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Metallic materials — Sheet and strip — Biaxial tensile testing method using a cruciform test piece

Matériaux métalliques — Tôles et bandes — Méthode d'essai de traction biaxiale sur éprouvette cruciforme

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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*.

This second edition cancels and replaces the first edition (ISO 16842:2014), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

— the font of “a” Figure 1 has been modified to “*a*”;

— the description in 6.1 h) has been modified for clarity;

— the title of Figure 2 b) has been modified for clarity;

— ISO 10275 has been moved from Clause 2 (Normative references) to the Bibliography;

— ISO 7500-1 has been added to Clause 2 (Normative references);

— the font of “C” Figure C.2 has been modified to “*C*”;

— general editorial corrections have been made.

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

This document specifies the testing method for measuring the biaxial stress-strain curves of sheet metals subject to biaxial tension at an arbitrary stress ratio using a cruciform test piece made of flat sheet metals. The document applies to the shape and strain measurement position for the cruciform test piece. The biaxial tensile testing machine is described in Annex C, only in terms of the typical example of the machine and the requirements with which the machine ought to conform.

The cruciform test piece recommended in this document has the following features:

a) the gauge area of the test piece ensures superior homogeneity of stress, enabling measurement of biaxial stress with satisfactory accuracy;

b) capability of measuring the elasto-plastic deformation behaviour of sheet metals at arbitrary stress or strain rate ratios;

c) free from the out-of-plane deformation as is encountered in the hydrostatic bulge testing method;

d) easy to fabricate from a flat metal sheet by laser cutting, water jet cutting, or other alternative manufacturing methods.

Metallic materials — Sheet and strip — Biaxial tensile testing method using a cruciform test piece

1 Scope

This document specifies the method for measuring the stress-strain curves of sheet metals subject to biaxial tension using a cruciform test piece fabricated from a sheet metal sample. The applicable thickness of the sheet is 0,1 mm or more and 0,08 times or less of the arm width of the cruciform test piece (see Figure 1). The test temperature ranges from 10 °C to 35 °C. The amount of plastic strain applicable to the gauge area of the cruciform test piece depends on the force ratio, slit width of the arms, work hardening exponent (n-value) (see Annex B) and anisotropy of a test material.

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

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*

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:

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

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

3.1
cruciform test piece
test piece which is recommended in the biaxial tensile test and whose geometry is specified in this document

Note 1 to entry: See Figure 1.

3.2
gauge area
square area which is located in the middle of the cruciform test piece and is enclosed by the four arms of the cruciform test piece

Note 1 to entry: See Figure 1.

3.3
arm
generic name for all areas other than the gauge area in the cruciform test piece

Note 1 to entry: The arms play a role of transmitting tensile forces in two orthogonal directions to the gauge area of the cruciform test piece (see Figure 1).

3.4
biaxial tensile testing machine
testing machine for applying biaxial tensile forces to a cruciform test piece in the orthogonal directions parallel to the arms of the test piece

Note 1 to entry: See Annex C.

3.5
yield surface
group of stress determined in a stress space, at which a metal starts plastic deformation when probing from the elastic region into the plastic range

Note 1 to entry: See Annex A and Reference [1].

3.6
yield function
mathematical function used to generate the conditional equation (yield criterion) to which the stress components ought to conform when the material subject to the stress is in the plastic deformation state

Note 1 to entry: See Annex A.

3.7
contour of plastic work
graphic figure derived by subjecting the material to plastic deformation along various linear stress paths and plotting the stress points in stress space at the instance when the plastic work consumed per unit volume along each stress path becomes identical and the plotted stress points are approximated into either a smooth curve or curved surface

Note 1 to entry: See Annex A.

4 Principle

Measurement is made at room temperature on the yield stress and the stress-strain curves of sheet metals under biaxial tensile stresses by measuring simultaneously and continuously the biaxial tensile forces and strain components applied to the gauge area of a cruciform test piece while applying biaxial tensile forces in the orthogonal directions parallel to the arms of the test piece. The test piece is made of a flat sheet metal and has a uniform thickness. The measured biaxial stress-strain curves are used to determine contours of plastic work of the sheet samples (see Annex A). According to the finite element analyses of the cruciform test piece (as recommended in Clause 5) and the strain measurement position (as specified in 6.2.4), the stress calculation error is estimated to be less than 2,0 %[2][3].

5 Test piece

5.1 Shape and dimensions

Figure 1 shows the shape and dimensions of the cruciform test piece recommended in document. The test piece shall be as described as follows:

a) In principle, the thickness of a test piece, a, shall be the same as that of the as-received sheet sample, without any work done in the thickness direction. See 5.1 b) for an exception to the rule.

b) The arm width, B, should be 30 mm or more, except where it is determined according to the agreement between parties involved in transaction. It shall satisfy $a \leq 0{,}08B$ and should be accurate to within ±0,1 mm for all four arms. The sheet thickness can be reduced to satisfy $a \leq 0{,}08B$ according to the agreement between the parties involved in transaction.

c) Seven slits per one arm shall be made. Specifically, one slit shall be made on the centreline (x-axis or y-axis) of the test piece with a positional accuracy of ±0,1 mm, and three slits shall be made at an interval of $B/8$ with a positional accuracy of ±0,1 mm on each side of the centreline. All slits shall have the same length, L, and should be accurate to within ±0,1 mm. The relationship of $B \leq L \leq 2B$ should be established. The opposing slit ends shall be made at an equal distance, $B_{Sx}/2$ and $B_{Sy}/2$, from the centreline with a positional accuracy of $B/2 \pm 0,1$ mm.

d) The slit width, w_S, should be made as small as possible (see Figure B.2), preferably less than 0,3 mm.

e) The grip length, C, is considered to be sufficient if it can secure the test piece to the grips of the biaxial tensile testing machine and can transmit the necessary tensile force to the test piece. The standard grip length would be $B/2 \leq C \leq B$, but it can be determined arbitrarily according to the agreement between the parties involved in the transaction.

f) An alternative test piece geometry can be used. In the use of the alternative cruciform test pieces, the evidence of the stress measurement accuracy shall be clarified between the contractual partners.

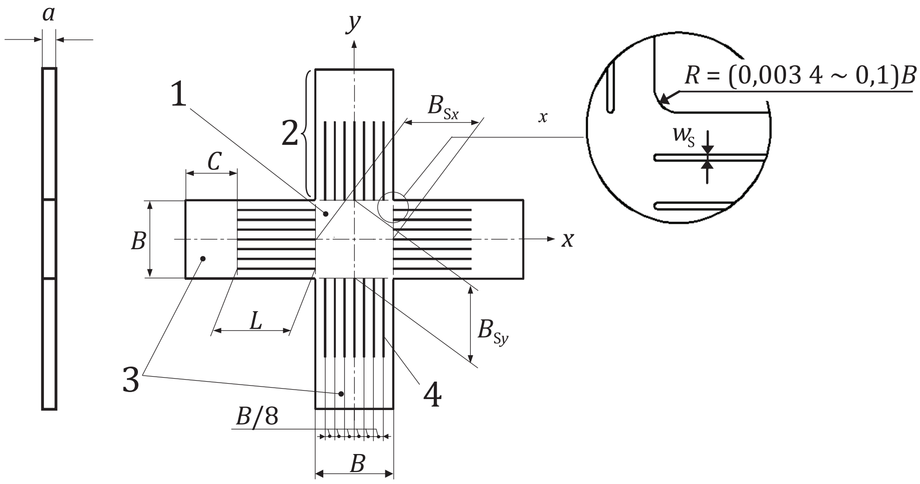
5.2 Preparation of the test pieces

a) The permitted variations in thickness and the permitted variations from a flat surface of the sheet metal sample from which the cruciform test pieces are taken shall be in accordance with relevant product standards or national standards.

b) The standard sampling direction of the test piece shall be such that the directions of arms are parallel to the rolling (x) and transverse (y) directions of the sheet sample, respectively. The test piece sampling direction can be determined according to the agreement between parties involved in transaction.

c) For the fabrication of the test piece (including making of slits), any method, e.g. laser cutting, water jet cutting, or other alternative manufacturing methods, demonstrated to work satisfactorily can be used if agreed upon by the parties.

d) Unless otherwise specified and except for the sampling work, unnecessary deformation or heating to the test piece shall be avoided.



Key

1 gauge area

2 arm

3 grip

4 slit

a thickness of a test piece

B arm width

B_{Sx} distance between opposing slit ends in the *x* direction

B_{Sy} distance between opposing slit ends in the *y* direction

C grip length

L slit length

R corner radius at the junctions of arms to the gauge area

w_S slit width

Figure 1 — Standard shape and dimensions of the recommended cruciform test piece[2][3]

6 Testing method

6.1 Testing machine

The specifications required for the biaxial tensile testing machine (hereinafter referred to as testing machine) are as follows (for examples of typical testing machines, see Annex C):

a) It shall have sufficient functions and durability to hold four grips of a cruciform test piece (hereinafter referred to as test piece) in one single plane with a tolerance of ±0,1 mm during testing.

b) Two opposing grips shall move along a single straight line (hereinafter referred to as *x*-axis and *y*-axis), and the *x*- and *y*-axes shall intersect at an angle of 90° ± 0,1° (The plane that contains the *x*- and *y*-axes is referred to as the reference plane, while the intersection of *x*- and *y*-axes is referred to as the centre of testing machine).

c) It shall have a function for adjusting the two opposing grips to the position at an equal distance from the centre of the testing machine with a tolerance of ±0,1 mm before the installation of a test piece to the grips.

d) It shall have a function for enabling the installation of a test piece to the grips while aligning the centre of the test piece to the centre of the testing machine.

e) It shall have a function for enabling equal displacement of two opposing grips or the maintenance of the centre of the test piece always on the centre of the testing machine with a tolerance of ±0,1 mm during biaxial tensile test (for example, the testing machines shown in Figures C.1 and C.2 use a link mechanism to ensure equivalent displacement of two opposing grips).

f) It shall have a capability of servo-controlled biaxial tensile testing to perform a test with a constant nominal stress ratio (constant force ratio) and/or a test with a constant true stress ratio, and/or a test with a constant strain-rate ratio, according to the purpose of the test (see C.2). For a link type biaxial tensile testing machine, it shall ensure equal displacement of two opposing grips (see C.3).

g) Modern control electronics allow independent and combined control of each actuator. This is called modal control (see C.4).

h) It shall have a function for measuring and storing the values of the tensile forces (two channels, one for each of the two axes, x and y) and strain components (two channels, one for each of the two axes, x and y) during biaxial tensile test with the specified accuracy and time interval agreed by the parties concerned.

6.2 Measurement method of force and strain

6.2.1 General

This subclause specifies the method for measuring the tensile forces (F_x, F_y) and nominal strain components (e_x, e_y) applied to the x and y directions of a cruciform test piece.

6.2.2 Measurement method of force

For measurement of F_x and F_y, load cells shall be used in the x and y directions. The force-measuring system of the testing machine shall be calibrated in accordance with ISO 7500-1, class 1, or better.

6.2.3 Measurement method of strain

For measurement of e_x and e_y, strain gauges or other methods (e.g. an optical measurement system) shall be used. Measure e_x and e_y to the nearest 0,000 1 or better.

6.2.4 Strain measurement positions

Figure 2 shows the position(s) of a strain gauge (or strain gauges) for measuring e_x and e_y. e_x and e_y shall be measured at a position, with a distance of (0,35 ± 0,05)B from the centre of test piece, on the centreline parallel to the maximum tensile force. The strain measurement position can also be determined according to the agreement between parties involved in transaction.

NOTE According to the finite element analyses of the cruciform test piece as recommended in Clause 5 and the strain measurement position as specified in Figure 2, the stress calculation error is estimated to be less than 2,0 %[2][3].