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Metallic materials — Determination of forming-limit curves for sheet and strip —

Part 1: Measurement and application of forming-limit diagrams in the press shop

Matériaux métalliques — Détermination des courbes limites de formage pour les tôles et bandes —

Partie 1: Mesurage et application des diagrammes limites de formage dans les ateliers d'emboutissage

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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*, 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 second edition cancels and replaces the first edition (ISO 12004-1:2008), which has been technically revised.

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

1) The title was changed to have three elements.

2) Clauses 2 and 3 were added from the previous edition, and the subsequent sections were renumbered.

3) The description of when to use this document (ISO 12004-1) or ISO 12004-2 was revised in the Introduction.

4) Throughout the document the use of engineering strain was clarified.

5) Subclause 6.2 was extended to include what was the subsequent Clause in the previous version.

6) The former note was moved to part of Clause 7, since it gives permission to use another method.

7) The text in Annex A and the figure captions in Annex B were clarified.

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 measured major/minor strain points on a formed part.

An FLD can distinguish between safe 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 of failed press shop components to determine component and process dependent FLCs

   In the press shop, strain paths 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 this document 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 can be measured. The determination of FLC must be specific and uses multiple linear strain paths. The ISO 12004-2 is intended for this type of material characterization.

Metallic materials — Determination of forming-limit curves for sheet and strip —

Part 1: Measurement and application of forming-limit diagrams in the press shop

1 Scope

This document specifies a procedure for developing forming-limit diagrams and forming-limit curves for metal sheets and strips of thicknesses from 0,3 mm to 4 mm.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

The symbols and abbreviated terms used in forming-limit diagrams are specified in Table 1, and examples of grid patterns used are given in Annex B.

Table 1 — Symbols and abbreviated terms

Symbol	Definition	Unit
l_0	Original gauge length of grid pattern	mm
l_1	Final length in major strain direction	mm
l_2	Final length at 90° to major strain direction	mm
e	Engineering strain	%
e_1	Major engineering strain	%
e_2	Minor engineering strain (90° to major)	%
FLD	Forming-limit diagram	—
FLC	Forming-limit curve	—

5 Principle

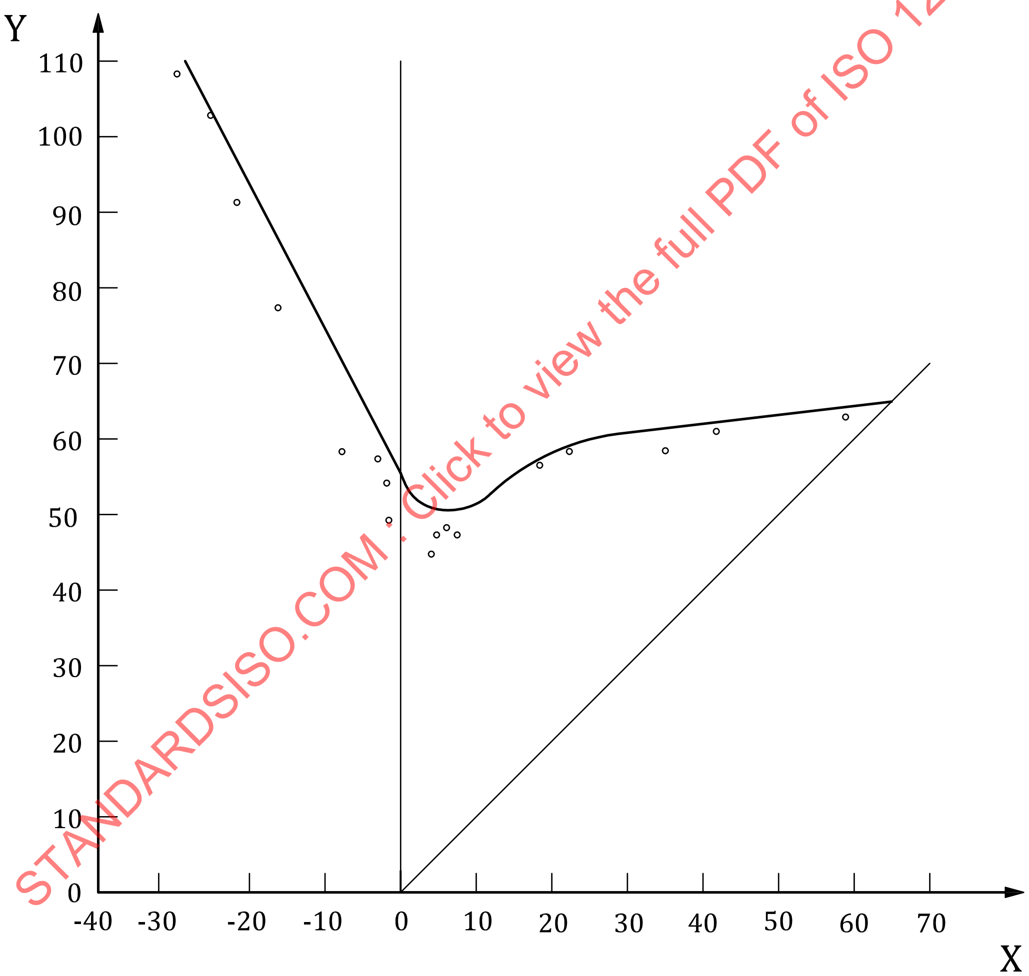
A pattern of precise gauge lengths of appropriate size is applied to the flat surface of a metal sheet test piece, then the test piece is formed until fracture, and the percent change in the gauge length in the major direction and in the minor strain direction at 90° to this is measured in order to determine the forming-limit under the imposed strain conditions. A number of repeated tests under varying strain conditions are carried out to provide data for the forming-limit curve (FLC) for the material when these limiting strains are plotted on the forming-limit diagram (FLD) (see Figure 1).

6 Test conditions

6.1 Gauge lengths in the range of 1,5 mm to 5,0 mm are recommended. The actual gauge lengths shall be known to an accuracy of 2 %.

6.2 During the forming of test pieces, the strain in the critical area shall be uniform before onset of necking. In order to achieve this, any set of tooling employing a holding force and a deformation force may be used to develop the limiting strain condition.

6.3 The forming-limit curve shall be plotted on the forming-limit diagram. Figure 1 shows an example of a forming-limit curve.



Key

X minor engineering strain, in percent

Y major engineering strain, in percent

Figure 1 — Typical forming-limit curve

7 Procedure

The procedure for the determination of the forming limit is as follows:

1) Take a representative sample of the material to be evaluated.

2) Apply a suitable grid pattern, that has been checked for accuracy of the initial gauge lengths, to the surface of a test piece in areas of the part to be formed which are known, or have been established by investigation, to be critical.

3) Any test device that satisfies Clause 6 may be used to form the test piece, such as a universal tensile testing machine, a stamping press, a cupping press, a hydraulic bulge machine and their combinations or any other equipment capable of clamping the test piece and applying a plastic deformation force in an area remote from the edge. A universal testing machine may be employed and forming limits established using a tensile test.

4) Test pieces shall be tested while clamped around the whole of their periphery or shall be cut into strips of varying widths to give a range of strain conditions. The surface between the punch and the specimen shall be suitably lubricated using a standard product for the operation. A combination of polyethylene sheet and lubricant can be used.

5) Stop the test at the first occurrence of fracture.

6) Determine the engineering strains e_1 and e_2 as follows:

   a) Measure (for example with calliper or optical measurement system) three adjacent gauge lengths in the direction of e_1 that were originally in a straight line. Repeat until the three values obtained are the same to within ±10 %. Record the average of these three values as l_1. A more accurate method may be prescribed as provided for in ISO 12004-2[2].

   NOTE Although engineering strain is specified in this document, true strain is specified in the forming limit determination for ISO 12004-2[2].

   b) If it is not possible to obtain three values within ±10 %, form a new test piece and repeat the measurements.

   c) Select one of the gauge lengths measured in step 6) a) and measure the gauge length at 90° to the original e_1 direction, and report this as l_2.

   d) Calculate the percent engineering strains e_1 and e_2 as follows:

$$e_1 = \frac{l_1 - l_0}{l_0} \times 100 \quad (1)$$

$$e_2 = \frac{l_2 - l_0}{l_0} \times 100 \quad (2)$$

7) Make measurements on a sufficient number of test pieces to plot a forming-limit curve.

8 Interpretation of results

8.1 Plot e_1 against e_2 on a forming-limit diagram. As shown in Figure 1, the major engineering strain e_1 is plotted along the Y-axis and the minor engineering strain e_2 is plotted along the X-axis.

8.2 Draw the forming-limit curve through the points of maximum e_1 strain (see Figure 1).

8.3 The effect of a forming operation on a particular part may be estimated from the diagram by measuring the strains in critical areas and comparing the results with the curve for the material used.

9 Test report

9.1 The test report shall contain the following information:

a) a reference to this document, i.e. ISO 12004-1:2020;

b) the identification of the test piece;

c) the thickness of the test piece;

d) the forming-limit curve (FLC) plotted on the forming-limit diagram (FLD) (as shown in Figure 1);

e) the gauge length of the grid pattern used;

f) lubrication conditions.

9.2 The test report may also include the following information:

a) selected mechanical properties of the material tested;

b) the chemical composition (percentage content of major elements) of the material tested;

c) a description of the procedure used;

d) the type of grid pattern used;

e) details of any deviation from the procedure specified (see, in particular, Annex A).

Annex A
(informative)

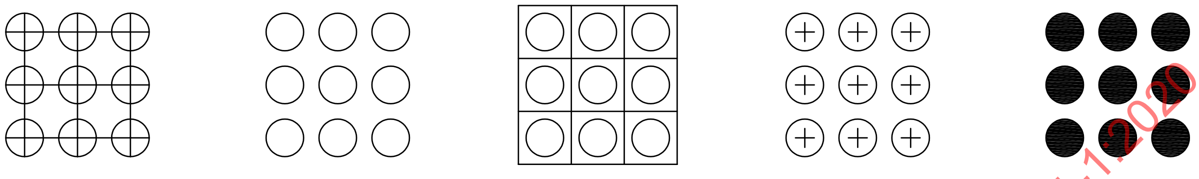
Modification to forming-limit curves

To accommodate the variations experienced in the production of a given commercial product and to allow corrections to be made for known differences, such as the different behaviour of similar materials of different thicknesses when formed using the same tooling, or different strain-hardening characteristics, modifications have been proposed to the forming-limit curve. These modifications displace the curve upwards for thicker materials and for materials with a higher strain hardening exponent (*n*-value) (see ISO 10275[1]). Such modifications to FLCs have not been established as viable corrections and, if employed, shall be specifically noted in the test report.

Figure 1 shows an example of an FLC. Deformed areas in a formed part which have strains lying above, or close below, the FLC are likely to fail. These points should be examined to either reduce the strain or replace the material with another having a higher FLC.

Annex B
(informative)

Examples of grid patterns currently in use



a) circle grid with lines | b) circle grid | c) circle grid in squares | d) circle grid with centre crosses | e) filled circle grid

Figure B.1 — Examples of various types of circular grid patterns

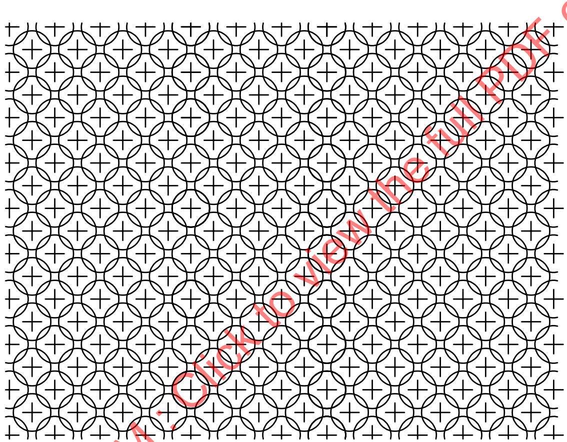


Figure B.2 — Example of a circular grid pattern with centre crosses

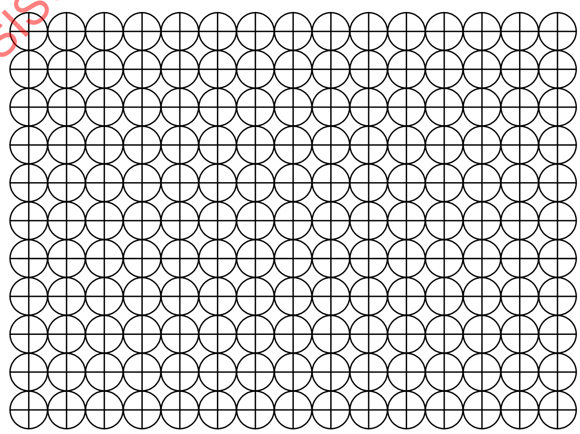


Figure B.3 — Example of a circular grid pattern with lines