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Metallic materials — Ductility testing — High speed compression test for porous and cellular metals

Matériaux métalliques — Essais de ductilité — Essai de compression à haute vitesse des métaux poreux et cellulaires

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Foreword

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

Introduction

Porous and cellular metals have attractive properties due to their unique cell morphology. When they are used as impact energy absorbing components in automotive structures, knowledge of their high-speed compressive properties is necessary for industrial design. The high-speed compressive deformation behaviour of porous and cellular metals is quite different from their static compressive properties. Testing methods for static compressive deformation are, therefore, insufficient for characterization of high-speed compressive deformation. Standardization of a testing method for the high-speed compressive behaviour of porous and cellular metals is required.

Metallic materials — Ductility testing — High speed compression test for porous and cellular metals

1 Scope

This International Standard specifies methods for high speed compression testing, at room temperature, of porous and cellular metals having a porosity of 50 % or more. The speed range applicable to this test method is 0,1 m/s to 100 m/s (or 1 s^{-1} to 10^3 s^{-1} in terms of the initial strain rate when the specimen height is 100 mm).

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 376, *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 13314, *Mechanical testing of metals — Ductility testing — Compression test for porous and cellular metals*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13314 and the following apply.

3.1
test speed
movement speed of the pressing jig, which applies the compressive force to the test piece, when the pressing jig contacts the test piece

3.2
initial strain rate
value derived by dividing the test speed by the initial height of the test piece

3.3
sampling frequency
frequency used to sample the measurement data per unit time

3.4
drop height
initial distance between the pressure application plane of the pressing jig and the top surface of the test piece in the drop weight impact testing machine

3.5
approach length
initial distance between the pressure application plane of the pressing jig and the top surface of the test piece in the servo-type high-speed compression testing machine

4 Principle

This test consists of applying an impact force at test speeds between 0,1 m/s and 100 m/s to porous and cellular metals and measuring the compressive force and displacement for evaluation of their high-speed compressive deformation characteristics, such as plateau stress and energy absorption. Test methods that apply high-speed compressive forces to porous and cellular metals are the drop weight impact test and the servo-type high-speed compression test.

The drop weight impact test applies the compressive force by dropping a weight from a specified height. The test speed is controlled by the drop height. Due attention should be paid to the fact that the weight will be decelerated during the period of compressive deformation. When the drop height necessary to reach the specified test speed cannot be obtained, application of an initial velocity to the weight is possible.

The servo-type high-speed compression test applies the compressive force using a hydraulic or electric high-speed servo mechanism. The test speed is changed by the servo control. The drive unit shall be capable of following the test speed.

5 Testing machine

5.1 Type of testing machine

The testing machines to be used for high-speed compression testing of porous and cellular metals are the drop weight impact testing machine and the servo-type high speed compression testing machine.

5.2 Drop weight impact testing machine

5.2.1 General

An example of the basic composition of the drop weight impact testing machine is shown in Figure 1.

The drop weight impact testing machine consists of a weight, guide frame, pressing jig, load cell, displacement sensor, and absorber, as described below.

5.2.2 Weight

The weight shall drop vertically along the guide frame and shall be capable of applying the compressive force to the test piece.

The weight shall not be deformed by the impact when dropped and it should be possible to change the mass freely.

5.2.3 Pressing jig

The pressing jigs are located above and below the test piece and are used to apply the compressive force to the test piece. The pressing jig shall be of a construction such that it does not deform due to the compressive force, allowing correct transmission of the compressive force in the axial direction and preventing the action of forces, such as bending stress, etc., other than the compressive force on the test piece.

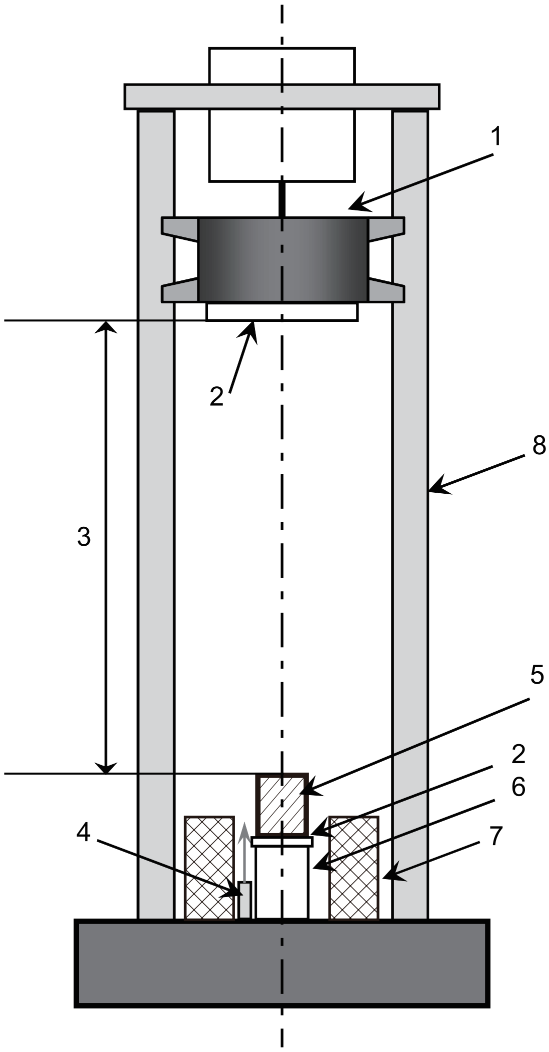
The area of the pressing surfaces shall be sufficiently large to ensure an even application of the compressive force over the entire end surface of the test piece until compressive deformation is complete.

The pressing surfaces shall be polished flat and installed in such a manner that the centre of the planes is aligned with the centre line of the testing machine and the planes are parallel to each other.

5.2.4 Load cell

The load cell shall be capable of measuring the compressive force acting on the test piece. For calibration of the load cell, ISO 376 shall be taken into consideration.

The resonant frequency and stiffness of the load cell shall be sufficiently high and the compressive force shall be measured to an accuracy of ±1 %.



Key

1 weight
2 pressing jig
3 drop height
4 displacement sensor
5 test piece
6 load cell
7 absorber
8 guide frame

Figure 1 — Schematic of a drop weight impact testing machine

5.2.5 Displacement sensor

The displacement sensor shall be capable of measuring the travel of a drop weight during tests and shall be of a non-contact type to avoid inertia effects.

The response speed of the displacement sensor shall be higher than the test speed. Measurement with laser-type displacement sensors, optical displacement sensors, etc. with high accuracy is recommended.

5.2.6 Absorber

The absorber shall be capable of stopping the weight and preventing it from damaging the load cell after compressing the test piece to the specified height.

5.3 Servo-type high-speed compression testing machine

5.3.1 General

Among servo-type high-speed compression testing machines, the basic composition of the servo-hydraulic-type high-speed compression testing machine is shown in Figure 2.

The servo-type high-speed compression testing machine consists of a pressing jig, load cell, displacement sensor, rupture pin, and stopper, as described below.

5.3.2 Pressing jig

The pressing jig shall be the same as described in 5.2.3.

5.3.3 Load cell

The load cell shall be the same as described in 5.2.4.

5.3.4 Displacement sensor

The displacement sensor shall be the same as described in 5.2.5.

5.3.5 Rupture pin

The rupture pin is a test force transmission part provided to protect the load cell and the pressing jig from damage resulting from excessively large compressive forces.

The material and the size of the rupture pin shall be capable of resisting the required test force adequately and of breaking, without large plastic deformation, below the load capacity of the load cell and the pressing jig.

5.3.6 Stopper

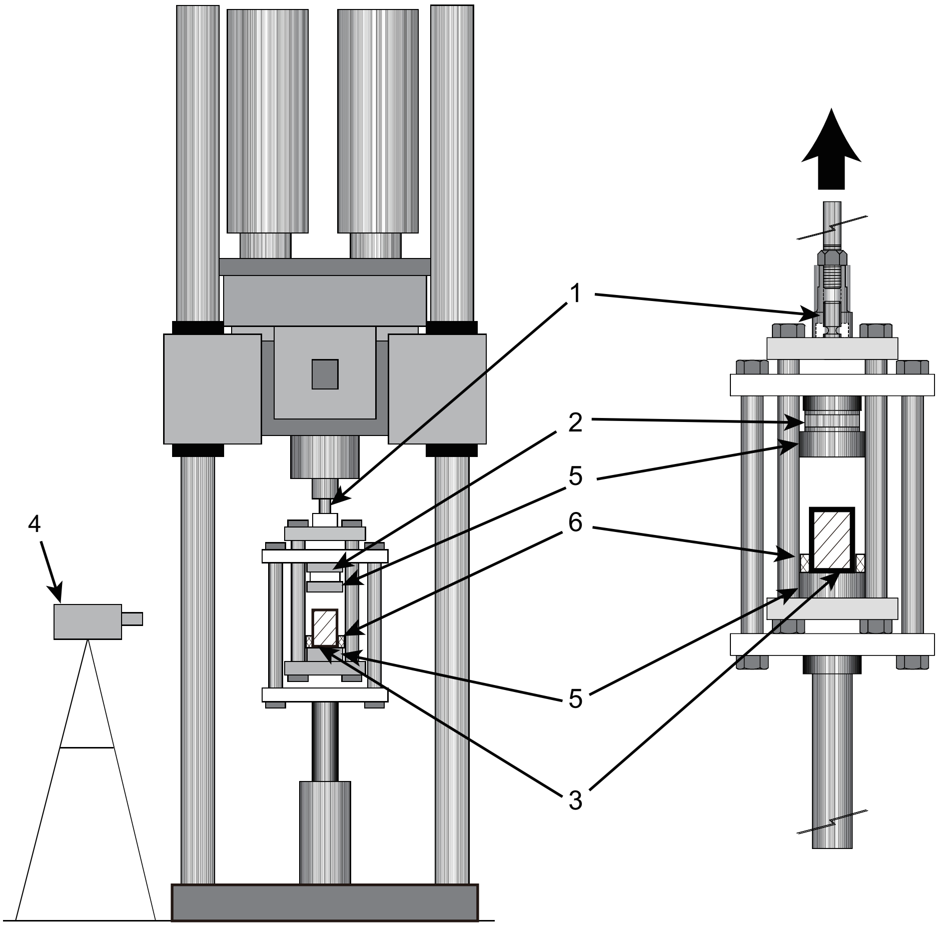
The stopper shall be provided between pressing jigs and shall be capable of stopping the movement of the pressing jigs after having deformed the test piece to the specified height.

6 Test piece

6.1 Preparation of test piece

The test piece shall be prepared by machining, electro-discharge machining, etc., as specified in ISO 13314.

Cutting into test pieces shall be executed with the utmost care so as not to alter the cellular structure or pore shape of the porous and cellular metals.



Key

1 rupture pin
2 load cell
3 test piece
4 displacement sensor
5 pressing jig
6 stopper

Figure 2 — Schematic of a servo-hydraulic type high-speed compression testing machine

6.2 Shape and dimensions of the test piece

The shape and dimensions of the test piece shall be as described below.

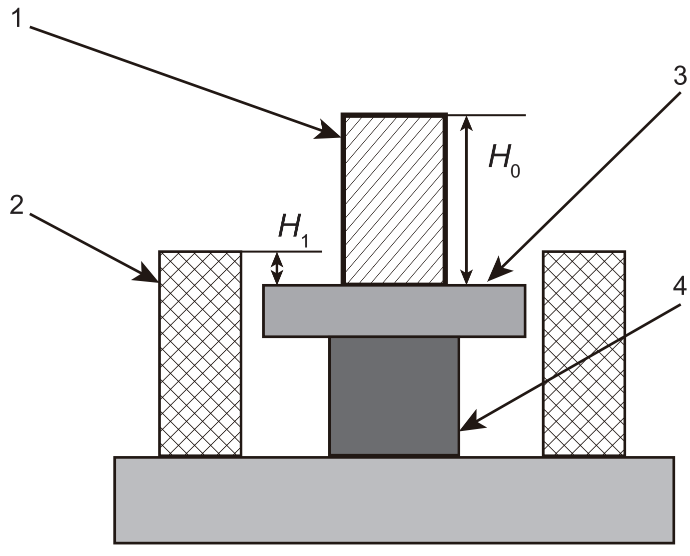
a) The shape of the test piece shall be a square prism, a rectangular prism, or a column.

b) The length of the shorter side or diameter of the test piece shall be no less than 10 times the average pore size.

c) The average pore size shall be measured in the cut section.

d) The initial height of the test piece, H_0, shall be between one and two times the diameter or length of the shorter side of the test piece. In the case of the drop weight impact test, however, the initial height of the test piece shall be more than two times the test piece height, H_1, at a time when the weight contacts the absorber, as shown in Figure 3.

e) The shape and size of the test piece used for the preliminary test of the drop weight impact test shall be as specified in ISO 13314 regardless of items a) to d) above.



Key

1 test piece

2 absorber

3 pressing jig

4 load cell

Figure 3 — Relation between the initial height of the test piece and that of the absorber in a drop weight impact test

7 Drop weight impact test

7.1 Preparation

The drop weight impact test shall be prepared as follows.

a) Preliminary test

For the preliminary test, the compression test in accordance with ISO 13314 shall be executed using a test piece of the same material, so as to determine the mass of the weight before starting the main test.

The preliminary test shall be made once or more to measure the energy absorption up to 50 % of compressive strain.

b) Setting the drop height

The drop height can be determined from Formula (1) according to the desired test speed:

$$h=\frac{V_0^2}{2g} \tag{1}$$

where

h is the drop height (m);

V_0 is the test speed (m/s);

g is the acceleration of gravity (m/s^2).

The initial strain rate is calculated from Formula (2):

$$a=1\ 000\times\frac{V_0}{H_0} \tag{2}$$

where

a is the initial strain rate (s^{-1});

H_0 is the initial height of the test piece (mm).

c) Mass of the weight

The mass of the weight shall meet Formula (3):

$$m\geq\frac{4W_{\text{sta}}AH_0\times10^{-3}}{3gh} \tag{3}$$

where

m is the mass of the weight (kg);

W_{sta} is the energy absorption (MJ/m^3) up to 50 % of the compressive strain, as determined in 7.1 item a);

A is the initial cross-sectional area of the test piece (mm^2).

The mass of the weight shall be sufficiently large to ensure the appropriate evaluation of the compressive characteristics at the specified test speed.

d) Operation check

Confirmation shall be made that the measuring instrument used to acquire the compressive force from the testing machine and the displacement data operates correctly in accordance with the method specified in ISO 7500-1.

e) Safety measures

Depending on the type of porous metal, the test piece might break during compressive deformation, with possible scattering of broken pieces. A suitable guard around the testing machine is recommended to contain any ejected fragments.

7.2 Test

The drop weight impact test shall be as follows.

a) The dimensions of the test piece shall be measured using suitable measuring equipment. The measured values shall be rounded to the nearest 0,1 mm in accordance with the method specified in ISO 80000-1.

b) The test piece shall be installed with its centre aligned to that of the pressing jig. The pressure-application plane may be coated with lubricant.

To prevent movement of the test piece during the compression test, adhesive can be applied to the bottom surface of the test piece to fix it to the pressing jig. Adhesive in the form of solid tape or liquid film shall be applied. Penetration of adhesive into the open pores shall be avoided in order to prevent constraint of the deformation of cells at the bottom surface of the test piece.

c) The absorber shall be installed in the specified position.

d) The weight shall be dropped and the compressive force and displacement shall be recorded. The data shall be recorded and synchronized with a sampling frequency of 10 kHz or higher.

8 Servo-type high-speed compression test

8.1 Preparation

The servo-type high-speed compression test shall be prepared as follows.

a) Stopper

The stopper shall have a height appropriate to the maximum displacement, in compression, of the test piece.

b) Approach length

It is necessary to establish the approach length according to the test speed so that the servo-type high-speed compression test can be made at the specified test speed.

The pressing jig shall be moved without installation of the test piece to the testing machine to make the pressing jig movement distance-time curve. On the basis of this curve, the approach length necessary to reach the test speed of the main test shall be determined.

c) Operation check

An operation check shall be made similarly to the case of 7.1 item d).

d) Safety measures

Safety measures shall be taken similarly as in the case of 7.1 item e).

8.2 Test

The servo-type high-speed compression test shall be as follows.

a) The dimensions of the test piece shall be similar as in the case of 7.2 item a).

b) Installation of the test piece shall be similar as in the case of 7.2 item b).

c) The rupture pin shall be installed in the testing machine.

d) The stopper shall be installed on top of the pressing jig. The stopper shall be positioned in such a manner that the test piece under compressive deformation does not contact the stopper.

e) The approach length appropriate to the specified test speed shall be provided.

f) The compressive force shall be applied to the test piece with the specified test speed and the compressive force and displacement shall be recorded. Recording shall be made with the sampling frequency of 10 kHz or higher.

9 Calculations

9.1 Compressive strain

The compressive strain shall be calculated from Formula (4):

$$e = \frac{\Delta L}{H_0} \times 100 \quad (4)$$

where

e is the compressive strain (%);

ΔL is the displacement of the pressing jig from the initial contact position with the test piece (mm).

9.2 Compressive stress

The compressive stress shall be calculated from Formula (5):

$$\sigma = \frac{F}{A} \quad (5)$$

where

σ is the compressive stress (N/mm^2);

F is the compressive force (N).

9.3 Compressive stress-strain curve

The compressive stress-strain curve shall be prepared as follows.

a) From the compressive strain and the compressive stress determined in 9.1 and 9.2, the compressive stress-strain curve (see Figure 4) shall be prepared.

b) When the compressive stress contains any periodic noise [see Figure 4 a)], the compressive stress-strain curve [see Figure 4 b)] shall be prepared by removing unnecessary noise through adequate filtering. For filtering, see Annex A.

9.4 Plateau stress (σ_{pl})

The plateau stress defined in ISO 13314 shall be determined as the arithmetical mean of the stresses with 0,1 % or smaller strain intervals between 20 and 30 % or 20 and 40 % compressive strain [see Figure 5 a)].

9.5 Plateau end

The plateau end defined in ISO 13314 shall be determined as the point in the stress-strain curve at which the stress is 1,3 times the plateau stress [see Figure 5 a)].

9.6 Plateau end strain (e_{ple})

The plateau end strain defined in ISO 13314 shall be determined as the compressive strain at the plateau end [see Figure 5 a)].

9.7 Energy absorption

The energy absorption per unit volume defined in ISO 13314 shall be calculated from Formula (6):

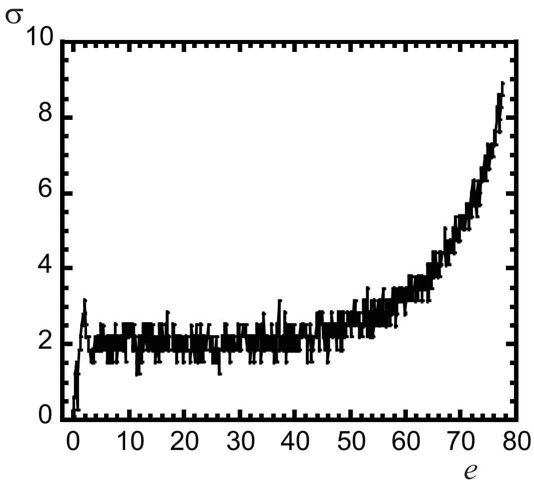
$$W = \frac{1}{100}\int_0^{e_{max}} \sigma \mathrm{d}e \quad (6)$$

where

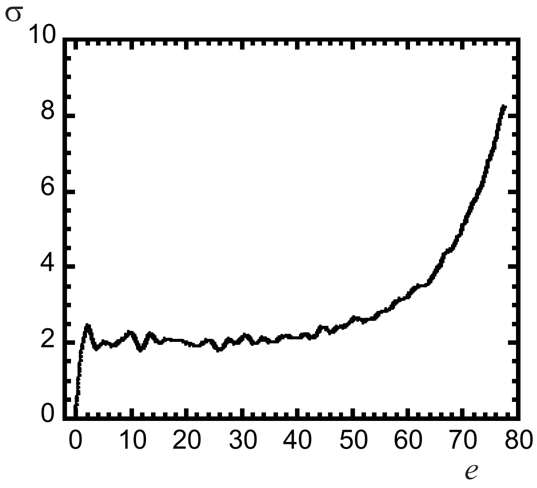
W is the energy absorption per unit volume (MJ/m^3);

e_{max} is the upper limit value of the compressive strain (%).

The upper limit value of the integration range shall be either the 50 % compressive strain value or the plateau end strain value. However, different upper limit values can be employed as required [see Figure 5 b)].



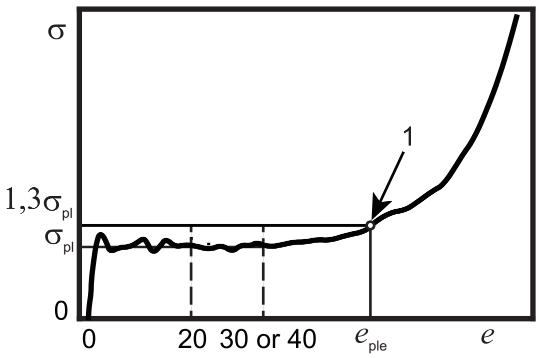
a) Compressive stress-strain curve containing noise



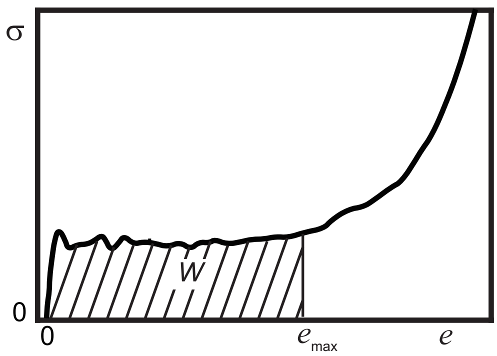
b) Compressive stress-strain curve after noise removal

NOTE Test speed: 4 m/s.

Figure 4 — Compressive stress-strain curves for porous aluminium



a) Plateau stress, plateau end, and plateau end strain



b) Energy absorption

Key

1 plateau end

Figure 5 — Schematic of compressive stress-strain curves for porous and cellular metals

10 Test report

The test report shall specify the following:

a) test piece:

1) nature and designation of the product;

2) the material, density, porosity, type of pores (open or closed), and average pore size;

3) dimensions and whether it has a surface skin or not;

4) the number of test pieces;

b) testing method:

1) ambient temperature;

2) testing machine used;

EXAMPLE Drop weight impact testing machine or servo-type high-speed compression testing machine.

3) the test speed and initial strain rate;

4) with/without lubricant and with/without adhesion;

5) sampling frequency recording the compressive force and displacement;

c) test results:

1) plateau stress;

NOTE If there is no visible plateau in the diagram, then report that there is no plateau.

2) energy absorption (indicating the upper strain for determination, e.g. 50 %).

The following optional information can be included in the test report:

a) compressive force-displacement curve;

NOTE In the case of the drop weight impact test, the absorber operation start displacement shall be clearly indicated.

b) compressive stress-strain curve;

NOTE If filtering has been carried out, the information on the filter used shall be clearly indicated.

c) plateau end and plateau end strain.

d) statistics of measured quantities.

Annex A
(informative)

Filtering of the measurement data

A.1 General

This Annex provides a supplementary description of filtering for preparation of the compressive stress-strain curve of porous and cellular metals.

A.2 Filtering

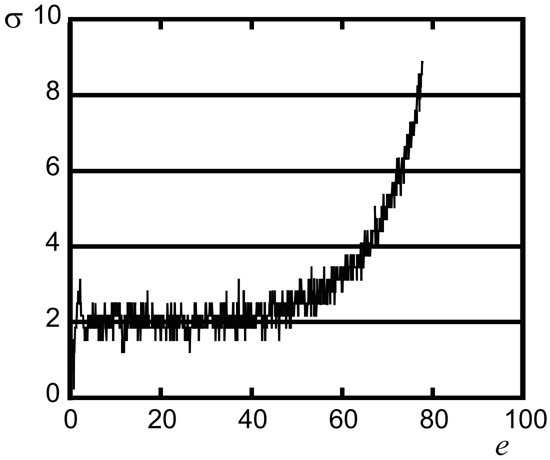
The measurement data of the compressive force and displacement might contain periodic noise which has arisen from the response performance of the load cell and displacement meter in the high-speed compression testing machine or from the stiffness of the testing machine as a whole, as well as the resonance frequency. Figure A.1 shows an example for a compressive stress-strain curve derived from the drop weight impact testing machine with a strain-gauge-type load cell. In this case, the compressive stress (compressive force) contains periodic noise.

When the measurement data contain such noise, a filter can be used to remove noise. It is recommended, however, that the filter to be used does not distort the original high-speed compressive deformation characteristics of the material being tested.

A.3 Frequency characteristics of the filter

ISO 6487[1] and SAE J 211-1[2] categorize the measuring-channel frequency class (CFC) into four types: CFC60, CFC180, CFC600, and CFC1000. The number of each class represents the frequency (Hz) at which the frequency characteristics on the high-frequency side starts to decrease (to be removed), which means that, with the number being smaller, the lower frequencies will be removed.

For filtering in the high-speed compression test of porous and cellular metals, it is recommended to refer to the above description. Figure A.2 shows the compressive stress-strain curves obtained by applying numerical filtering equivalent to their CFC classes to the original waveform of Figure A.1. Lowering the CFC frequency characteristics used for filtering causes the waveform to become smoother, but can possibly distort the original compressive stress-strain characteristics of materials. In this example, the filter approximately equivalent to CFC600 is recommended.



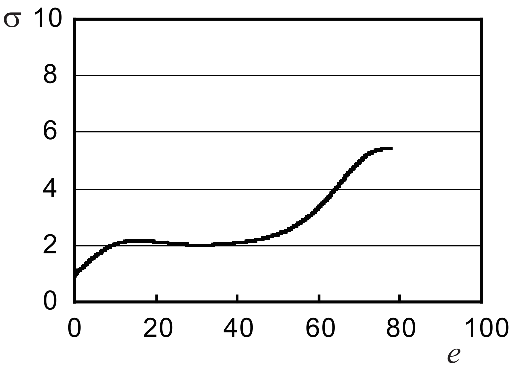
Key

e compressive strain (%)

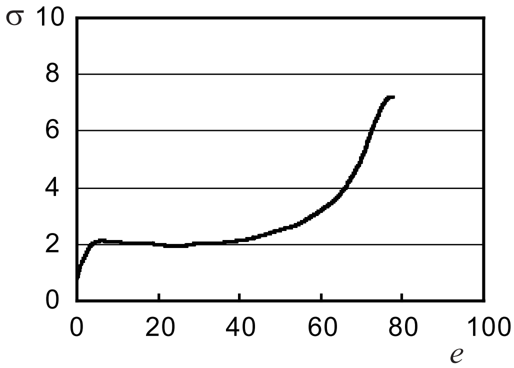
σ compressive stress (N/mm²)

NOTE Porosity: 91,4 %; test speed: 4 m/s.

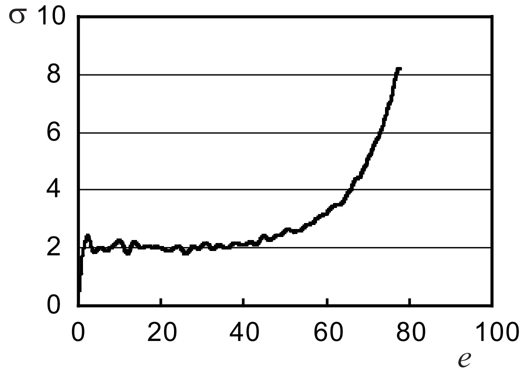
Figure A.1 — Example of a compressive stress-strain curve from a high-speed compression test of porous aluminium



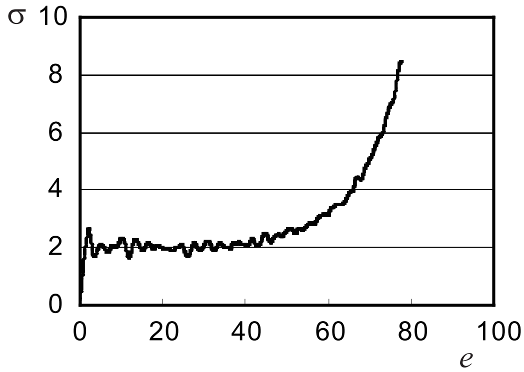
a) CFC60



b) CFC180



c) CFC600



d) CFC1000

Figure A.2 — Compressive stress-strain curves of porous aluminium derived after filtering the original waveform of Figure A.1

Bibliography

[1] ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

[2] SAE J 211-1, *Instrumentation for Impact Test — Part 1 — Electronic Instrumentation*

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