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Metallic materials — Guidelines for the determination of forming-limit diagrams

Matériaux métalliques — Lignes directrices pour la détermination de diagrammes limites de formage

Reference number
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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 12004 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, subcommittee SC 2, *Ductility testing*.

Annexes A and B of this International Standard are for information only.

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Introduction

Forming-limit diagrams are determined for specific materials to define, by a forming-limit curve, the extent to which the material can be formed by drawing or stretching or any combination of drawing and stretching.

This capability is limited by the occurrence of fracture, localized thinning or wrinkling. Knowing the limits of formability is important in designing parts to utilize the material fully without exceeding its forming limit.

Therefore, this International Standard is intended as a guide to the definition of the forming limit and to testing procedures which incorporate known variables affecting the forming limit.

There are other methods that use strain interpolations for detection of the onset of necking. It should be borne in mind, however, that results obtained using different methods cannot be used for comparison purposes.

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Metallic materials — Guidelines for the determination of forming-limit diagrams

1 Scope

This International Standard provides guidelines for developing forming-limit diagrams and forming-limit curves for metal sheets and strips of nominal thicknesses from 0,2 mm to 3 mm.

2 Symbols

The symbols used in forming-limit diagrams are specified in table 1, and examples of the grid patterns used are given in annex B.

Table 1 — Symbols and their meanings

Symbol	Meaning	Unit
a	Thickness of test piece	mm
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_1	Major strain	%
e_2	Minor strain (90° to major)	%
FLD	Forming-limit diagram	
FLC	Forming-limit curve	

3 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 just prior to the onset of localized thinning (necking), and the percent change in the gauge length in the major strain 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 a forming-limit diagram (FDL) (see figure 1).

4 Test conditions

4.1 Gauge lengths in the range 1,5 mm to 5,0 mm are recommended. The actual gauge lengths shall be known to within 2 %.

4.2 During the forming of test pieces, the strain shall be as uniform as possible.

4.3 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.

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

4.5 The forming limit is reached just prior to the onset of localized thinning referred to as necking. Thus it is necessary to stop the forming process before this point. The approximate position of this point may be established by an initial trial or estimated from preliminary tests on ungridded test pieces.

5 Procedure

The recommended procedure for determining the forming limit is as follows:

5.1 Take a representative sample of the material to be evaluated.

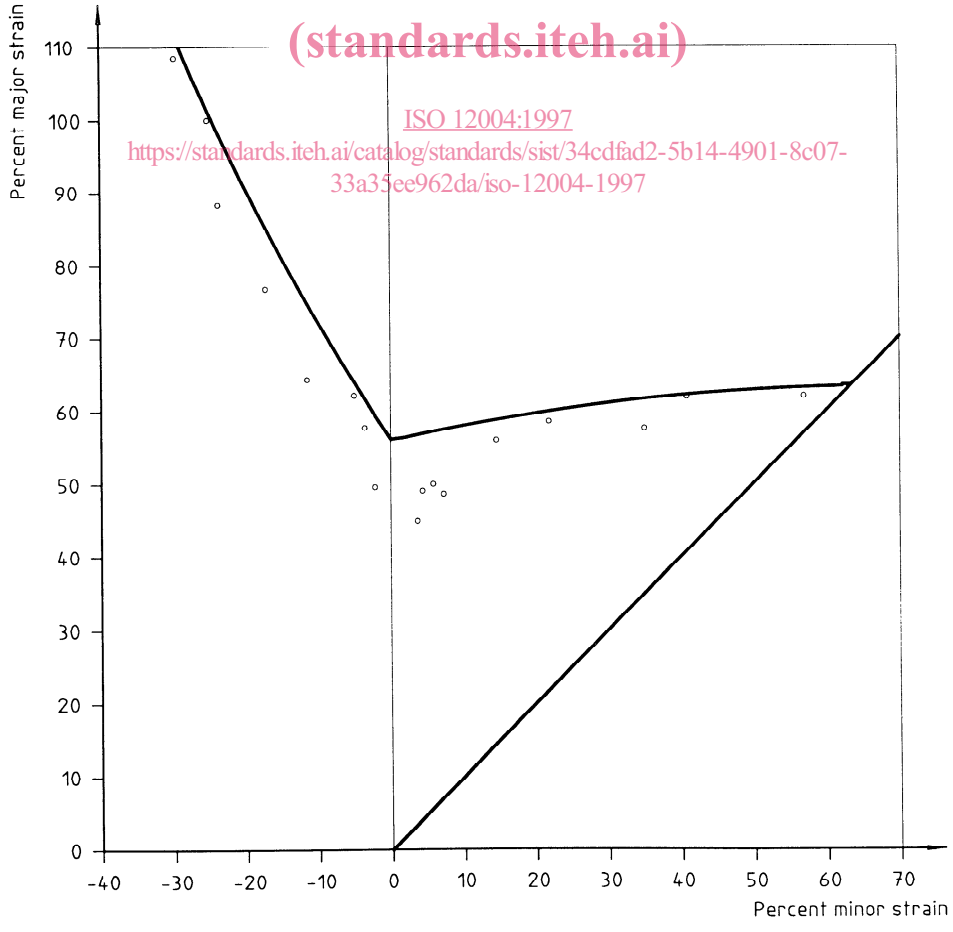

Figure 1 — Typical forming-limit curve

5.2 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.

5.3 Any test device that satisfies clause 4 may be used to form the test piece, such as a stamping press, a cupping press, a hydraulic bulge machine 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.

5.4 Test pieces shall be tested clamped round the whole of their periphery or shall cut into strips of varying widths to give a range of strain conditions. If necessary, different lubricants may be used.

5.5 Stop the test at the first indication of localized necking. One method is to lightly burnish the surface of the test piece using a flat, hard stone such as a sharpening stone.

5.6 Determine the strains e_1 and e_2 as follows:

5.6.1 Measure 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.

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

5.6.3 Select one of the gauge lengths measured in 5.6.1 and measure the gauge length at 90° to the original e_1 direction, and report this as l_2.

5.7 Calculate the percent e_1 and e_2 as follows:

$$e_1 = \frac{l_1 - l_0}{l_0} \times 100$$

$$e_2 = \frac{l_2 - l_0}{l_0} \times 100$$

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

6 Interpretation of results

6.1 Plot e_1 against e_2 on a forming-limit diagram. As shown in figure 1, the major strain e_1 is plotted along the y-axis and the minor strain e_2 is plotted along the x-axis.

6.2 Draw the forming-limit curve through the maximum number of points (see figure 1).

6.3 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.

7 Test report

7.1 The test report shall include the following information:

a) a reference to this International standard;

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.

7.2 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)

Modifications 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 due to prior cold working before testing, modifications have been proposed to the forming-limit curve. These modifications displace the curve upwards for thicker test pieces of a given material, or change the shape within a given commercial grade if processing has resulted in significantly different plastic strain ratios (r values) (see ISO 10113:1991, *Metallic materials — Sheet and strip — Determination of plastic strain ratio*) or strain hardening exponents (n values) (see ISO 10275:1993, *Metallic materials — Sheet and strip — Determination of tensile strain hardening exponent*). 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 close to the FLC are likely to fail and should be examined to reduce the strain, or a material employed which has a superior formability.

The relationship between the critical strains e_1 and e_2 and the original rolling direction in a sheet product can affect the forming limit.