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**Biaxial tensile testing method for sheet
metals using a cruciform test piece**

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Foreword

This Japanese Industrial Standard has been established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal for establishment of Japanese Industrial Standard submitted by Osaka Science & Technology Center (OSTEC)/Japanese Standards Association (JSA) with a draft being attached, based on the provision of Article 12, paragraph (1) of the Industrial Standardization Act.

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Biaxial tensile testing method for sheet metals using a cruciform test piece

Introduction

This Japanese Industrial Standard has been prepared based on **ISO 16842** : 2014, Edition 1, with some modifications of the technical contents.

The dotted underlines indicate changes from the corresponding International Standard. A list of modifications with the explanations is given in Annex JA.

1 Scope

This Standard specifies the method for measuring the stress-strain curves of sheet metals under biaxial tensile stresses using a cruciform test piece having a uniform thickness, fabricated from a sheet metal sample (hereafter referred to as test piece), by applying tensile forces in the orthogonal directions parallel to the centrelines of the test piece.

NOTE The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows.

ISO 16842 : 2014 *Metallic materials — Sheet and strip — Biaxial tensile testing method using a cruciform test piece* (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21-1**.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS G 0202 *Glossary of terms used in iron and steel (Testing)*

JIS Z 2241 *Metallic materials — Tensile testing — Method of test at room temperature*

JIS Z 8401 *Rounding of numbers*

3 Terms and definitions

For the purpose of this Standard, the terms and definitions given in JIS G 0202 and JIS Z 2241, and the following apply.

3.1

cruciform test piece

test piece to be used for biaxial tensile testing, which is cut out in a cruciform from a sheet metal (see Figure 1)

3.2

gauge area

square area which is located in the middle of the 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 test piece (see Figure 1)

The arms play a role of transmitting tensile forces in two orthogonal directions to the gauge area of the cruciform test piece.

3.4

biaxial tensile testing machine

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

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 (see Annex A)

3.6

yield function

mathematical function used to generate the conditional equation (yield criterion) that the stress components shall satisfy 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

In the case where the plastic work per unit volume is made sufficiently small, the contour of plastic work is approximated into a yield surface (see Annex A).

4 Principle

Measurement is made on the yield stress and the stress-strain curves of sheet metal samples under biaxial tensile stresses by measuring simultaneously and continuously the tensile forces and strain components applied to a test piece while applying biaxial tensile forces in the orthogonal directions parallel to the arms of the test piece. The

measured true stress-plastic strain curves are used to determine contours of plastic work of the sheet metal samples (see Annex A).

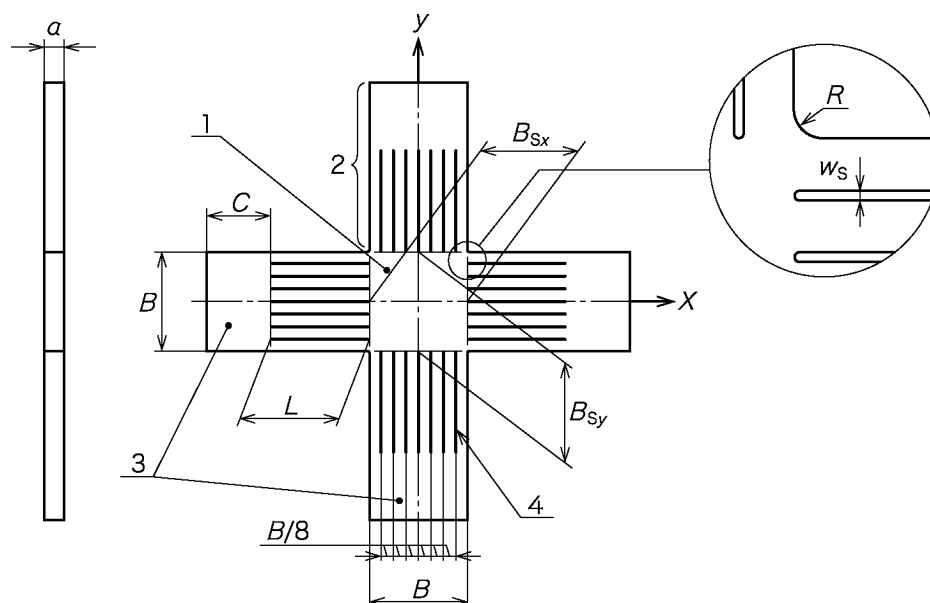
The applicable strain range depends on the stress ratio, the slit width of the arm, the work hardening exponent (n -value) of the test material and the anisotropy of the test material (see Annex B).

5 Test piece

5.1 Shape and dimensions

Figure 1 shows the shape of test piece. The dimensions of test piece shall be as follows.

- a) The thickness of test piece, a , shall be 0.1 mm or over. The test piece shall be the sheet metal sample as-received, without any work done in the thickness direction.
- b) The arm width, B , should be 30 mm or over. It shall be not less than 12.5 times the thickness of test piece, a , and accurate to within ± 0.1 mm for all four arms.
- c) The slits shall be made as follows.
 - 1) Seven slits per one arm shall be made.
 - 2) One slit shall be made on two orthogonal centrelines (hereafter referred to as x -axis and y -axis) of the test piece, and three slits shall be made at an interval of $B/8$ on each side of the centreline.
 - 3) All slits shall have the same length, L , and should be accurate to within ± 0.1 mm. The relationship of $B \leq L \leq 2B$ shall be established.
 - 4) The opposing slit ends shall be made at an equal distance, $B_{sx}/2$ and $B_{sy}/2$, from the centreline of test piece with a positional accuracy of $B/2 \pm 0.1$ mm.
 - 5) The slit width, w_s , should be made as small as possible (see Figure B.2), preferably not more than 0.3 mm.
- d) For the grip length, C , the relationship of $B/2 \leq C \leq B$ shall be established.
- e) For the corner radius at the junctions of arms to the gauge area, R , the relationship of $0.0034 \times B \leq R \leq 0.1 \times B$ shall be established.
- f) An alternative test piece geometry different from that shown in Figure 1 may be used in the case where the evidence of the stress measurement accuracy shall be clarified between parties involved in transaction.



Key

- 1 gauge area
- 2 arm
- 3 grip
- 4 slit
- a thickness of test piece
- B arm width
- B_{sx} distance between opposing slit ends on x -axis
- B_{sy} distance between opposing slit ends on y -axis
- C grip length
- L slit length
- R corner radius at the junctions of arms to the gauge area
- w_s slit width

Figure 1 Shape of cruciform test piece [2] [3]

5.2 Preparation of the test pieces

The preparation of the test pieces shall be as follows.

- 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 **JIS** and the like of relevant materials.
- b) The sampling direction of the test piece shall be such that the directions of arms are parallel to the rolling and transverse directions of the sheet metal sample, respectively. The test piece sampling direction may 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 may be used.
- d) Unnecessary deformation or heating to the test piece, which may affect the tests,

shall be avoided.

6 Testing machine and testing method

6.1 Testing machine

The specifications required for the biaxial tensile testing machine (hereinafter referred to as testing machine) shall be as follows. Typical testing machines are shown in Annex C.

- a) It shall have sufficient functions and durability to hold four grips of a test piece in one single plane with a tolerance of ± 0.1 mm during testing.
- b) Two opposing grips shall move along x -axis and y -axis, and x -axis and y -axis shall intersect at an angle of $90^\circ \pm 0.1^\circ$ (hereafter the intersection of x -axis and y -axis 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 testing.

Example The testing machines shown in Figure C.1 and Figure 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, a test with a constant true stress ratio 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) A testing machine which allows independent and combined control of each actuator may be used (see C.4).
- h) It shall also have a function for measuring and storing the values of the tensile forces (two channels in the x -axis and y -axis directions) simultaneously and continuously and strain components (two channels in the x -axis and y -axis directions) during biaxial tensile testing.

6.2 Measurement method of tensile force and strain

6.2.1 General

The tensile forces in the x -axis and y -axis directions of test piece [hereafter referred to as (F_x, F_y)] and the nominal strain components [hereafter referred to as (e_x, e_y)] shall be measured.

6.2.2 Measurement method of tensile force

For measurement of (F_x, F_y) , load cells shall be used in the x -axis and y -axis directions.

6.2.3 Measurement method of strain

For measurement of (e_x, e_y) , strain gauges or other methods with equivalent or better performance (e.g. an optical measurement system) shall be used. Measure (e_x, e_y) to the nearest 0.000 1 or better.

6.2.4 Strain measurement positions

Figure 2 shows the measuring positions of (e_x, e_y) , which are with a distance of $(0.35 \pm 0.05)B$ from the centre of test piece, on the centreline (within 0.5 mm as the deviation from the centreline) parallel to the axis of larger tensile force. For measurement of (e_x, e_y) using strain gauges, they shall be attached to the position so that the whole sensor part of strain gauge is placed within the range of $0.30B$ to $0.40B$.

NOTE According to the finite element analyses of test piece (see Clause 5) and the strain measurement position of two biaxial strain components as specified in Figure 2, the stress measurement error e_s is estimated to be less than 2 % [2] [3]. Here, e_s is defined by Formula (1).

$$e_s \equiv \frac{|\sigma^G - \sigma^L|}{|\sigma^L|} = \frac{\sqrt{(\sigma_{ij}^G - \sigma_{ij}^L)(\sigma_{ij}^G - \sigma_{ij}^L)}}{\sqrt{\sigma_{kl}^L \sigma_{kl}^L}} \quad \dots\dots\dots (1)$$

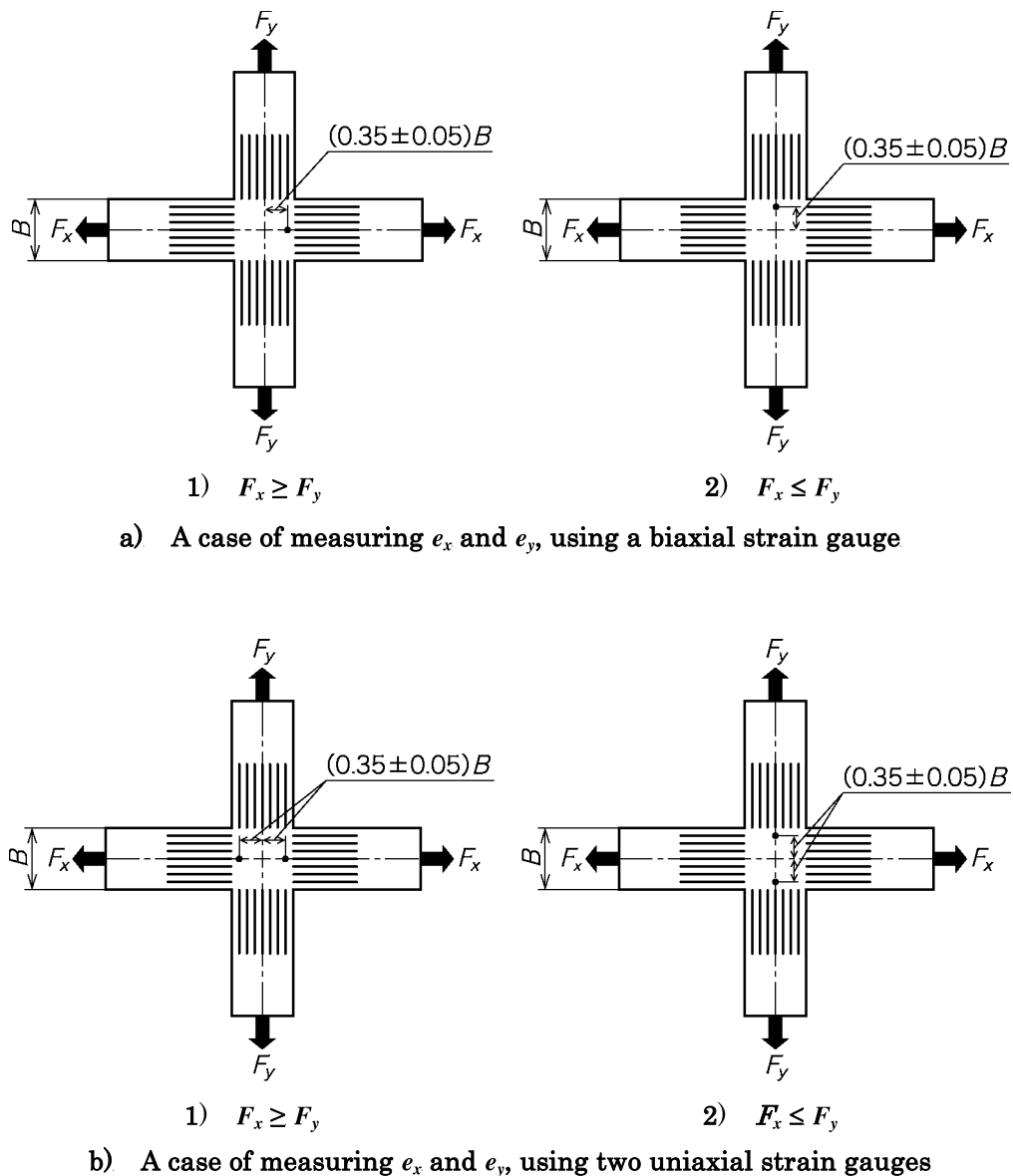
where, σ^G : mean stress of gauge area [calculated according to cross-sectional area after deformation estimated from the measured value of local strain (uniform distribution and volume constant condition of gauge area are supposed) and biaxial tensile force F_x, F_y]

σ^L : local stress at the strain measuring position obtained from finite element analysis method

in this case, $\sigma_{12}^G = \sigma_{23}^G = \sigma_{31}^G = \sigma_{33}^G = 0$

$\sigma_{23}^L = \sigma_{31}^L = \sigma_{33}^L = 0$ (the case of plane stress element)

The position shown in Figure 2 gives the optimum strain measurement position to minimize e_s .



Key

B arm width

e_x nominal strain in the x -axis direction

e_y nominal strain in the y -axis direction

F_x tensile force in the x -axis direction

F_y tensile force in the y -axis 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 the test piece with the centre of the testing machine.

6.4 Testing methods

While keeping the nominal stress ratio, strain-rate ratio or the grip displacement-