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Metallic materials — Sheet and strip — Determination of plastic strain ratio

Matériaux métalliques — Tôles et bandes — Détermination du coefficient d'anisotropie plastique

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 2, *Ductility testing*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 459/SC 1, *Test methods for steel (other than chemical analysis)*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 10113:2006), which has been technically revised. The main changes compared to the previous edition are as follows:

— a new structure;

— the addition of the semi-automatic method (see 8.3);

— a clear differentiation between the manual, the semi-automatic and the automatic methods (see 8.2, 8.3 and 8.4);

— the addition of the methods of investigating sources of errors in *r*-value determination (see Annex A).

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.

This corrected version of ISO 10113:2020 incorporates the following corrections:

— Correction of the description of the test in the fourth paragraph of 8.4.2.

Metallic materials — Sheet and strip — Determination of plastic strain ratio

1 Scope

This document specifies a method for determining the plastic strain ratio of flat products (sheet and strip) made of metallic materials.

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 6892-1:2019, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

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

ISO 80000-1, *Quantities and units — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6892-1 and the following apply.

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

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

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

3.1
plastic strain ratio
r
ratio of the true plastic width strain to the true plastic thickness strain in a test piece that has been subjected to uniaxial tensile stress calculated using Formula (1)

$$r = \frac{\varepsilon_{p\_b}}{\varepsilon_{p\_a}} \tag{1}$$

where

ε_{p_a} is the true plastic thickness strain;

ε_{p_b} is the true plastic width strain.

Note 1 to entry: The above expression using a single point is only valid in the region where the plastic strain is homogeneous.

Note 2 to entry: Since it is easier and more precise to measure changes in length than in thickness, the following relationship derived from the law of constancy of volume is used up to the percentage plastic extension at maximum force, A_g, to calculate the plastic strain ratio, *r* [see Formula (2)].

$$r=\frac{\ln\left(\frac{b_1}{b_o}\right)}{\ln\left(\frac{L_o b_o}{L_1 b_1}\right)} \tag{2}$$

Note 3 to entry: For some materials exhibiting a phase change during plastic deformation, the volume of the measured section cannot always be assumed to be constant. In such cases, the procedure shall be defined and agreed between the parties involved.

Note 4 to entry: As the value r depends on the orientation of the test piece relative to the rolling direction, as well as on the strain, the symbol r can be supplemented by the angle which characterises this orientation and the plastic (engineering) strain. For example $r_{45/20}$ (see Table 1).

3.2
weighted average plastic strain ratio
$\overline{r}$
weighted average as calculated using Formula (3) of the $r_{x/y}$ values for different test piece orientations, x, where $r_{x/y}$ are determined using the same selected test method and at the same plastic (engineering) strain, y, or plastic (engineering) strain range, α - β

$$\overline{r}=\frac{r_{0/y}+r_{90/y}+2r_{45/y}}{4} \tag{3}$$

Note 1 to entry: For some materials, other test piece orientations may be chosen, in which case formulas other than Formula (3) shall be used.

3.3
degree of planar anisotropy
Δr
value calculated using Formula (4) where $r_{x/y}$ values for different test piece orientations, x, are determined using the same selected test method and at the same plastic (engineering) strain, y, or plastic (engineering) strain range, α - β

$$\Delta r=\frac{\left(r_{0/y}+r_{90/y}-2r_{45/y}\right)}{2} \tag{4}$$

Note 1 to entry: For some materials, other test piece orientations may be chosen, in which case formulas other than Formula (4) shall be used.

3.4
Poisson´s ratio
ν
ratio of the elastic width strain to the elastic length strain of the material

4 Symbols

The designations of the symbols used in this document are given in Table 1.

Table 1 — General symbols, designations, definitions and units

Symbol	Designation	Unit
a_o	original thickness of the test piece	mm
a_1	thickness of the test piece after straining and unloading	mm
A_g	percentage of plastic extension at maximum force	%
b_o	average original gauge width of the test piece	mm
b_1	average width of the test piece after straining and unloading	mm
Δb	instantaneous width reduction measured with a width extensometer	mm
e_{py}	plastic (engineering) strain at which the plastic strain ratio should be determined (single point method, e_{py} = plastic (engineering) strain in percent)[a]; this value should be in the range of work hardening of the individual test (equal or lower than A_g)	%
$e_{p\alpha} - e_{p\beta}$	plastic (engineering) strain range at which the plastic strain ratio should be determined (linear regression method, where $e_{p\alpha}$ = lower limit of the plastic (engineering) strain in percent and $e_{p\beta}$ = upper limit of the plastic (engineering) strain in percent)[b]; the value β should be in the range of work hardening of the individual test (equal or lower than A_g)	%
e_{p_b}	instantaneous plastic (engineering) width strain of the test piece during testing	%
e_{p_l}	instantaneous plastic (engineering) length strain of the test piece during testing	%
ε_{p_a}	true plastic thickness strain	—
ε_{p_b}	true plastic width strain	—
ε_{p_l}	true plastic length strain	—
F	force	N
L_o	original gauge length	mm
L_1	length between the marks of the original gauge length, L_o, on the test piece after straining and unloading	mm
ΔL	instantaneous extension of the original extensometer gauge length under load	mm
L_e	original extensometer gauge length	mm
m_E	slope of the elastic part of the engineering stress/percentage length extension curve multiplied by 100 %	MPa
m_r	slope of the corresponding straight line of the true plastic width strain vs. true plastic length strain curve	—
r	plastic strain ratio	—
$\overline{r}$	weighted average of $r_{x/y}$ values[c]	—
Δr	degree of planar anisotropy	—
$r_{x/y}$	plastic strain ratio in x-direction (in degrees) relative to the rolling direction, and at plastic (engineering) strain e_p (y in %)	—
$r_{x/\alpha\text{-}\beta}$	plastic strain ratio in x-direction (in degrees) relative to the rolling direction, and at plastic (engineering) strain range from $e_{p\alpha}$ to $e_{p\beta}$ (α and β in %)	—
R_m	tensile strength	MPa
S_o	original cross-sectional area of the parallel length	mm^2
S_i	instantaneous cross-sectional area	mm^2
ν	Poisson's ratio	—
α, β, x, y	variables used as subscripts	—

NOTE 1 In the literature, the readers may encounter other symbols: for an international comparison of symbols, see Annex B.

NOTE 2 1 MPa = 1 N/mm^2.

[a] Normally, this value is specified in product standards.

[b] Normally, these values are specified in product standards.

[c] In some countries, r_m is used instead of $\overline{r}$.

5 Principle

The plastic strain ratio r is often used for the characterisation and qualification of materials, and for the numerical simulation of forming processes.

To determine the plastic strain ratio, a test piece is subjected to a tensile test to a specified plastic (engineering) strain and the plastic strain ratio, r, is calculated from measurements of the changes in width and thickness after unloading or after subtraction of the elastic strains. However, it is easier and more precise to measure changes in length than in thickness. Therefore, the plastic strain ratio r is typically derived from changes in length and width using the law of constancy of volume, see Formula (5).

$$\varepsilon_{p\_a} + \varepsilon_{p\_b} + \varepsilon_{p\_l} = 0 \qquad (5)$$

where

ε_{p_a} is the true plastic thickness strain $\varepsilon_{p\_a} = \ln \frac{a_1}{a_o}$;

ε_{p_b} is the true plastic width strain $\varepsilon_{p\_b} = \ln \frac{b_1}{b_o}$;

ε_{p_l} is the true plastic length strain $\varepsilon_{p\_l} = \ln \frac{L_1}{L_o}$.

The law of constancy of volume is only applicable up to the percentage of plastic extension at maximum force, A_g because after this point local necking starts and the used mathematical approaches are no longer valid.

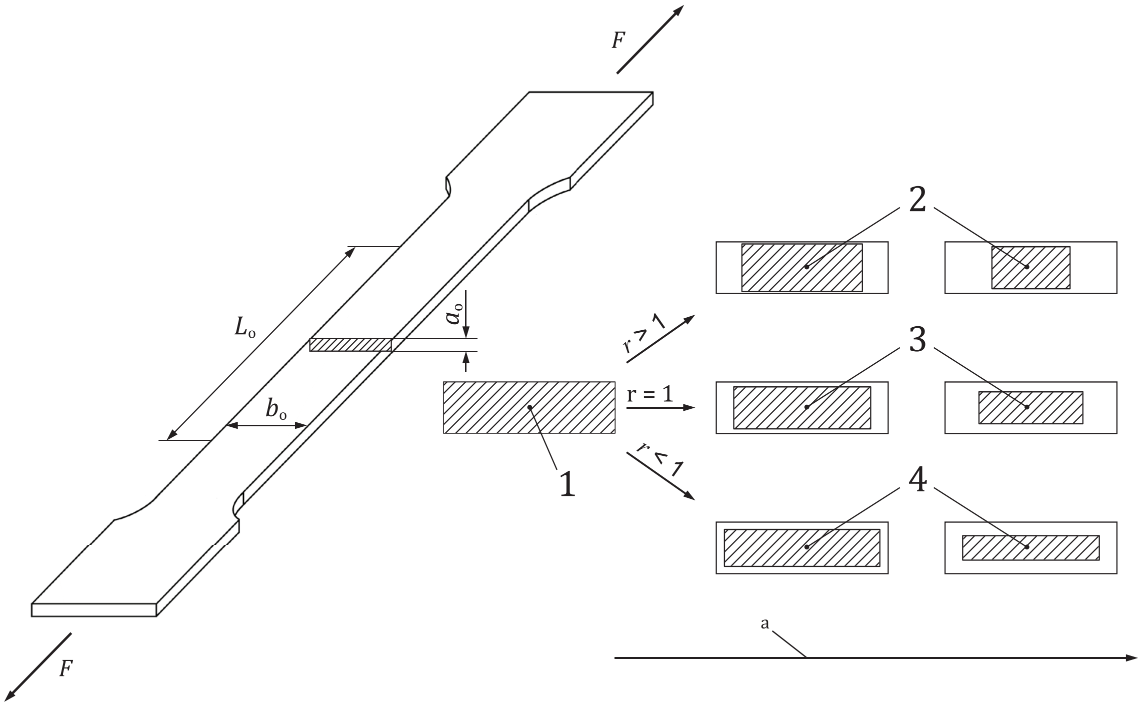
Several materials clearly show a slight local necking before A_g. This can lead to higher instantaneous width reduction values and results in higher r-values, especially when an extensometer is used which measures the instantaneous width reduction only in the central region of the gauge length. In these cases, the following points are recommended:

a) extensometers for measurement of the instantaneous width reduction which are able to measure the change of width in multiple locations ideally evenly distributed across the entire gauge length (see Clause 6) should be used;

b) the parallel length of the test piece should be minimum six times of the original gauge width of the test piece b_o.

The orientation of the test piece relative to the rolling direction, and the plastic (engineering) strain for which the values of r are determined, are as specified in the relevant product standards.

An r-value greater than one describes a behaviour where the material deforms more in the width than in the thickness ($\varepsilon_{p\_b} > \varepsilon_{p\_a}$; see Figure 1). An r-value lower than one describes a behaviour where the material deforms more in the thickness than in the width ($\varepsilon_{p\_b} < \varepsilon_{p\_a}$; see Figure 1). An r-value of one describes an isotropic forming behaviour in width and thickness ($\varepsilon_{p\_b} = \varepsilon_{p\_a}$; see Figure 1).



Key

1 original cross-sectional area of the parallel length
2 material, deformed more in the width
3 isotropic material (same deformation in width and thickness [$\varepsilon_{p\_b} = \varepsilon_{p\_a}$])
4 material, deformed more in the thickness
a Increase of plastic extension.

Figure 1 — Illustration of the cross-section changes for different *r*-values[1]

6 Test equipment

The tensile testing machine used shall comply with the requirements of ISO 6892-1.

For the manual method (see 8.2), the device for the measurement of the original gauge length and the gauge length after plastic straining and unloading shall be capable of measuring with an accuracy of ±0,2 % or better. The device used for determining the original width and the gauge width of the test piece after plastic straining and unloading shall be capable of measuring with an accuracy of ±0,005 mm or better.

For the semi-automatic method (see 8.3), an extensometer for length measurement in accordance with ISO 9513, of class 1 or better, shall be used. The device used for determining the original width and the gauge width of the test piece after plastic straining and unloading shall be capable of measuring with an accuracy of ±0,005 mm or better.

For the automatic method (see 8.4), extensometers in accordance with ISO 9513, of class 1 or better in the relevant strain range, shall be used. The device used for determining the original width shall be capable of measuring with an accuracy of ±0,1 % or better.

NOTE When using a long gauge length and large extensions are applied, the maximum error of the class 1 extensometer can be greater than ±0,01 mm.

The method of gripping the test piece shall be as specified in ISO 6892-1.

7 Test piece

The test piece shall be taken in accordance with the requirements of the relevant product standard or, if not specified therein, as agreed between the parties involved.

The type of the test piece and its preparation, including machining tolerances, the tolerances on shape and the marking of the original gauge length, shall be as defined in ISO 6892-1:2019, Annex B. In addition, within the gauge length the edges shall be sufficiently parallel that two width measurements do not differ by more than 0,1 % of the mean of all the width measurements.

To reach a homogeneous strain distribution in the gauge length for all types of test pieces (ISO 6892-1:2019, Annex B), the parallel length L_c shall be equal to or larger than (L_o + 2 b_o).

The test piece thickness shall be the full sheet thickness, unless otherwise specified.

The parallel length of the test piece shall be free of surface defects (e.g. scratches).

8 Procedure

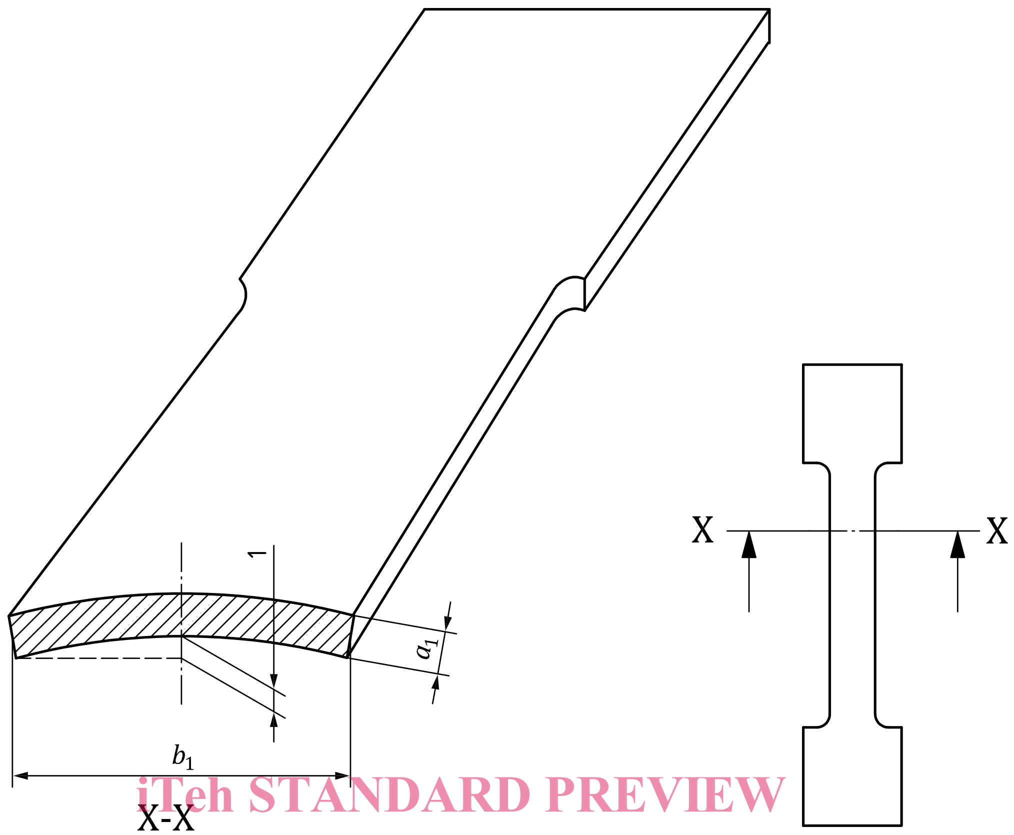
8.1 General

In general, tests are carried out at ambient temperature between 10 °C and 35 °C. Tests carried out under controlled conditions, where required, shall be made at a temperature of (23 ± 5) °C.

In the range of evaluation, the strain rate of the parallel length shall be constant with a relative tolerance of ±20 % and not exceed 0,008/s. Any strain rate changes should be finished at least 0,2 % strain before the start of the range of evaluation.

NOTE In the case of coated material (e.g. galvanised or with organic coatings), the *r*-values obtained can differ from those of base material without coating.

If, after the test, the test piece shows transverse bow (see Figure 2), the test shall be considered invalid, and a new test shall be carried out, because the test results could be influenced.



Key

1 transverse bow

Figure 2 — Schematic illustration of transverse bow in a test piece cross-section

The test may be performed by three different methods. Unless otherwise agreed, the choice of the method is at the discretion of the producer or the test laboratory assigned by the producer.

If there are differences in results by using different methods, the origin of these differences shall be investigated. Methods for investigations are described in Annex A.

8.2 Method without using any extensometer (manual method)

8.2.1 General

This method is based on the measurement of the relevant dimensions before and after straining without using an extensometer for either length or width measurements.

8.2.2 Testing

The original gauge length L_0 shall be marked by means of fine marks or scribed lines to an accuracy of ±1,0 % and measured with an accuracy of 0,2 % or better. In cases that the marked gauge length is known with an accuracy better than 0,2 %, it is not necessary to measure the gauge length of every single test piece.

The original width of the test piece shall be measured with an accuracy better than ±0,005 mm at a minimum of three points evenly distributed along the gauge length, including one measurement at each end of the gauge length. The average value of these width measurements b_0 shall be used in calculating the plastic strain ratio.

The test piece is installed in the testing machine and is strained to the desired level and unloaded.

NOTE It is not necessary to apply a preload before straining when using this method.

After unloading, the gauge length L_1 of the test piece and the width b_1 is measured in the same manner and to the same accuracy as for the original gauge length and width.

8.2.3 Evaluation

The plastic (engineering) strain for each individual test shall be calculated according to Formula (6).

$$e_{p\_l} = \frac{(L_1 - L_o)}{L_o} \cdot 100\ \% \tag{6}$$

The r-value shall be calculated according to the following Formula (7).

$$r = \frac{\ln\left(\frac{b_1}{b_o}\right)}{\ln\left(\frac{L_o b_o}{L_1 b_1}\right)} \tag{7}$$

This method of r-value determination is only valid if plastic strain is homogeneous.

8.3 Method only with length extensometer (semi-automatic method)

8.3.1 General

This method is based on using an extensometer for length measuring combined with manual width measurement.

8.3.2 Testing

The original width of the test piece shall be measured with an accuracy of ±0,005 mm or better at a minimum of three points evenly distributed along the gauge length, including one measurement close to the position of each end of the gauge length. The average value of these width measurements b_o shall be used in calculating the plastic strain ratio.

The test piece is installed in the testing machine and is strained to the desired level and unloaded.

After unloading, the width b_1 is measured in the same manner and to the same accuracy as for the original width.

This method of r-value determination is only valid, if plastic strain is homogeneous.

A small preliminary force may be used to ensure the alignment of the test piece and grip arrangement, provided this force does not exceed a value corresponding to 5 % of the specified or expected yield strength. A zero-correction of the extensometer signal should be carried out to take into account the effect of the preliminary force.