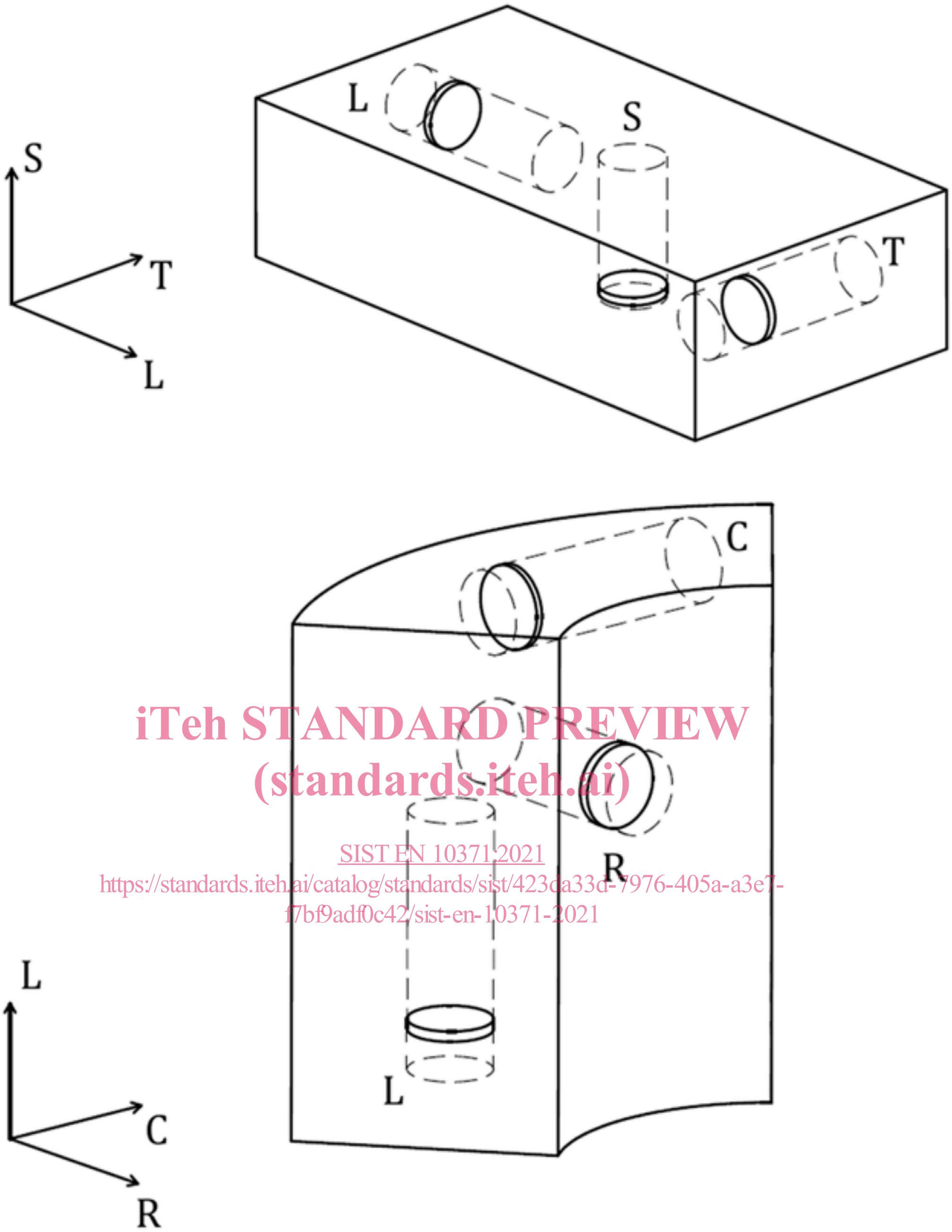
These cases shall be reported accordingly; the recommended correlations for tensile and fracture estimations might not apply.

To eliminate the influence of surface damage, the specimen should be machined to a minimal thickness of h_0+0,1 mm and then should be ground from both sides on abrasive paper with a recommended abrasive grit size designation P320 followed by fine grinding (P1200) to reach the final thickness with a tolerance of no more than 1 %. Grinding on both faces shall be done with minimal 0,03 mm material removal from each side of the test piece. Since the test piece is clamped during test, the tolerance of its diameter, D_S is not critical, but it shall not be less than the value indicated in Table 1 to ensure sufficient clamping. The thickness of the test disc specimen shall be measured at four positions around the perimeter at 90° intervals from each other and in the centre. Each measurement shall be within the specifications. The diameter shall be measured in two positions at 90° from each other.

Table 1 — Required test piece dimensions, tolerances and surface roughness

D_S [mm]		h_0 [mm]		*Ra* [μm]
Ø 8	0	0,50	+0,005	< 0,25
	−0,1		−0,005	
Ø 3	0	0,25	+0,0025	< 0,25
	−0,025		−0,0025	

Orientation of the test piece shall be defined by Figure 1 in the test report.



Key

L longitudinal direction (i.e. rolling direction)

T transverse direction

S short transverse direction

C circumferential direction

R radial direction

NOTE The specimens are classified so that the letter designating the axis falls together with the axis along which the force is applied. Because of the multiaxial stress state, the directions tested in a SP test do not coincide with the force axis.

Figure 1 — Orientation of SP specimen