
**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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Contents

| | Page |
|---|-----------|
| Foreword | iv |
| Introduction | v |
| 1 Scope | 1 |
| 2 Normative references | 1 |
| 3 Terms and definitions | 1 |
| 4 Principle | 2 |
| 5 Test piece | 2 |
| 5.1 Shape and dimensions..... | 2 |
| 5.2 Preparation of the test pieces..... | 2 |
| 6 Testing method | 4 |
| 6.1 Testing machine..... | 4 |
| 6.2 Measurement method of force and strain..... | 4 |
| 6.3 Installation of the test piece to a biaxial tensile testing machine..... | 6 |
| 6.4 Testing methods..... | 7 |
| 7 Determination of biaxial stress-strain curves | 7 |
| 7.1 General..... | 7 |
| 7.2 Determination of the original cross-sectional area of the test piece..... | 7 |
| 7.3 Determination of true stress..... | 7 |
| 7.4 Determination of true strain..... | 8 |
| 7.5 Determination of true plastic strain..... | 8 |
| 8 Test report | 10 |
| 8.1 Information in the report..... | 10 |
| 8.2 Additional note..... | 11 |
| Annex A (informative) Method for measuring a yield surface | 12 |
| Annex B (informative) Factors affecting the maximum equivalent plastic strain applicable to the gauge area of the test piece | 17 |
| Annex C (informative) Biaxial tensile testing machine | 19 |
| Bibliography | 23 |

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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee 2, *Ductility testing*.

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Introduction

This International Standard 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 International Standard 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 that the machine should comply with.

The cruciform test piece recommended in this International Standard 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.

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

1 Scope

This International Standard 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 shall be 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 shall range 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, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10275, *Metallic materials — Sheet and strip — Determination of tensile strain hardening exponent*

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

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1

cruciform test piece

test piece which is recommended in the biaxial tensile test and whose geometry is specified in this International Standard (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 (see [Figure 1](#))

3.3

arm

generic name for all areas other than the gauge area in the cruciform test piece. 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 (see [Annex C](#))

3.5

yield surface

a 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^[1] (see [Annex A](#))

3.6

yield function

mathematical function used to generate the conditional equation (yield criterion) which the stress components should comply with when the material subject to the stress is in the plastic deformation state (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 (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 [Clause 6.2.4](#), the stress calculation error is estimated to be less than 2,0 %.^{[2][3]}

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5 Test piece

5.1 Shape and dimensions

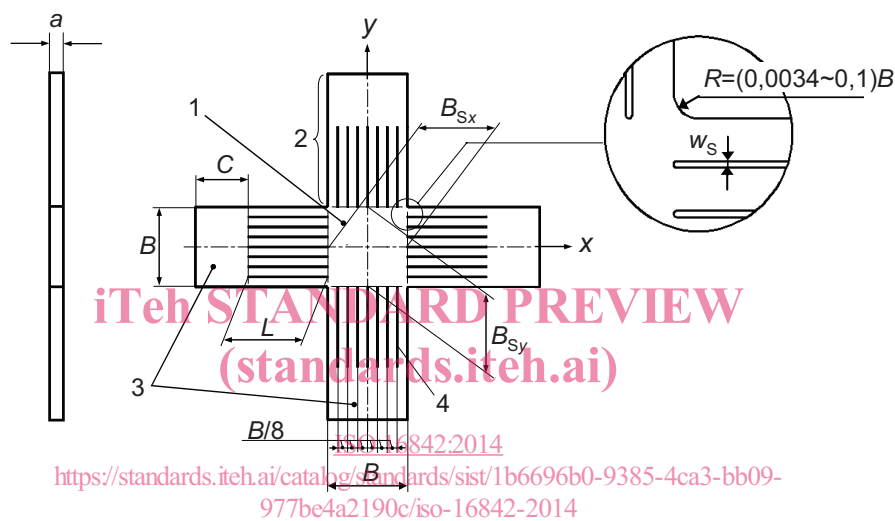
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[Figure 1](#) shows the shape and dimensions of the cruciform test piece recommended in this International Standard. The test piece shall be as described below.

- 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 that it can be determined according to the agreement between parties involved in transaction. It shall satisfy $a \leq 0,08B$ and should be accurate to within $\pm 0,1$ mm for all four arms. The sheet thickness can be reduced to satisfy $a \leq 0,08B$ according to the agreement between parties involved in transaction.
- c) Seven slits per one arm shall be made. Specifically, one slit shall be made on the centerline (x -axis or y -axis) of the test piece with a positional accuracy of $\pm 0,1$ mm, and three slits shall be made at an interval of $B/8$ with an positional accuracy of $\pm 0,1$ mm on each side of the centerline. All slits shall have the same length, L , and should be accurate to within $\pm 0,1$ 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 centerline 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 enough 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 can be determined arbitrarily according to the agreement between parties involved in 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 has to 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 $\pm 0,1$ 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 $90^\circ \pm 0,1^\circ$ (The plane that contains the x - and y -axes is referred to as the reference plane, while the intersection of x - and y -axes 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 $\pm 0,1$ 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 $\pm 0,1$ 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 [Annex C.2](#)). For a link type biaxial tensile testing machine, it shall ensure equal displacement of two opposing grips (see [Annex C.3](#)).
- g) Modern control electronics allow independent and combined control of each actuator — it is called modal control (see [Annex C.4](#)).
- h) It shall have a function for measuring and storing the values of the tensile forces (two channels for the x - and y -axes) and strain components (two channels for the x - and y -axes) 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 , 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 , 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

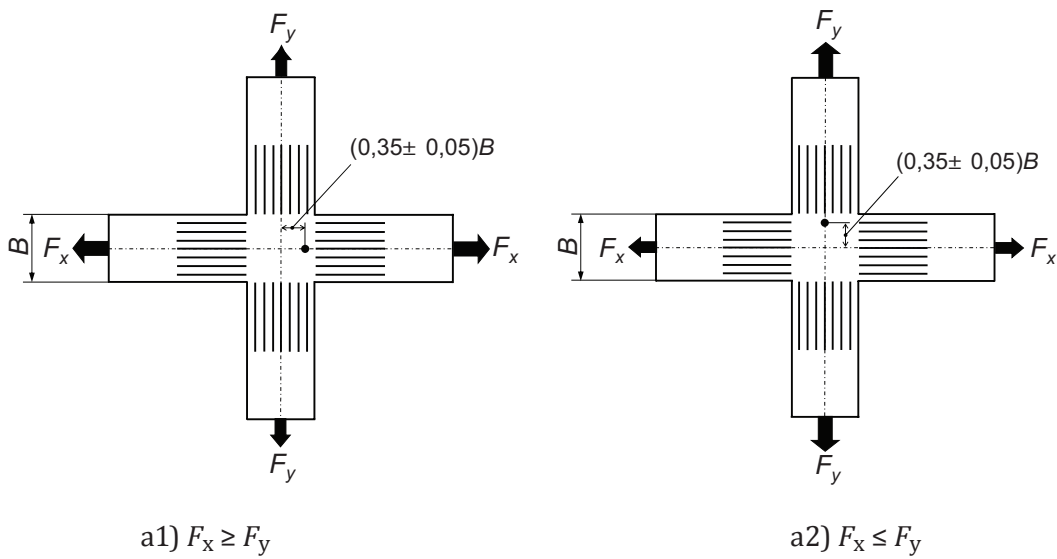
[Figure 2](#) shows the position(s) of a strain gauge (or strain gauges) for measuring (e_x, e_y) . (e_x, e_y) shall be measured at a position, with a distance of $(0,35 \pm 0,05)B$ from the centre of test piece, on the centerline parallel to the maximum tensile force. The strain measurement position 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]}

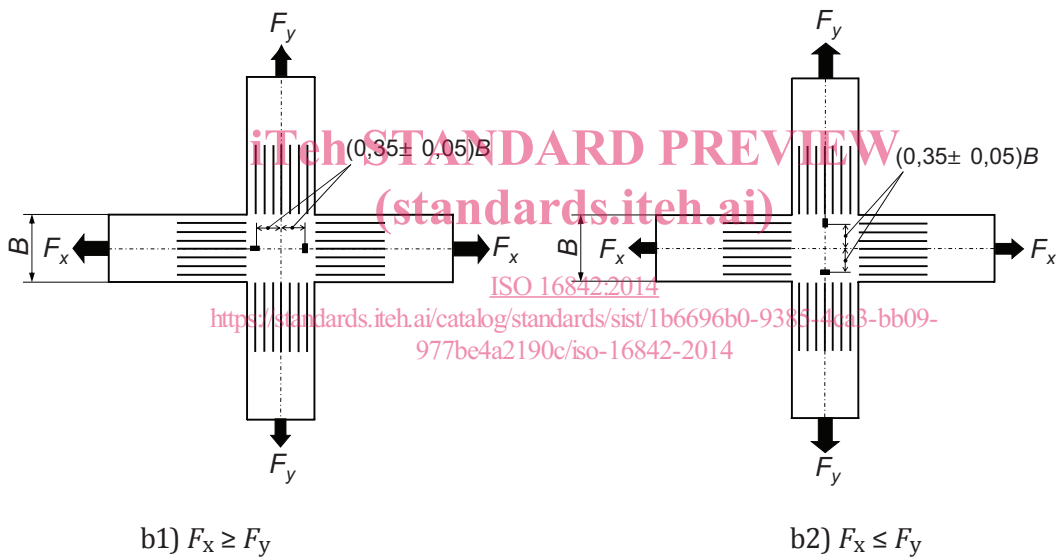
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a) A case of measuring e_x and e_y , using a biaxial foil strain gauge



b) A case of measuring e_x and e_y , using two pieces of uniaxial strain gauge

Key

- B arm width
- e_x nominal strain in the x direction
- e_y nominal strain in the y direction
- F_x tensile force in the x direction
- F_y tensile force in the y direction

Figure 2 — Strain measurement position^{[2][3]}

6.3 Installation of the test piece to a biaxial tensile testing machine

The test piece shall be fixed by four grips of a biaxial tensile testing machine. Care shall be taken to ensure alignment of the centre of test piece with that of the testing machine.