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Plastics — Determination of tensile properties at high strain rates

Plastiques — Détermination des propriétés en traction à hautes vitesses de déformation

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 18872 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Plastics — Determination of tensile properties at high strain rates

1 Scope

This International Standard specifies procedures for determining the tensile properties of moulding and extrusion plastics over a wide range of strain rates, including high rates appropriate to impact-loading situations. Properties are determined through a combination of measurements at low and moderate strain rates, the use of mathematical functions to model these results, the rate-dependence of parameters and the determination of parameters at high strain rates by extrapolation. Tensile properties at high strain rates are then derived by calculation. In this way, the experimental problems and associated errors with the measurement of properties at high rates are avoided.

The measurement of properties at low and moderate strain rates is based on ISO 527-2, which identifies the types of plastics materials to which this International Standard is applicable.

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 527-1:1993, *Plastics — Determination of tensile properties — Part 1: General principles*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 2818, *Plastics — Preparation of test specimens by machining*

3 Principle

Tensile stress versus strain curves are measured in accordance with ISO 527-2 at selected speeds in the range 0,1 mm/s to 100 mm/s. In order to maximize the accuracy of these results at the higher speeds, it is necessary to pay attention to certain features of the design of the test assembly as described in Clause 5. Measurements are also made of the variation of Poisson's ratio with strain. From these results, values of true stress and true plastic strain are calculated at each strain rate. A mathematical function is used to accurately model the shape of each stress/plastic strain curve. The variation of parameters in this function with strain rate is also modelled to enable the values of parameters at higher strain rates to be determined by extrapolation. Stress/strain curves at these higher strain rates can then be derived by calculation.

4 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 527-1 and the following apply.

4.1
true stress
σ_T
force divided by the cross-sectional area of the specimen within the gauge length at the same time as the force is measured

4.2
true strain
ε_T
incremental increase in the gauge length divided by the gauge length at the same time as the increase is measured

4.3
true plastic strain
ε_{Tp}
true strain at any true stress σ_T minus the elastic component of true strain ε_{Te} at that stress

5 Apparatus

5.1 Test assembly

See ISO 527-1:1993, 5.1, for general guidance on apparatus. Servo-hydraulic testing machines usually need to be employed to achieve test speeds above 10 mm/s. At test speeds above around 10 mm/s, errors may arise in the measurement of force. These are associated with the presence of resonance modes in the force transducer, the test specimen and components in the test assembly. To maximize the speed range over which measurements of satisfactory accuracy can be made, attention should be paid to the design of the test assembly so that it incorporates a high stiffness (e.g. piezoelectric) force transducer and components of low mass and high rigidity.

5.2 Extensometers

To maximize the upper limit for the test speed at which accurate measurements are possible, light-weight extensometers or non-contacting devices should be employed. For the measurement of large strains in the specimen, devices capable of defining a small gauge length (typically 4 mm) should be used (see 6.2).

5.3 Data-recording equipment

The data-acquisition rate of the equipment used to record force and extensometer signals shall be high enough to accurately record the shape of the force/extension curve at all test speeds.

6 Test specimens

6.1 Low-strain measurements

For the measurement of properties at strains below the yield strain (see ISO 527-1:1993, 4.7), ISO specimen geometries 1A, 1B or 1BA shall be used. Where specimens are cut from sheet or mouldings, the machining shall be carried out in accordance with ISO 2818.

6.2 High-strain measurements

6.2.1 At strains above the yield strain, where the stress reaches a maximum or increases only slowly with strain, the strain distribution in the gauge region in standard specimens becomes non-uniform. In extreme situations, this is visible as a neck, and is the reason that International Standards refer to recording the nominal strain (see ISO 527-1:1993, 4.10) through measurements of changes in the grip separation. These strain values have an unknown error which, for some materials, can be very large. Where higher accuracy is required, an alternative specimen geometry shall be used as shown in Figure 1. This specimen has a uniform thickness but the width is reduced from 10 mm to 8 mm by a circular waist cut at the centre of the specimen length. The specimen thickness is not critical, so it can be machined from the central region of type 1A or 1B specimens or from sheet or mouldings (see ISO 2818). The region of strain localization is now in the centre of the specimen, which is where axial and transverse strains are measured. A gauge length of 4 mm ± 1 mm shall be used for the measurement of axial strain (see 6.2.2). Transverse strains are needed for the determination of true stresses and these can be measured using transverse extensometers applied to the specimen width or thickness.

6.2.2 Because of strain localization at strains beyond yield, a small gauge length shall be used in order to achieve a fairly uniform strain distribution in the gauge region. This small gauge length will give rise to a significant reduction in the accuracy of strain measurements at low strains. For this reason, standard specimens are used for the determination of properties at strains below the yield strain (see 6.1). At strains above this, use of the small gauge length with the new specimen in Figure 1 will give strain measurements of satisfactory accuracy.

7 Conditioning

See ISO 527-1:1993, Clause 8.

8 Test procedure

8.1 General

See ISO 527-1:1993, 9.1 to 9.5.

8.2 Test speeds

Specimens shall be tested at speeds of 0,1 mm/s, 1 mm/s, 10 mm/s and 100 mm/s. If results at the highest speed are unreliable, or if greater confidence is required in the analysis of results (see 11.2), additional speeds may be used which should be selected from the values 0,3 mm/s, 3 mm/s and 30 mm/s.

8.3 Recording of data

Record the force and the changes in the gauge length and width or thickness of the specimen at suitable intervals of time throughout the test.

9 Calculation and expression of results

9.1 Low-strain measurements

9.1.1 Determination of engineering stresses σ, engineering strains ε, tensile moduli E and Poisson's ratio μ

Using results from type 1A, 1B or 1BA specimens, determine the stress and strain values up to the yield strain for each test speed (see ISO 527-1:1993, 10.1 and 10.2). From these results, calculate the tensile modulus values at each strain rate using the method of ISO 527-1:1993, 10.3. Calculate also an average value for Poisson's ratio for each test over this range of strain (see Note below and ISO 527-1:1993, 10.4).

NOTE Whilst tensile modulus and stress/strain curves will vary with the speed of testing, Poisson's ratio will be essentially constant with the test speed and strain up to the yield strain (see Note in 9.2.1).

9.1.2 Determination of true stress, σ_T

Calculate values for the true stress σ_T at each strain ε using the equation

$$\sigma_T = \frac{\sigma}{(1 - \mu\varepsilon)^2} \tag{1}$$

where σ is an engineering stress and μ is Poisson's ratio calculated from engineering strains.

9.1.3 Determination of true strain, ε_T

Calculate values for the true strain ε_T using the equation

$$\varepsilon_T = \log_e(1 + \varepsilon) \tag{2}$$

9.1.4 Determination of true plastic strain, ε_{Tp}

NOTE For the determination of properties at high strain rates, it is proposed to model measured stress/strain curves and extrapolate parameters to higher strain rates. For this purpose, it is constructive to separate the effects of elasticity and plasticity. It is then possible to identify a function that describes the shape of the curves over a wide range of strain and whereby only one parameter shows any significant variation with strain rate. Furthermore, the separation of elastic and plastic behaviour produces data in a form (hardening functions) required by finite element analyses of deformation of ductile materials.

Calculate values for the true plastic strain ε_{Tp} at each strain ε_T using the equation

$$\varepsilon_{Tp} = \varepsilon_T - \varepsilon_e = \varepsilon_T - \frac{\sigma}{E} \tag{3}$$

where ε_e is the elastic component of strain and there is a small approximation in Equation (3) based on the fact that $\varepsilon_e << 1$ so there is no need to calculate true elastic strains.

9.1.5 Determination of plastic strain rate, $\dot{\varepsilon}_{Tp}$

Calculate a value for the effective plastic strain rate for each test by determining the gradient of a plot of the true plastic strain against time at the value for plastic strain corresponding to the peak in stress or, if no peak is observed, the yield stress (see Note below).

NOTE The plastic strain rate will vary throughout a test and will generally increase at a maximum rate in the region of the peak in stress or the yield stress.

9.1.6 Determination of elastic strain rate, $\dot{\varepsilon}_e$

Where necessary, a value for the elastic strain rate for each test can be calculated by determining the gradient of a plot of strain against time at small strains where behaviour is linear.

9.2 High-strain measurements

9.2.1 Determination of stresses, strains and Poisson's ratio μ vs strain

Using results from specimens of the geometry shown in Figure 1, determine the stress and strain values for each test speed (see ISO 527-1:1993, 10.1 and 10.2). Also, determine curves of Poisson's ratio against strain (see ISO 527-1:1993, 10.4). Select a single curve of Poisson's ratio against strain that is typical of measurements made at each test speed (see Note below).

NOTE Poisson's ratio is a difficult quantity to measure accurately, and large variations in measurements can occur from one test to another. Through repeated measurements of Poisson's ratio, it should be possible to obtain a single curve that is representative of the variation of Poisson's ratio with strain at each strain rate.

9.2.2 Determination of true stress, σ_T

Calculate values for the true stress σ_T at each strain ε using Equation (1) in 9.1.2, where μ is now the value for Poisson's ratio at the strain ε.

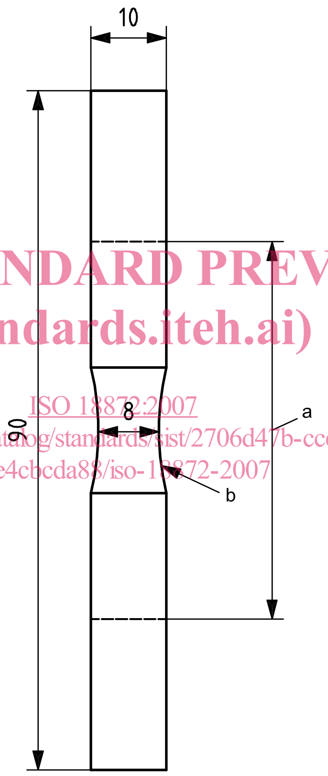
9.2.3 Determination of true strain, ε_T

Calculate values for the true strain using Equation (2) in 9.1.3.

9.2.4 Determination of true plastic strains and plastic strain rates

Calculate values for the true plastic strain at each strain ε_T and the effective plastic strain rate for each test as described in 9.1.4 and 9.1.5, respectively.

Dimensions in millimetres



[a] Grip separation = 50 mm.

[b] Cut radius = 35 mm.

Figure 1 — New tensile specimen for the determination of tensile behaviour at high strains