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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 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).

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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 17340:2014), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

— the title of ISO 7500-1 has been updated in Clause 2;

— a list of symbols and units has been added as Clause 4;

— information about the use of adhesives in 8.2 b) has been revised;

— minor editorial changes have been made to align with ISO/IEC Directives Part 2:2018.

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

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

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*

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.

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
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 Symbols and units

Symbol	Unit	Designation
m	kg	mass of the weight
h	m	drop height
V_0	m/s	test speed
g	m/s^2	acceleration of gravity
a	s^{-1}	initial strain rate of the test piece
H_0	mm	initial height of the test piece
H_1	mm	test piece height at a time when the weight contacts the absorber
A	mm^2	initial cross-sectional area of the test piece
ΔL	mm	displacement of the pressing jig from the initial contact position with the test piece
e	%	compressive strain
F	N	compressive force
σ	N/mm^2	compressive stress
σ_{pl}	N/mm^2	plateau stress defined in ISO 13314
e_{ple}	%	plateau end strain defined in ISO 13314
W	MJ/m^3	energy absorption per unit volume
e_{max}	%	upper limit value of the compressive strain
W_{sta}	MJ/m^3	energy absorption up to 50 % of the compressive strain, as determined in 8.1 a)

5 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.

6 Testing machine

6.1 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.

6.2 Drop weight impact testing machine

6.2.1 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 in 6.2.2 through 6.2.6.

6.2.2 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.

6.2.3 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.

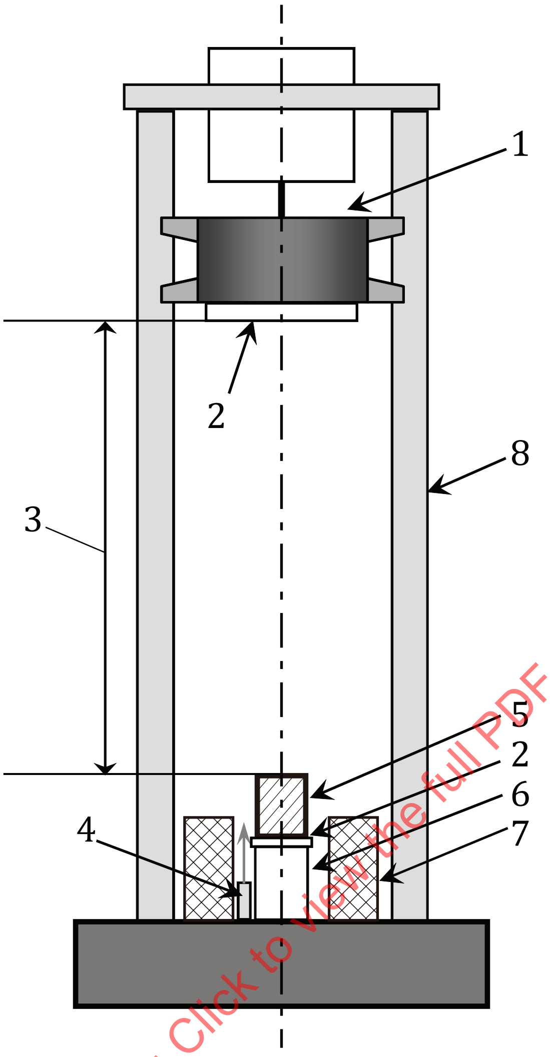
The area of the pressing surfaces shall be sufficiently large to ensure an even application of the compressive force over the entire end surface of the test piece until compressive deformation is complete.

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.

6.2.4 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

6.2.5 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.

6.2.6 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.

6.3 Servo-type high-speed compression testing machine

6.3.1 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 in 6.3.2 through 6.3.6.

6.3.2 Pressing jig

The pressing jig shall be the same as described in 6.2.3.

6.3.3 Load cell

The load cell shall be the same as described in 6.2.4.

6.3.4 Displacement sensor

The displacement sensor shall be the same as described in 6.2.5.

6.3.5 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.

6.3.6 Stopper

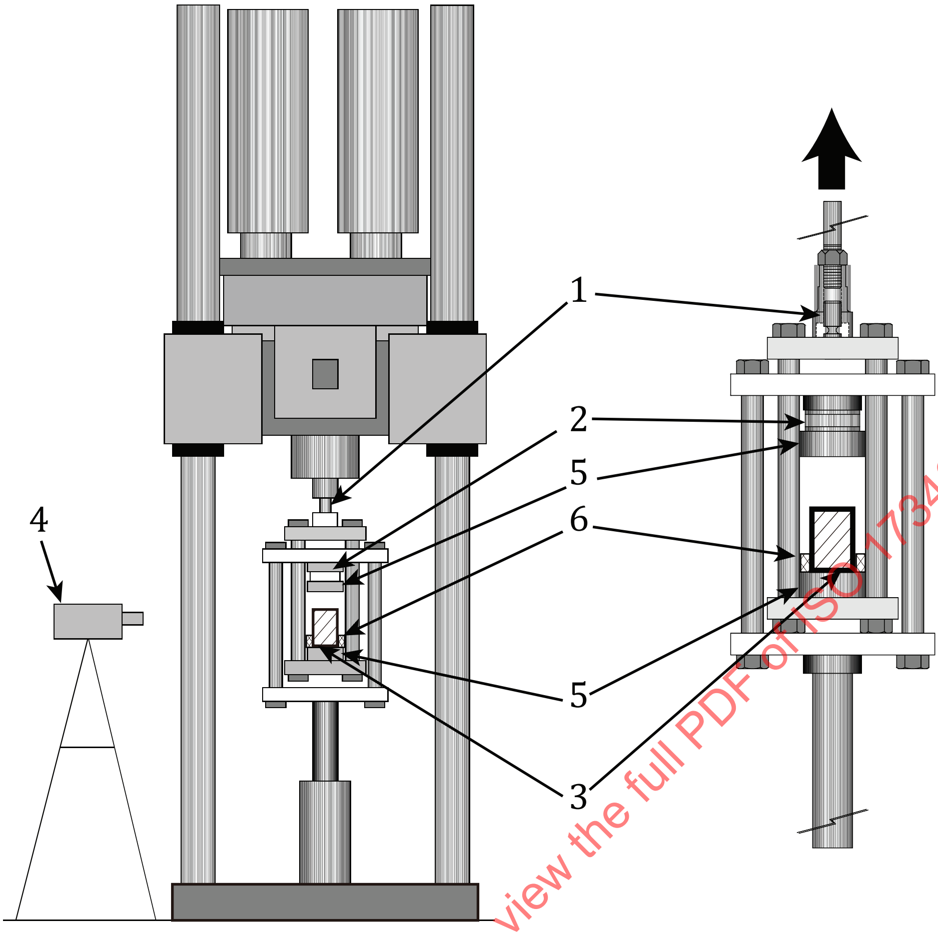
The stopper shall be provided between pressing jigs and shall be capable of stopping the movement of the pressing jigs after having deformed the test piece to the specified height.

7 Test piece

7.1 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

7.2 Shape and dimensions of the test piece

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

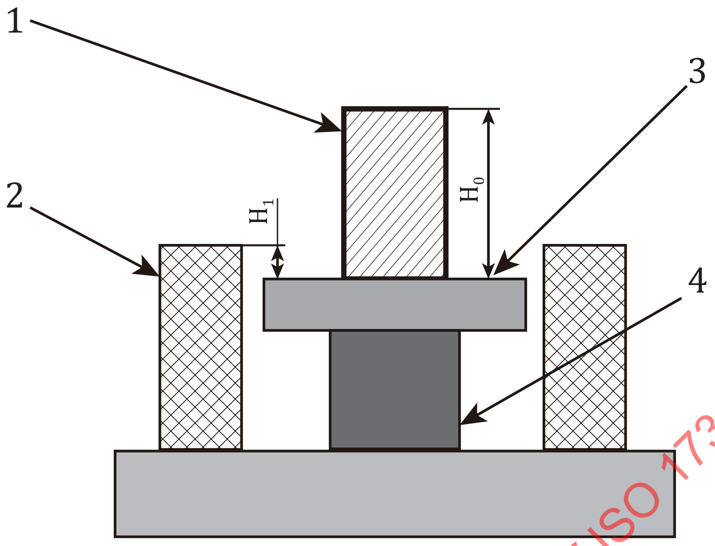
a) The shape of the test piece shall be a square prism, a rectangular prism, or a column.

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

8 Drop weight impact test

8.1 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 of the test piece (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):

$$m \geq \frac{4 W_{sta} A H_0 \times 10^{-3}}{3 g h} \tag{3}$$

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 8.1 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.

8.2 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 may be applied to the bottom surface of the test piece to fix it to the pressing jig. If adhesive is used it shall be applied in the form of solid tape or liquid film. Penetration of adhesive into the open pores should 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.

9 Servo-type high-speed compression test

9.1 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 8.1 d).

d) Safety measures

   Safety measures shall be taken similarly as in the case of 8.1 e).

9.2 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 8.2 a).

b) Installation of the test piece shall be similar as in the case of 8.2 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.

10 Calculations

10.1 Compressive strain

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

$$e = \frac{\Delta L}{H_0} \times 100 \tag{4}$$

where

e is the compressive strain (%);

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

10.2 Compressive stress

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

$$\sigma = \frac{F}{A} \tag{5}$$

where

σ is the compressive stress (N/mm^2);

F is the compressive force (N).

10.3 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 10.1 and 10.2, 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.

10.4 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)].

10.5 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)].

10.6 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)].

10.7 Energy absorption

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

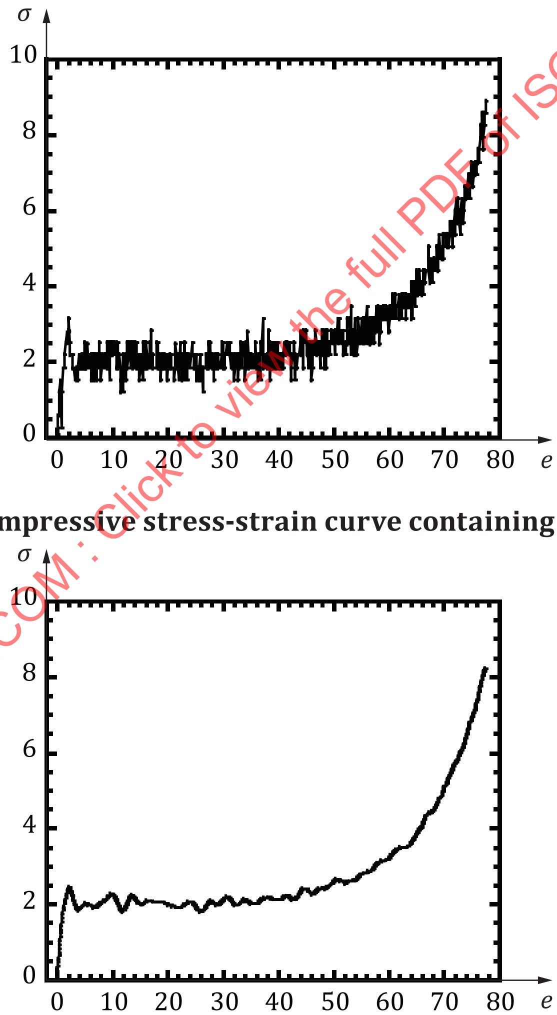
$$W = \frac{1}{100}\int_0^{e_{max}} \sigma \mathrm{d}e \tag{6}$$

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)].

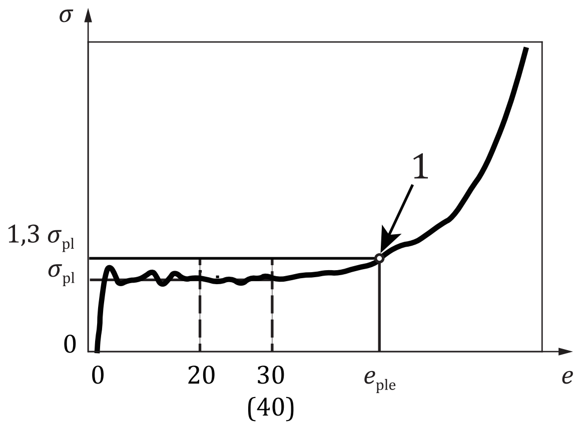


a) Compressive stress-strain curve containing noise

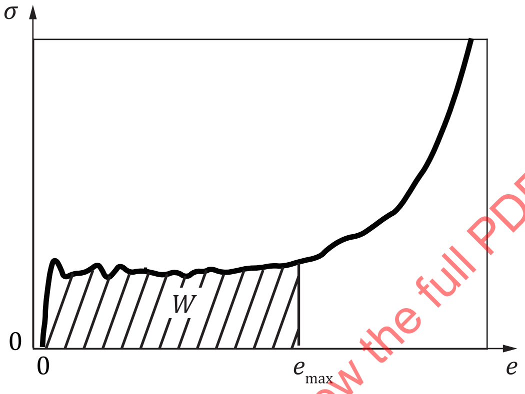
b) Compressive stress-strain curve after noise removal

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

11 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;

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;

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

b) compressive stress-strain curve;

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.