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Metallic materials - Tensile testing at high strain rates - Part 1: Elastic-bar-type systems (ISO/DIS 26203-1:2024)

Metallische Werkstoffe - Zugversuch bei hohen Dehngeschwindigkeiten - Teil 1: Elastische Stoßwellentechnik (ISO/DIS 26203-1:2024)

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Part 1: Elastic-bar-type systems

Matériaux métalliques — Essai de traction à vitesses de déformation élevées —

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Foreword

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

This third edition cancels and replaces the second edition (ISO 26203-1:2018), which has been technically revised.

The main changes are as follows:

— Modification of sentence regarding Annex A in Clause 5

— Modification of NOTE in subclause 7.1

— Modification of Annex A (see A.6)

A list of all parts in the ISO 26203 series can be found on the ISO website.

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

Tensile testing of metallic sheet materials at high strain rates is important to achieve a reliable analysis of vehicle crashworthiness. During a crash event, the maximum strain rate often reaches 103 s–1, at which the strength of the material can be significantly higher than that under quasi-static loading conditions. Thus, the reliability of crash simulation depends on the accuracy of the input data specifying the strain-rate sensitivity of the materials.

Although there are several methods for high-strain rate testing, solutions for three significant problems are required.

The first problem is the noise in the force measurement signal.

— The test force is generally detected at a measurement point on the force measurement device that is located some distance away from the test piece.

— Furthermore, the elastic wave which has already passed the measurement point returns there by reflection at the end of the force measurement device. If the testing time is comparable to the time for wave propagation through the force measurement device, the stress-strain curve may have large oscillations as a result of the superposition of the direct and indirect waves. In quasi-static testing, contrarily, the testing time is sufficiently long to have multiple round-trips of the elastic wave. Thus, the force reaches a saturated state and equilibrates at any point of the force measurement device.

— There are two opposing solutions for this problem.

— The first solution is to use a short force measurement device which will reach the saturated state quickly. This approach is often adopted in the servo-hydraulic type system.

— The second solution is to use a very long force measurement device which allows the completion of a test before the reflected wave returns to the measurement point. The elastic-bar-type system is based on the latter approach.

The second problem is the need for rapid and accurate measurements of displacement or test piece elongation.

— Conventional extensometers are unsuitable because of their large inertia. Non-contact type methods such as optical and laser devices should be adopted. It is also acceptable to measure displacements using the theory of elastic wave propagation in a suitably-designed apparatus, examples of which are discussed in this document.

— The displacement of the bar end can be simply calculated from the same data as force measurement, i.e. the strain history at a known position on the bar. Thus, no assessment of machine stiffness is required in the elastic-bar-type system.

The last problem is the inhomogeneous section force distributed along the test piece.

— In quasi-static testing, a test piece with a long parallel section and large fillets is recommended to achieve a homogeneous uniaxial-stress state in the gauge section. In order to achieve a valid test with force equilibrium during the dynamic test, the test piece is to be designed differently from the typically designed quasi-static test piece. Dynamic test pieces are intended to be generally smaller in the dimension parallel to the loading axis than the test pieces typically used for quasi-static testing.

The elastic-bar-type system can thus provide solutions for dynamic testing problems and is widely used to obtain accurate stress-strain curves at around 10^3 s^{-1}. The International Iron and Steel Institute developed the "Recommendations for Dynamic Tensile Testing of Sheet Steel" based on the interlaboratory test conducted by various laboratories. The interlaboratory test results show the high data quality obtained by the elastic-bar-type system. The developed knowledge on the elastic-bar-type system is summarized in this document; ISO 26203-2 covers servo-hydraulic and other test systems used for high-strain-rate tensile testing.

Metallic materials — Tensile testing at high strain rates —

Part 1:
Elastic-bar-type systems

1 Scope

This document specifies methods for testing metallic sheet materials to determine the stress-strain characteristics at high strain rates. This document covers the use of elastic-bar-type systems.

The strain-rate range between 10^{-3} and 10^{3} s^{-1} is considered to be the most relevant to vehicle crash events based on experimental and numerical calculations such as the finite element analysis (FEA) work for crashworthiness.

In order to evaluate the crashworthiness of a vehicle with accuracy, reliable stress-strain characterization of metallic materials at strain rates higher than 10^{-3} s^{-1} is essential.

This test method covers the strain-rate range above 10^{2} s^{-1}.

NOTE 1 At strain rates lower than 10^{-1} s^{-1}, a quasi-static tensile testing machine that is specified in ISO 7500-1 and ISO 6892-1 can be applied.

NOTE 2 This testing method is also applicable to tensile test-piece geometries other than the flat test pieces considered here.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
elastic-bar-type system
measuring system in which the force-measuring device is lengthened in the axial direction to prevent force measurement from being affected by waves reflected from the ends of the apparatus

Note 1 to entry: The designation “elastic-bar-type system” comes from the fact that this type of system normally employs a long elastic bar as force-measuring device.

4 Symbols and designations

Symbols and their corresponding designations are given in Table 1.

Table 1 — Symbols and designations

Symbol	Unit	Designation
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_g	mm	width(s) of the grip section of a test piece
L_o	mm	original gauge length [see 7.1 e)]
L_c	mm	parallel length
L_{total}	mm	total length that includes the parallel length and the shoulders
L_u	mm	final gauge length after fracture
r	mm	radius of the shoulder
S_o	mm^2	original cross-sectional area of the parallel length
S_b	mm^2	cross-sectional area of the elastic bar
Time		
t	s	time
Elongation		
A	%	percentage elongation after fracture NOTE With non-proportional test pieces, the symbol A is supplemented with an index which shows the basic initial measured length in millimetres, e.g. A_{20mm} = Percentage elongation after fracture with an original gauge length L_o = 20 mm.
A_u	%	specified upper limit of percentage elongation for mean strain rate
Displacement		
u	mm	displacement by the elastic wave
u_1	mm	displacement at the end of the original gauge length
u_2	mm	displacement at the end of the original gauge length
$u_B(t)$	mm	displacement of the end of the elastic bar at time t
Strain		
e	—	engineering strain
e_s	—	desired engineering strain before achieving equilibrium
ε	—	elastic strain
ε_B	—	elastic strain at the end of the elastic bar (see Annex B)
ε_g	—	elastic strain at section C (see Annex B)
Strain rate		
$\dot{e}$	s^{-1}	engineering strain rate
$\bar{\dot{e}}$	s^{-1}	mean engineering strain rate
Force		
F	N	force
F_m	N	maximum force
Stress		
R	MPa	engineering stress
R_m	MPa	tensile strength
R_t	MPa	proof strength, total extension
Modulus of elasticity		
E	MPa	modulus of elasticity
E_b	MPa	modulus of elasticity of the bar

Table 1 *(continued)*

Symbol	Unit	Designation
		Wave velocity
c_0	mm s^{-1}	velocity of the wave propagation in the elastic bar
c	mm s^{-1}	elastic wave propagation velocity in the test piece
		Velocity
$v_A(t)$	mm s^{-1}	velocity of the impact block (see Annex B)
v	mm s^{-1}	particle velocity at any point in the bar (see Annex C)
v_i	mm s^{-1}	incident particle velocity (see Annex C)
v_r	mm s^{-1}	reflected particle velocity (see Annex C)
v_t	mm s^{-1}	transmitted particle velocity (see Annex C)
		Signal
U_A	V	amplified signal

5 Principles

The stress-strain characteristics of metallic materials at high strain rates are evaluated.

At a strain rate higher than 10 s^{-1}, the signal of the loading force is greatly perturbed by multiple passages of waves reflected within the load cell that is used in the quasi-static test. Thus, special techniques are required for force measurement. This may be accomplished in two opposite ways:

— one is to lengthen the force measurement device in the loading direction, in order to finish the measurement before the elastic wave is reflected back from the other end (elastic-bar-type systems);

— another way is to shorten the force measurement device, thus reducing the time needed to attain dynamic equilibrium within the force measurement device and realizing its higher natural frequency (servo-hydraulic type systems).

Tests at low strain rates (under 10^{-1} s^{-1}) can be carried out using a quasi-static tensile testing machine. However, special considerations are required when this machine is used for tests at strain rates higher than conventional ones. It is necessary to use a test piece specified for high-strain-rate testing methods. See Annex A regarding details of the test procedure for this practice.

6 Apparatus

6.1 Elastic bar. By using a long elastic bar, the test should be finished before the elastic wave is reflected back from the other end of the bar that is on the opposite side of the test piece. Consequently, the force can be measured without being perturbed by the reflected waves. For this method, the one-bar testing machine and the split Hopkinson bar (SHB) testing machine are normally used (see Annex B and Annex C).

6.2 Input device. For the input method, open-loop-type loading is normally applied. The upper limit of the input speed is approximately 20 m s^{-1}. For the SHB testing machine, a striker tube or striker bar is used. For the one-bar testing machine, a hammer is normally used.

6.3 Clamping mechanism. A proper clamping mechanism (a method for connecting a test piece and an elastic bar) is critical to data quality (see Annex B and Annex C).

The clamping fixtures for the SHB or one-bar testing machines are mounted directly on the elastic bars. The clamping fixtures should be of the same material and diameter as the elastic bars to ensure minimal impedance change when the stress wave propagates through the loading train. If a different material or size is used, proper consideration should be made in the evaluation of stress and strain.