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Mechanical testing of metals — Ductility testing — Compression test for porous and cellular metals

Essais mécaniques des métaux — Essais de ductilité — Essai de compression des métaux poreux et cellulaires

Reference number
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Foreword

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ISO 13314 was prepared by Technical Committee 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 a crush energy absorbing component of automotive machines, compressive properties are necessary for industrial design. However, the deformation behaviour of porous metals and metallic foams is quite different from conventional dense metals. Test methods for conventional metallic materials are not suitable for porous metals and metallic foams. Standardization of a test method for porous metals and metallic foams is required.

Mechanical testing of metals — Ductility testing — Compression test for porous and cellular metals

1 Scope

This International Standard specifies a test method for compressive properties of porous and cellular metals with a porosity of 50 % or more. Compressive tests can be carried out at ambient temperature under quasi-static strain rate conditions.

2 Normative references

The following referenced documents are indispensable for the application 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 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 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing*

3 Terms and definitions

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

3.1
compressive stress
σ
compressive force divided by the initial cross-sectional area perpendicular to the loading direction

NOTE Compressive stress is expressed in newtons per square millimetre.

3.2
compressive strain
e
overall compressive displacement divided by the initial height (gauge length) of the test specimen

NOTE Compressive strain is expressed as a percentage.

3.3
first maximum compressive strength
compressive stress corresponding to the first local maximum in the stress-strain curve

See Figure 1.

NOTE It cannot be determined if no local maximum occurs.

3.4
plateau stress
σ_{pl}
arithmetical mean of the stresses at 0,1 % or smaller strain intervals between 20 % and 30 % or 20 % and 40 % compressive strain

See Figure 1.

NOTE The strain range/interval, 20 % and 30 % or 20 % and 40 %, for arithmetical mean varies depending on the plateau end strain.

3.5
plateau end
point in the stress-strain curve at which the stress is 1,3 times the plateau stress

See Figure 1.

NOTE If this point does not adequately represent the end of the plateau range, another stress can be selected which corresponds to the curve trace (see 7.4).

3.6
energy absorption
W
area under the stress-strain curve up to 50 % strain or up to the plateau end strain, e_{ple}

NOTE The energy absorption up to other strain values can also be determined (see 7.7).

3.7
energy absorption efficiency
W_e
energy absorption divided by the product of the maximum compressive stress within the strain range and the magnitude of the strain range

3.8
quasi-elastic gradient
gradient of the straight line determined within the linear deformation region at the beginning of the compressive stress-strain curve

NOTE This gradient is not a modulus for the material (see Figure 1). The quasi-elastic gradient is optionally measured and it is used to determine the zero point for the compressive strain [see Figure 2 a)].

3.9
compressive offset stress
compressive stress at the plastic compressive strain of 0,2 %, unless otherwise specified or recorded

NOTE The plastic strain is determined using of the quasi-elastic gradient [see Figure 2 a)]. The compressive 0,2 % offset stress is optionally measured and it can be used as an alternative to the compressive yield strength.

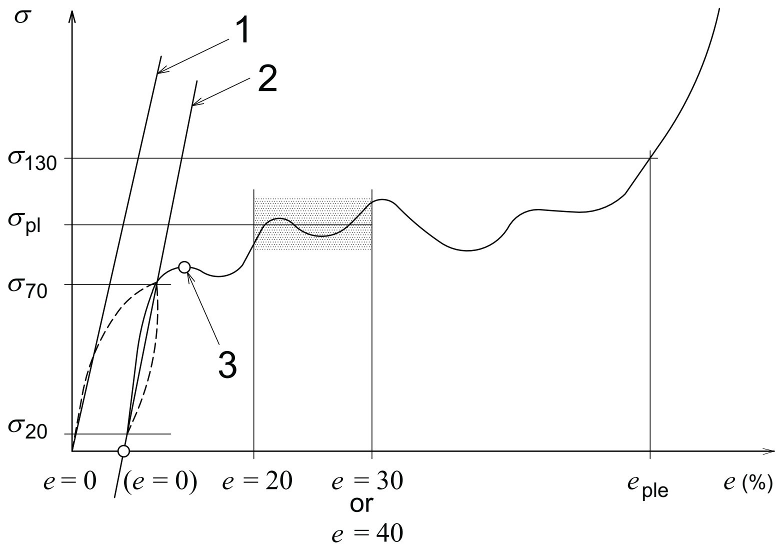
3.10
elastic gradient
gradient of the elastic straight lines determined by elastic loading and unloading between stresses of σ_{70} and σ_{20}

NOTE 1 σ_{70} and σ_{20} correspond to 70 % and 20 %, respectively, of the plateau stress, σ_{pl}.

NOTE 2 The elastic straight line is the secant line obtained from the hysteresis loop which occurs during unloading and subsequent loading (see Figure 1). The elastic gradient represents a porosity-dependent rigidity, not a modulus of the material, and generally changes during the course of compression. The elastic gradient is optionally measured and it is used to determine the zero point for the compressive strain [see Figure 2 b)].

3.11
compressive proof strength
compressive stress at a plastic compressive strain of 1,0 %, unless otherwise specified or recorded

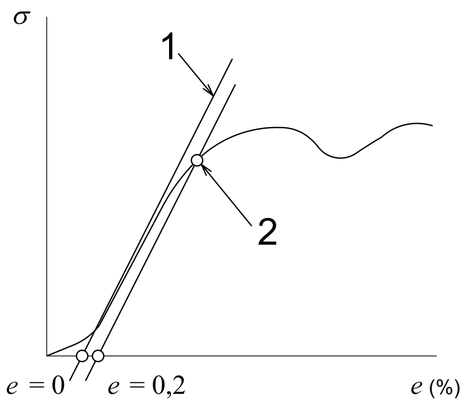
NOTE The plastic strain is determined using of the elastic gradient [see Figure 2 b)]. The compressive proof strength is optionally measured and it can be used as an alternative to the compressive yield strength.



Key

1 quasi-elastic gradient
2 elastic gradient
3 first maximum compressive strength

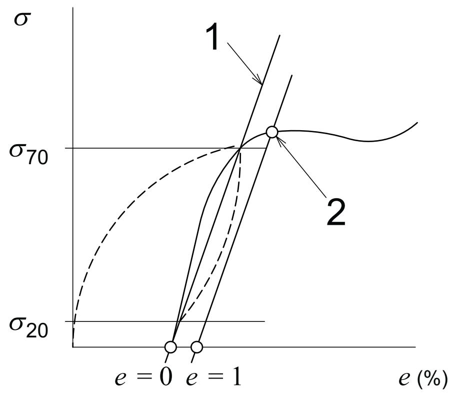
Figure 1 — Stress-strain curve to determine the characteristic values from compression testing of porous and cellular metals



Key

1 quasi-elastic gradient
2 compressive offset stress

a) Quasi-elastic gradient and compressive offset stress



Key

1 elastic gradient
2 compressive proof strength

b) Elastic gradient and compressive proof strength

Figure 2 — Stress-strain curve to determine the optional characteristic values from compression testing of porous and cellular metals

4 Principle

This test is a method for evaluating compressive properties of porous and cellular metals. The compressive test is carried out using a compression test machine with constant crosshead speed. Compressive stress, σ, and compressive strain, e, are measured from the applied force, F, and displacement of the compressive specimen, respectively.

5 Apparatus

5.1 Test machine, conforming to ISO 7500-1. The machine shall be able to test at constant crosshead speed. Unless otherwise agreed between the parties, a machine of class 1 shall be used for this test.

5.2 Pressing device, consisting of a couple of polished parallel platens, used to apply compressive force to the test specimen. The platens' geometry shall be such that the centres of the upper and lower platens can be aligned to the centre line of the machine casing. Plane-ground, mirror-finished platens with a minimum hardness of at least 60 HRC shall be used. Lubricant may be applied to press surfaces.

5.3 Device for the measurement of compressive strain, consisting of an extensometer or calculated from the measured displacement between two parallel platens.

For the measurement of the elastic gradient and the compressive proof strength, an extensometer mounted on the platens or directly on the respective sample shall be used to measure the compressive strain. Alternatively, the measurement may be carried out using an optical extensometer. In the relevant range, the accuracy of the extensometer shall, as a minimum requirement, correspond to class 1 in accordance with ISO 9513.

6 Test specimen

6.1 Geometry

Test specimens which are cylindrical (recommended) or rectangular in cross-section shall be used in the compressive test (see Figure 3). All spatial dimensions of the specimen (W_0 and D_0 in Figure 3) shall be at least 10 times the average pore size, d_a, and no less than 10 mm, with a sample length to diameter ratio (H_0:D_0) or sample length to edge length ratio (H_0:W_0) of between 1 and 2. The sample geometry shall be recorded in the test report. The average pore size (i.e. diameter, in the case of spherical porosity, and the axial and transverse dimensions in the case of non-spherical porosity) shall be measured in the cut section and recorded in the test report. The type of porosity (i.e. open or closed) shall also be recorded.

The pore size distribution shall be checked where necessary in the case of closed-pore metal foams by cutting. The average pore size shall be measured in the cut section.

6.2 Number of test specimens

The number of test specimens shall be no less than three and a minimum of five is recommended.

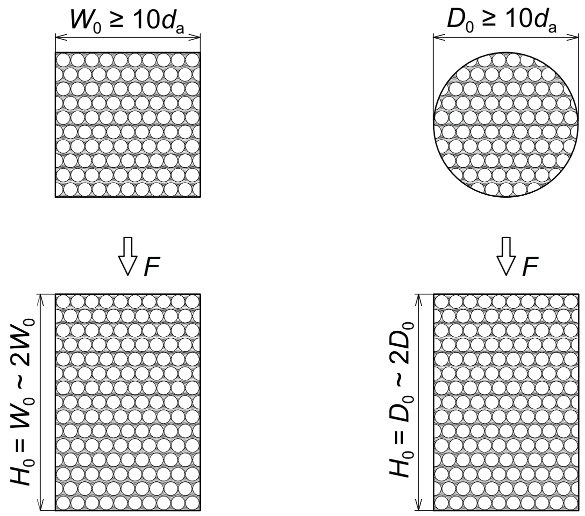
In addition, for the optional measurement of elastic gradient, a specimen for a preliminary test providing an initial estimate of the plateau stress is required.

6.3 Sampling of test specimen

The test specimen shall be sampled from the material structure under test by cutting, milling, turning, electric discharge machining, etc.. Under no circumstances shall the material properties be affected by the cutting procedure.

The areas in contact with the platens during the test shall be parallel. The remaining cut surfaces shall be perpendicular to the contact surfaces. Cut surfaces shall have any burrs removed.

In the case of foamed metals, the skin, in general, is removed. If specimens with skin are used, this fact shall be recorded in the test report.



a) Rectangular specimen **b) Cylindrical specimen**

Key

F force

Figure 3 — Schematic illustration of test specimen

7 Test procedure

7.1 Test temperature

The compressive test shall be carried out at ambient temperature within the range of 10 °C to 35 °C, and temperature shall be recorded, if necessary. When temperature control is especially necessary, it shall be kept in the range of (23 ± 5) °C.

7.2 Measurement of initial dimensions of test specimen

The width, thickness, diameter, etc. of the test specimen shall be measured to the order of 0,1 mm, followed by calculation of the initial cross-sectional area. The height of the test specimen shall be measured to an accuracy of 0,1 mm.

Measurement at a minimum of three measuring points is recommended.

7.3 Test speed

The compression tests are conducted at a constant crosshead speed. The crosshead speed is calculated to obtain an initial compression strain rate of between 10^{-3} s^{-1} and 10^{-2} s^{-1}. The compression speed or the initial strain rate shall be recorded in the test report/record.

7.4 General conduct of test

The test specimen shall be placed between the platens of the test machine while allowing the centre line of the test specimen to coincide with the centre line of the upper and lower platens.

During the compression test, a force/displacement curve shall be recorded for each sample to determine characteristic values according to their definitions in Clause 3.

Data sampling frequency should be at least 30 Hz up to 5 % strain or the strain corresponding to compressive proof strength, whichever is the greater. The data sampling frequency may then be reduced to a minimum of 10 Hz.

If the plateau end does not adequately represent the end of the plateau range, another stress may be selected, which corresponds to the curve trace and it should be recorded in the test report.

7.5 Preliminary test and unloading test

For the optional measurement of elastic gradient, a preliminary test should be carried out to estimate the plateau stress. The plateau stress is used to determine the start and reversal point of hysteresis.

The start of hysteresis is determined at 70 % of the plateau stress; the reversal point is determined at 20 % of the plateau stress from the preliminary test.

7.6 Zero point for the compressive strain

The zero point for the compressive strain is determined as an intersection point of the straight line corresponding to the quasi-elastic gradient or the elastic gradient with the compressive strain axis (see Figure 1).

7.7 Energy absorption and energy absorption efficiency

Energy absorption, W, and energy absorption efficiency, W_e, are calculated using Formulae (1) and (2), respectively.

$$W = \frac{1}{100} \int_0^{e_0} \sigma \mathrm{d}e \tag{1}$$

$$W_e = \frac{W}{\sigma_0 \times e_0} \times 10^4 \tag{2}$$

where

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

W_e is the energy absorption efficiency (%);

σ is the compressive stress (N/mm^2);

e_0 is upper limit of the compressive strain (%);

σ_0 is the compressive stress at the upper limit of the compressive strain (N/mm^2).

The recommended upper limit of the compressive strain 50 % or the plateau end strain, e_{ple} (see Figure 1). Another upper limit may also be used; in this case, it shall be recorded in the test report.

8 Test report

8.1 General information

The following information shall be included in the test report:

a) reference to this International Standard, i.e. ISO 13314:2011;

b) nature and designation of the product being tested;

c) material, density, porosity, type of porosity (open or closed) and average pore size (diameter, if spherical; axial and transverse dimensions, if nonspherical) of the sample;

d) dimensions of the test specimens, giving the ratio of length to diameter or length to edge length;

e) number of test specimens;

f) test conditions (temperature, lubrication);

g) compression speed in metres per second [compressive strain rate (s^{-1})];

h) test results for:

1) plateau stress (indicating the strain range used for determination, e.g. 20 % to 30 %);

2) first maximum compressive strength, if applicable;

3) plateau end strain (indicating the method used for determination);

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

5) energy absorption efficiency;

6) stress-strain diagrams.

8.2 Optional information

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

a) type of test machine and measuring range of the measuring equipment;

b) sample preparation method;

c) test results for:

1) quasi-elastic gradient;

2) compressive offset stress;

3) elastic gradient;

4) compressive proof strength;

d) statistics of the quantities measured.

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