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Metallic materials — Tensile testing at high strain rates —

Part 2:
Servo-hydraulic and other test systems

Matériaux métalliques — Essai de traction à vitesses de déformation élevées — Partie 2: Systèmes d'essai servo-hydrauliques et autres systèmes d'essai

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Foreword

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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 26203-2 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

ISO 26203 consists of the following parts, under the general title *Metallic materials — Tensile testing at high strain rates*:

- *Part 1: Elastic-bar-type systems*
- *Part 2: Servo-hydraulic and other test systems*

This corrected version of ISO 26203-2:2011 incorporates the following correction:

- Figure A.2 a)   The figure missing above Example 1 has been added.

Introduction

The deformation behaviour of many technical materials shows a positive strain-rate effect up to ductile failure, i.e. with increasing strain rate, an increase of yield stress and strain to failure can be observed. This information is of great importance for the reliable assessment of crashworthiness of automobile structures, which is increasingly determined by numerical methods to minimize the need for cost-intensive and time-consuming crash tests. For the numerical simulation of crash-type loads, stress-strain curves determined at higher strain rates are required. The quasi-static values determined according to ISO 6892-1, i.e. strain rates lower than or equal to 0,008 s^{-1}, are not suitable for the description of the behaviour of the material of a component under dynamic load, i.e. at strain rates higher than those in quasi-static tests.

Metallic materials — Tensile testing at high strain rates —

Part 2:
Servo-hydraulic and other test systems

1 Scope

This part of ISO 26203 gives requirements for the testing of metallic materials. Only examples for testing flat geometries are given; however, other geometries can be tested. The area of application spans a range of strain rates from 10^{-2} s^{-1} to 10^3 s^{-1}. Tests are carried out between 10 °C and 35 °C and, unless otherwise specified, using a servo-hydraulic-type test system.

NOTE 1 Measurements at strain rates lower than 10^{-2} s^{-1} can be performed using machines designed for quasi-static testing.

NOTE 2 For test piece geometries other than those shown in 7.1 and Annex B, see ESIS P7 (Reference [1]) and FAT Guideline (Reference [2]).

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 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6892-1 apply.

4 Symbols

For the purposes of this document, the symbols given in ISO 6892-1 apply. Additional symbols, units and descriptions are provided in Table 1.

Table 1 — Symbols

Symbol	Unit	Description
		Test piece
a_o	mm	Original thickness of a flat test piece
b_o	mm	Original width of the parallel length of a flat test piece
b_k	mm	Width(s) of the clamping area of the test piece
L_o	mm	Original gauge length
L_c	mm	Parallel length
L_e	mm	Extensometer gauge length
r	mm	Transition radius
S_o	mm^2	Original cross-sectional area of the parallel length
S_D	mm^2	Dynamometer area: area on the fixed side of the test piece where only elastic deformations are required during the test

Table 1 *(continued)*

Symbol	Unit	Description
Time		
t	s	Time
t_f	s	Duration from beginning of test to moment of fracture initiation
Elongation		
A	%	Percentage elongation after fracture NOTE For non-proportional test pieces, the symbol A is supplemented by a subscript, which shows the original gauge length, in millimetres, e.g. $A_{20\ \text{mm}}$ = percentage elongation after fracture with an original gauge length $L_o = 20$ mm.
Extension		
A_g	%	Percentage plastic extension at maximum force, F_m (plastic strain at maximum force, F_m)
A_{gt}	%	Percentage total extension at maximum force, F_m (total strain at maximum force, F_m)
Strain		
$e(t)$	%	Time-dependent engineering strain
e_{pl}	%	Plastic engineering strain
e_t	%	Total engineering strain
ε_{pl}		True plastic strain
ε_t		True total strain
Rates		
v_o	mm s^{-1}	Initial displacement rate
$\dot{e}_{nom}$	s^{-1}	Nominal engineering strain rate $= v_o / L_c$ [Equation (1)]
$\dot{e}_{mean}$	s^{-1}	Mean engineering strain rate $= A / t_f$ [Equation (4)]
$\dot{e}(t)$	s^{-1}	Time-dependent engineering strain rate $= \mathrm{d}e(t)/\mathrm{d}t$
$\dot{e}_{pl}$	s^{-1}	Mean value of the time-dependent engineering strain rate: $\mathrm{d}e(t)/\mathrm{d}t$ in the range between start of yield or 1 % strain and strain at maximum force [Equation (5)]
f_u	Hz	Upper frequency limit of the relevant measuring system (force or extension)
Force		
F_m	N	Maximum force
Engineering stress — True stress		
R	MPa[a]	Engineering stress
σ	MPa	True stress
Yield strength — Proof strength — Tensile strength		
R_{eL}	MPa	Lower yield strength
R_p	MPa	Proof strength, plastic extension
R_m	MPa	Tensile strength
Modulus of elasticity — Slope of stress-strain curve		
E	MPa	Modulus of elasticity
m_E	MPa	Slope of the elastic part of the stress-strain curve[b]

[a] 1 MPa = 1 N/mm^2.

[b] In the elastic part of the stress-strain curve the value of the slope can closely agree with the value of the modulus of elasticity if optimal conditions (high resolution, double-sided averaging extensometers, proper alignment of the test piece, etc.) are used.

5 Principle

The stress-strain characteristics of metallic materials at specific plastic strain rates are determined.

To perform tension tests at strain rates above those described in ISO 6892-1, the measurement of force and elongation of the original gauge length, L_o, shall meet additional requirements in order to obtain reliable high-rate stress-strain curves. This part of ISO 26203 describes the requirements for determining and evaluating the stress and strain in force equilibrium during plastic deformation at strain rates up to 10^3 s^{-1}.

6 Apparatus

Testing machines in conformity with this part of ISO 26203 work on the principle that the kinetic energy required for the test is applied on the impact (or loading) side of the test piece (see Figure A.1). The load cell is located at the opposite end of the test piece, which is fixed or restrained in a clamp/grip (see Figure A.1). Loading at high strain rates is preferably impact-like and, therefore, often does not allow a fixed coupling of the test piece to the testing machine. All testing machines that permit a constant strain rate (within certain bounds; see 9.3) during the entire test are suitable for testing.

The most common high-rate testing machine applicable to this part of ISO 26203 utilizes a servo-hydraulic drive fitted with a slack adapter (see Reference [3]). Other systems, which may include, for example, flywheel impactors and drop towers, may be used on condition that the requirements given in this part of ISO 26203 are met.

An axial-symmetric parallel alignment of the test pieces in the load train shall be verified in order to prevent bending moments. The alignment of the load train elements may be performed in accordance with ASTM E1012 (see Reference [4]).

From a mechanical point of view, the load train should be compact and easy to manage. This enables the load train to attain short acceleration times while also maintaining the natural frequency of the clamping and load cell system at as high a level as possible.

7 Test pieces

7.1 Test piece geometry

Flat tensile test pieces are used for the dynamic testing of sheet materials. The strain rate developed in the test piece gauge length is dependent on both the applied displacement rate and the parallel length of the reduced section in the test piece. A test piece with a shorter parallel length enables higher strain rates. However, a parallel length, L_c, shall be maintained so that the original gauge length, L_o, is in a state of uniaxial stress (see Figure 1). Therefore, the recommended sizes of the parallel length, L_c, the width, b_o, the thickness, a_o, and the transition radius, r, for the test piece are as follows:

— $L_o / b_o \geq 2$

— $L_c \geq L_o + b_o / 2$

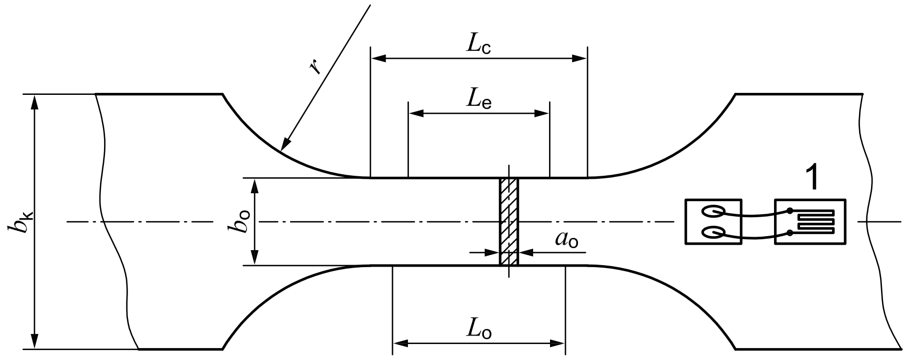
— $b_o / a_o \geq 2$

— b_o / b_k ″ 0,5

— $r \geq 10$ mm

Here b_k is the width of the clamping area.

Frequently used test piece dimensions based on ISO 6892-1 are given as examples in Annex B. Other geometries of test pieces (e.g. ISO 26203-1, ESIS P7 and FAT guideline) may be applied if agreed upon between the interested parties.



Key

1	strain gauge
a_o	original thickness
b_o	original width of the parallel length
b_k	width of the clamping area
L_c	parallel length
L_e	extensometer gauge length
L_o	original gauge length
r	transition radius

Figure 1 — Characteristic test piece dimensions

NOTE In order to reach force equilibrium at low strain (beginning of the test) for high strain rates up to 10^3 s^{-1}, it is important to choose an appropriate length for the test piece.

The ends of the test pieces are designed to fit the available machine clamping devices. The dimensions of the ends of the test pieces shall be designed such that only elastic deformation takes place within the sample ends during the test.

Force measurement using strain gauges attached to the test piece (see Figure 1) requires a dynamometer zone (see References [1] and [5]). The dynamometer zone is located at the fixed or restrained end of the test piece. No plastic deformation is permissible in the dynamometer zone.

The test piece design should be validated prior to high-strain-rate testing. Validation can typically involve conducting quasi-static tests on high rate test pieces within the strain rate limit permitted in ISO 6892-1. The material properties derived from these tests should be compared with the data derived using the test piece design, test procedure and test machine in accordance with ISO 6892-1.

7.2 Preparation of test pieces

The instructions and comments for the manufacture of flat tensile test pieces in ISO 6892-1:2009, Annex B, shall be followed. In addition, special care should be taken to prevent strain hardening at the cut edges. Spark erosion, water jet cutting, high-speed machining or other processes which mitigate the development of strain-hardened edges, surface roughness and test piece distortion are recommended. The surfaces of the sheet samples should remain in the original, as-received condition. The surface roughness of the cut edges shall be minimized.

8 Procedure and measurements

8.1 Velocity selection

The velocity of the actuator is selected prior to a high-strain-rate test to achieve the desired strain rate in the parallel length of the test piece. An initial displacement rate of v_0 permits the estimation of the achievable nominal engineering strain rate using Equation (1):

$$\dot{e}_{\text{nom}} = v_0 / L_c \quad (1)$$

where L_c is the parallel length of the test piece.

The strain rate recorded during a test deviates from the estimated value (see 9.3) due to the compliance in the loading train.

NOTE For drop towers, the speed is determined by a calculation based on the drop height.

The material behaviour is governed by the strain rate in the parallel length of the test piece during the test. Therefore, the purpose of the test procedure is to conduct a test with a constant strain rate in the parallel length of the test piece (see 9.3) and not necessarily a constant velocity of the actuator.

8.2 Force measurement

The natural frequency of piezo-electric load cells is typically high enough for an accurate force measurement at lower strain rates. For strain rates greater than approximately 50 s^{-1}, it is recommended that force be measured either by strain gauges in a test piece area subjected to purely elastic deformation (dynamometer zone; see Figure 1) or by means of a local dynamometer, such as a strain gauge placed on a grip (see References [2], [6], [7] and [8]).

Spontaneous transfer of force into a test piece at high strain rate causes the test piece and parts of the testing machine to oscillate increasingly as the displacement rate grows. These oscillations can be either of a longitudinal or of a bending type. They are recorded as oscillations superposed to the force signal and thus in the stress-strain curve. The inherent material deformation behaviour can be observed as phenomena similar to “force oscillations” (discontinuous yielding associated with Lüders band propagation, dynamic strain ageing, deformation twinning, etc,).

Prevention or at least reduction of oscillations in the force signal is an important criterion when selecting the dynamometric procedure. In general, it can be ascertained that the further the force is measured outside the gauge length and/or the higher the velocity of the actuator is, the greater are the oscillations.

It can be advantageous to apply a strain gauge on each side of the test piece to determine the proportion of oscillations resulting from bending effects. Each signal is analysed separately in order to assess any bending component. The use of damping elements in the load train in order to minimize oscillations should be carried out with care. Damping reduces the strain rate at the beginning of the test, which in turn can influence the yield strength.

Calibration of the dynamometer should be performed in a suitable manner. Test pieces fitted with strain gauges can be calibrated quasi-statically. To this end, a test piece is subjected to a force, which corresponds to a maximum of two thirds of the yield strength or proof stress in order to determine the calibration factor. Other methods of force calibration are described in References [2], [9] and [10].

For tests at strain rates lower than 10 s^{-1}, the upper frequency limit, f_u (–3dB) shall be at least 10 kHz. For higher strain rates, Equation (2) applies according to ESIS P7 (see Reference [1]):

$$f_u \geq 1000 \times \dot{e} \quad (2)$$

where

f_u is the upper frequency limit of the force measuring system;

$\dot{e}$ is the strain rate.