SLOVENSKI STANDARD
oSIST prEN ISO 12004-2:2019

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Kovinski materiali - Pločevina in trakovi - Določevanje krivulj preoblikovalnosti - 2. del: Določevanje krivulj preoblikovalnosti v laboratoriju (ISO/DIS 12004-2:2019)

Metallic materials - Sheet and strip - Determination of forming-limit curves - Part 2: Determination of forming-limit curves in the laboratory (ISO/DIS 12004-2:2019)

Metallische Werkstoffe - Bleche und Bänder - Bestimmung von Grenzformänderungskurven - Teil 2: Bestimmung von Grenzformänderungskurven im Labor (ISO/DIS 12004-2:2019)

Matériaux métalliques - Tôles et bandes - Détermination des courbes limites de formage - Partie 2: Détermination des courbes limites de formage en laboratoire (ISO/DIS 12004-2:2019)

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77.040.10	Mehansko preskušanje kovin	Mechanical testing of metals
77.140.50	Ploščati jekleni izdelki in polizdelki	Flat steel products and semi-products

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DRAFT INTERNATIONAL STANDARD
ISO/DIS 12004-2

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Metallic materials — Sheet and strip — Determination of forming-limit curves —

Part 2: **Determination of forming-limit curves in the laboratory**

Matériaux métalliques — Tôles et bandes — Détermination des courbes limites de formage —

Partie 2: Détermination des courbes limites de formage en laboratoire

ICS: 77.040.10

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Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

This second edition cancels and replaces the first edition (ISO 12004-2:2008), which has been technically revised.

The main changes compared to the previous edition are as follows:

— Clause 2 and Clause 3 were added from the previous edition, and the subsequent sections were renumbered.

— The descriptions of when to use part 1 or part 2 of this standard was revised in the Introduction.

— Permissions and requirements were clarified in Clauses 6.1.3, 6.1.5, 6.2.2, 6.2.3, 6.3.2, 6.3.4.3, and 7.2.2.

— Permission for exceptional cases in Aluminium, as well as Steel, was added in Clause 6.3.1.

— Clarification was added that although the Nakajima method is known to have non-linear strain paths (Clause 6.3.3.1), it is still acceptable. Clarification as to why the failure is required to be near the apex of the dome was added to Clause 6.3.3.3. In Clause 6.3.3.3, the "validity of test" requirement for the Nakajima test was made explicit in a similar format to that shown for the Marciniak test in Clause 6.3.4.4. In Clauses 6.3.3.3 and 6.3.4.4, a statement regarding rejection of specimens not meeting the valid test requirements was added.

— The "Measuring Instrument" clause (Clause 4.3.5 in the previous edition) was removed since it is a repetition of the "Measurement Instrument" section of 6.3.2 but had a different accuracy requirement. The required accuracy is now shown as originally described in 6.3.2.

— The requirement on the second derivative range was clarified in Clause 7.2.3(c), and the requirements in the Keys of Figures 8 and 9 were changed to match Clause 7.2.3(c).

— The permission to use other methods of measurement was moved from Clause 7.2.1 to Clause 7.1, and was clarified.

— The statement regarding the "time-dependent method" in Clause 7.1 was removed, but still appears in the Note in Clause 5. The Note in Clause 5 now mentions "time and position dependent methods".

— In Clause 7.2.2, the method of selecting the section line locations based on the crack position was clarified, and permission was added to use the maximum strain location, as long as the test validity requirements are still met.

— The use of the procedure in 7.2.3 when extracting the "bell-shaped curve" for use in evaluating the section lines using the position-dependent method, has been changed to being required rather than just suggested. This seems to be consistent with the original intent.

— In normative Annex A, the method was changed to be required rather than proposed. Normative Annex C was clarified to show that the procedure is required. Clarification to the text of normative Annex D was added, and it's use is explicitly permitted. In Annex F, explicit permission to use a regression using in-house functions was added, as well as the requirement that the function is reported.

— Editorial changes and clarifications were made to Clauses 4, 5, 6.3.1, 6.3.3.2, 6.3.3.3, 6.3.4.3, 7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4, 8, 9, Annexes B, F, G, and H, and Figures 2, 5, 6, 8, 9, and C.1.A list of all parts in the ISO 12004- series can be found on the ISO website.

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.

Introduction

A forming-limit diagram (FLD) is a diagram containing major/minor strain points.

An FLD can distinguish between safe points and necked or failed points. The transition from safe to failed points is defined by the forming-limit curve (FLC).

To determine the forming limit of materials, two different methods are possible.

1) Strain analysis on failed press shop components to determine component and process dependent FLCs:

   In the press shop, the strain paths followed to reach these points are generally not known. Such an FLC depends on the material, the component, and the chosen forming conditions. This method is described in ISO 12004-1, and is not intended to determine one unique FLC for each material.

2) Determination of FLCs under well-defined laboratory conditions:

   For evaluating formability, one unique FLC for each material in several strain states is necessary. The determination of the FLC has to be specific, and it is necessary to use different linear strain paths. The ISO 12004-2 method should be used for this type of material characterization.

For this part of ISO 12004 (concerning determination of forming-limit curves in laboratory), the following conditions are also valid.

— Forming-limit curves (FLCs) are determined for specific materials to define the extent to which they can be deformed by drawing, stretching or any combination of drawing and stretching. This capability is limited by the occurrence of fracture and/or localized necking. Many methods exist to determine the forming limit of a material; however, it should be noted that results obtained using different methods cannot be used for comparison purposes.

— The FLC characterizes the deformation limit of a material in the condition after a defined thermo-mechanical treatment and in the analysed thickness. For a judgement of formability, the additional knowledge of mechanical properties and the material's history prior to the FLC-test are important.

To compare the formability of different materials, it is important not only to judge the FLC but also the following parameters:

a) mechanical properties at least in the main direction;

b) percentage plastic extension at maximum force, according to ISO 6892-1;

c) r-value with given deformation range, according to ISO 10113;

d) n-value with given deformation range, according to ISO 10275.

Metallic materials — Sheet and strip — Determination of forming-limit curves —

Part 2: Determination of forming-limit curves in the laboratory

1 Scope *(mandatory)*

This part of ISO 12004 specifies the testing conditions to be used when constructing a forming-limit curve (FLC) at ambient temperature and using linear strain paths. The material considered is flat, metallic and of thickness between 0,3 mm and 4 mm.

NOTE The limitation in thickness of up to 4 mm is proposed, giving a maximum allowable thickness to the punch diameter ratio.

For steel sheet, a maximum thickness of 2,5 mm is recommended.

2 Normative references *(mandatory)*

There are no normative references in this document.

3 Terms and definitions *(mandatory)*

No terms and definitions are listed in this document.

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/

4 Symbols and abbreviated terms

For the purposes of this document, the symbols and terms given in Table 1 apply.

Table 1 — Symbols and abbreviated terms

Symbol	English	French	German	Unit
e	Engineering strain	Déformation conventionnelle	Technische Dehnung	%
ε	True strain (logarithmic strain)	Déformation vraie (déformation logarithmique)	Wahre Dehnung (Umformgrad, Formänderung)	—
ε_1	Major true strain	Déformation majeure vraie	Grössere Formänderung	—
ε_2	Minor true strain	Déformation mineure vraie	Kleinere Formänderung	—
ε_3	True thickness strain	Déformation vraie en épaisseur	Dickenformänderung	—
σ	Standard deviation	Ecart-type	Standardabweichung	—
D	Punch diameter	Diamètre du poinçon	Stempeldurchmesser	mm
D_{bh}	Carrier blank hole diameter	Diamètre du trou du contre-flan	Lochdurchmesser des Trägerblechs	mm

Table 1 *(continued)*

Symbol	English	French	German	Unit
X(0), X(1) X(m) ....X(n)	X-position	Position en X	X-Position	mm
$f(x) = ax^2 + bx + c$	Best-fit parabola	Parabole de meilleur fit	Best-Fit-Parabel	—
$f(x) = 1/(ax^2 + bx + c)$	Best-fit inverse parabola	Parabole inverse de meilleur fit	Inverse Best-Fit-Parabel	—
S(0), S(1)...S(5)	Section	Section	Schnitt	—
n	Number of X-positions	Nombre de points en X	Nummer der X-Positionen	—
m	Number of the X-position at the failure/crack position	Numéro du point en X correspondant à la rupture	Nummer der X-Position am Riss	—
w	Width of the fit window	Largeur de la fenêtre de fit	Breite des Fit-Fensters	mm
t_0	Initial sheet thickness	Épaisseur initiale de la tôle	Ausgangsblechdicke	mm
r	Plastic strain ratio	Coefficient d'anisotropie plastique	Senkrechte Anisotropie	—

Table 2 gives a comparison of the symbols used in different countries.

Table 2 — Comparison of symbols used in different countries

English	French	German	German symbol	Anglo-American symbol	Format	Unit
Engineering strain	Déformation conventionelle	Technische Dehnung	ε	e	—	%
True strain (logarithmic strain)	Déformation vraie (Déformation logarithmique)	Wahre Dehnung (Umformgrad, Formänderung)	φ	ε	Decimal	—
$\varepsilon = \ln(1 + e)$	$\varepsilon = \ln(1 + e)$	$\varphi = \ln(1 + \varepsilon)$	—	—	—	—

The symbol used for true strain in Anglo-American-speaking countries is “ε ”; in German-speaking countries, the symbol “φ” is used for true strain.

In German-speaking countries, the symbol “ε ” is used to define engineering strains.

The notation for true strain used in this text is “ε ” following the Anglo-American definition.

5 Principle

The FLC is intended to represent the almost intrinsic limit of a material in deformation assuming a linear strain path. To determine the FLC accurately, it is necessary to have as nearly linear a strain path as possible.

A deterministic grid of precise dimensions or a stochastic pattern is applied to the flat and undeformed surface of a blank. This blank is then deformed using either the Nakajima or the Marciniak procedure until failure, at which point the test is stopped.

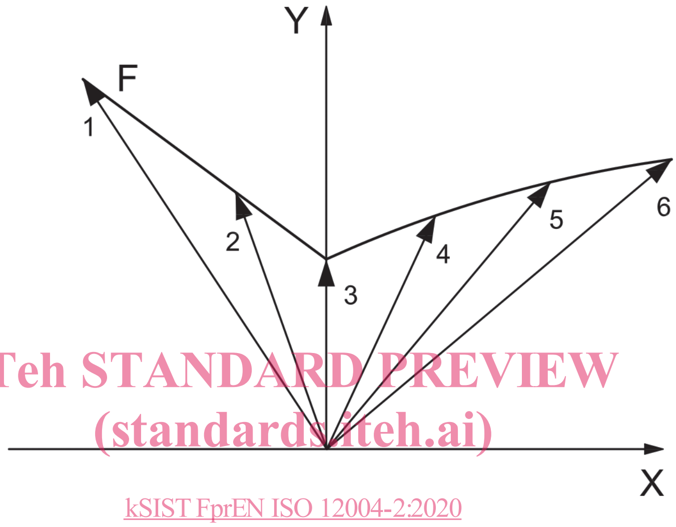
The FLC determination from the measurements should be performed using the “position-dependent” method described in 7.2.

NOTE “Time-dependent” methods and combined “time and position dependent” methods are under development, and may be added in later versions of this standard.

The deformation (strain) across the deformed test piece is determined and the measured strains are processed in such a way that the necked or failed area is eliminated from the results. The maximum strain that can be imposed on the material without failing is then determined through interpolation. This maximum of the interpolated curve is defined as the forming limit.

The forming limits are determined for several strain paths (different ratios between ε_1 and ε_2). The determined strain paths range from uniaxial tension to biaxial tension (stretch drawing). The collection of the individual forming limits in different strain states is plotted as the forming-limit curve. The curve is expressed as a function of the two true strains ε_1 and ε_2 on the sheet surface and plotted in a diagram, the forming-limit diagram. The minor true strains ε_2 are plotted on the X-axis and the major principal true strains ε_1 on the Y-axis (see Figure 1).

Standard conversion formulae permit the calculation of major (ε_1) and minor true strains (ε_2) from measured length changes or engineering strains. In the following, the word strain implies the true strain, which is also called logarithmic strain.



Key

X minor true strain, ε_2

Y major true strain, ε_1

F FLC

1 uniaxial tension, $\varepsilon_2 = -[r/(r + 1)]\ \varepsilon_1$

2 intermediate tensile strain

3 plane strain

4 intermediate stretching strain state

5 intermediate stretching strain state

6 equi-biaxial tension (= stretching strain state) $\varepsilon_2 = \varepsilon_1$

Figure 1 — Illustration of six different strain paths

6 Test pieces and equipment

6.1 Test pieces

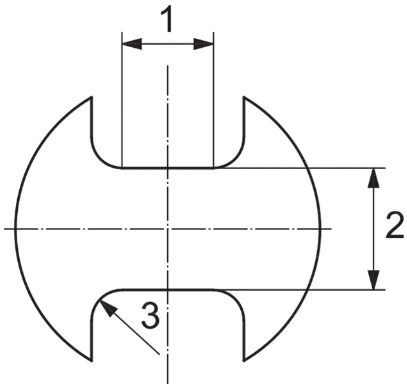
6.1.1 Thickness of test pieces

This procedure is intended for flat, metallic sheets with thickness between 0,3 mm and 4 mm.

6.1.2 Test piece geometry

The following geometries are recommended.

Waisted blanks with a central, parallel shaft longer than 25 % of the punch diameter (for a 100 mm punch: preferable shaft length 25 mm to 50 mm; fillet radius 20 mm to 30 mm) (see Figure 2).



Key

1 shaft length

2 remaining blank width

3 fillet radius

Figure 2 — Waisted test piece geometry with parallel shaft length (dog bone shape)

For $\varepsilon_2 > 0$, blanks with semi-circular cut-outs with different radii are possible.

For steel (mainly soft steel grades), rectangular strips with different widths are sufficient if test pieces do not fail at the die radius, otherwise use the test piece geometry as described above.

With an outer circular shape of the blanks, a more uniform distribution of the experimental forming-limit points is attainable than when rectangular strips are used.

6.1.3 Test piece preparation in test area

Milling or spark-erosion or other methods that do not cause cracks, work hardening or microstructure changes may be used ensuring that fracture never initiates from the edges of test pieces.

6.1.4 Number of different test piece geometries

At least five geometries for the description of a complete FLC are necessary. (A uniform allocation of the FLC from uniaxial to equi-biaxial tension is recommended.)

If the description of a complete FLC is not necessary, then a lower number of geometries is allowed, but this shall be mentioned in the test report.

6.1.5 Number of tests for each geometry

As many test pieces as are necessary shall be tested to achieve at least three valid samples for each test piece geometry.

6.2 Application of grid

6.2.1 Type of grid

The recommended grid size is approximately one times the material thickness (grid size is related to the material thickness due to necking width), a maximum grid size of 2,5 times the material thickness is allowed and the largest grid dimension allowed for a 100 mm punch is 2,54 mm (0,1 in). In general, grid sizes of 1 mm or 2 mm are used. Small grid sizes are often limited because of their lack of accuracy (if the undeformed grid is not measured before beginning of test).

