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split Hopkinson bar method

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Foreword

This Japanese Industrial Standard has been established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal for establishment of Japanese Industrial Standard submitted by High Pressure Institute of Japan (HPI)/Japanese Standards Association (JSA) with a draft being attached, based on the provision of Article 12, paragraph (1) of the Industrial Standardization Act.

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High deformation rate testing by split Hopkinson bar method

1 Scope

This Japanese Industrial Standard specifies the procedures for compression, tensile and bending tests conducted by the high deformation rate testing using split Hopkinson bar method.

Where compression, tensile and bending test methods are specified in the individual product standards, e.g. of metallic materials or non-metallic materials, those methods shall apply instead of the methods specified in this Standard.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS G 0202 *Glossary of terms used in iron and steel (Testing)*

JIS G 4805 *High carbon chromium bearing steels*

JIS H 4040 *Aluminium and aluminium alloy bars and wires*

JIS H 4080 *Aluminium and aluminium alloy extruded tubes and cold-drawn tubes*

JIS Z 2241 *Metallic materials—Tensile testing—Method of test at room temperature*

3 Terms and definitions

For the purpose of this Standard, the terms and definitions given in **JIS G 0202** and **JIS Z 2241**, and the following apply.

3.1

stress wave, strain wave

propagated wave of stress or strain

Stress and strain waves that propagate in the elastic deformation area are called elastic stress wave and elastic strain wave, respectively. In the calculation of stress and strain of a specimen, they are treated as one-dimensional longitudinal elastic stress wave and one-dimensional longitudinal elastic strain wave.

3.2

input bar

bar that is a component of a test apparatus for the split Hopkinson bar method, used for giving an elastic stress wave to the specimen

3.3

output bar

bar that is a component of a test apparatus for the split Hopkinson bar method, used for capturing an elastic stress wave that propagates due to deformation of the specimen

3.4

striker bar

bar that is a component of a compression and bending test apparatus for the split Hopkinson bar method, whose impact against the input bar generates an elastic stress wave in the input bar

3.5

striker tube

tube that is a component of a tensile test apparatus for the split Hopkinson bar method, serving as the equivalent of a striker bar for compression and bending tests

3.6

yoke

bar that is a component of a tensile test apparatus for the split Hopkinson bar method, fixed to one end of the input bar (the end opposite from the specimen fastening part), and impacted against the striker tube to generate an elastic stress wave in the input bar

3.7

incident wave

elastic stress wave or elastic strain wave induced by the impact force of a striker bar or an equivalent component and progresses toward the specimen, among other temporal changes of stress or strain that propagates through the input bar

3.8

reflected wave

elastic stress wave or elastic strain wave reflected by the specimen and propagates in the opposite direction to the incident wave, among other temporal changes of stress or strain that propagates through the input bar

3.9

transmitted wave

elastic stress wave or elastic strain wave induced by the deformation of the specimen caused by the incident wave, among other temporal changes of stress or strain that propagates through the output bar

3.10

dynamic equilibrium

state where the forces at two ends of a specimen undergoing deformation are in balance

3.11

mechanical impedance

cross-section of a material multiplied by density and elastic wave velocity

4 Symbols and their definitions

The symbols and their definitions are shown in Table 1.

Table 1 Symbols and definitions

Symbol	Unit	Definition
Test apparatus		
D_{ST}	mm	diameter of striker bar
D_{STi}	mm	inner diameter of striker tube
D_{STo}	mm	outer diameter of striker tube
D_1	mm	diameter of input bar
D_2	mm	diameter of output bar
L_{ST}	mm	length of striker bar
L_{STi}	mm	length of striker tube
L_1	mm	length of input bar
L_2	mm	length of output bar
C_{ST}	mm/s	elastic wave velocity of striker bar
C_{STi}	mm/s	elastic wave velocity of striker tube
C_1	mm/s	elastic wave velocity of input bar
C_2	mm/s	elastic wave velocity of output bar
A_1	mm ²	cross-sectional area of input bar
A_2	mm ²	cross-sectional area of output bar
E_1	MPa	modulus of longitudinal elasticity of input bar
E_2	MPa	modulus of longitudinal elasticity of output bar
ρ_1	kg/mm ³	density of input bar (see Annex A)
ρ_2	kg/mm ³	density of output bar (see Annex A)
V_0	mm/s	launch velocity of striker bar
V_{0t}	mm/s	launch velocity of striker tube
Z_{ST}	kg/s	mechanical impedance of striker bar
Z_{STi}	kg/s	mechanical impedance of striker tube
Z_1	kg/s	mechanical impedance of input bar
G_1	mm	distance between the end of the input bar in contact with the specimen to the centre of Strain gauge 1 (compression test)
G_2	mm	distance between the end of the output bar in contact with the specimen to the centre of Strain gauge 2 (compression test)
G_{1t}	mm	distance between the specimen fastening part of the input bar to the centre of Strain gauge 1 (tensile test)
G_{2t}	mm	distance between the specimen fastening part of the output bar to the centre of Strain gauge 1 (tensile test)
G_{1b}	mm	distance between the end of the input bar in contact with the specimen to the centre of Strain gauge 1 (bending test)
G_{2b}	mm	distance between the end of the output bar in contact with the specimen to the centre of Strain gauge 2 and Strain gauge 3 (bending test)
σ_Y	MPa	yield strength of input bar or striker bar, whichever is the smaller
σ_{Yt}	MPa	yield strength of input bar or striker tube, whichever is the smaller
r_1	mm	tip radius of input bar (bending test)
r_2	mm	tip radius of Output bar 1 and Output bar 2 (bending test)
l	mm	fulcrum span

Table 1 (continued)

Symbol	Unit	Definition
Specimen		
d_s	mm	diameter of columnar compression specimen
a_s	mm	side length of square prism compression specimen
L_s	mm	length of compression specimen
A_s	mm ²	cross-sectional area of compression specimen
d_{St}	mm	diameter of the parallel length of the round bar tensile specimen
w_t	mm	width of the parallel length of the strip tensile specimen
h_t	mm	thickness of strip tensile specimen
L_p	mm	parallel length of tensile specimen
R	mm	radius of shoulder of tensile specimen
L_F	mm	inter-fillet distance of tensile specimen
A_{St}	mm	cross-sectional area of the parallel length of the tensile specimen
L_{Sb}	mm	length of three-point bending specimen
h_b	mm	thickness of three-point bending specimen
w_b	mm	width of three-point bending specimen
$\dot{\epsilon}_{ave}$	s ⁻¹	absolute value of average nominal strain rate in specimen
ϵ_{max}	—	absolute value of maximum nominal strain in specimen
σ_{SY}	MPa	yield strength of specimen (average of flow stress)
σ_B	MPa	tensile strength of specimen
C_s	mm/s	elastic wave velocity of specimen
Incident wave, reflected wave, and transmitted wave		
ϵ_I	—	strain value of incident wave (compression test and tensile test)
ϵ_R	—	strain value of reflected wave (compression test and tensile test)
ϵ_T	—	strain value of transmitted wave (compression test and tensile test)
ϵ_{Ib}	—	strain value of incident wave (bending test)
ϵ_{Rb}	—	strain value of reflected wave (bending test)
ϵ_{Tb}	—	strain value of transmitted wave (bending test)
ϵ_1	—	strain recorded at Strain gauge 1 of input bar (compression test and tensile test)
ϵ_2	—	strain recorded at Strain gauge 2 of output bar (compression test and tensile test)
ϵ_{1b}	—	strain recorded at Strain gauge 1 of input bar (bending test)
ϵ_{2b}	—	strain recorded at Strain gauge 2 of output bar (bending test)
ϵ_{3b}	—	strain recorded at Strain gauge 3 of output bar (bending test)
ϵ_{ei}	—	elastic strain value of input bar (see Annex A)
ϵ_{eo}	—	elastic strain value of output bar (see Annex A)
Δt_I	s	measurable time of strain of incident wave
Δt_R	s	measurable time of strain of reflected wave
Δt_T	s	measurable time of strain of transmitted wave

Table 1 (concluded)

Symbol	Unit	Definition
Incident wave, reflected wave, and transmitted wave (concluded)		
u	mm	displacement of bar along the coordinates (x -axis) (see Annex A)
u_1	mm	displacement of specimen at the input-bar side (see Annex A)
u_2	mm	displacement of specimen at the output-bar side (see Annex A)
C	mm/s	elastic wave velocity propagating through the elastic bar (see Annex A)
C_a	mm/s	elastic wave velocity in the positive direction on the x -axis (see Annex A)
C_b	mm/s	elastic wave velocity in the negative direction on the x -axis (see Annex A)
Stress and load acting on specimen		
σ_1	MPa	stress on the left side (input-bar side) of the specimen (compression specimen)
σ_2	MPa	stress on the right side (output-bar side) of the specimen (compression specimen)
σ_{1t}	MPa	stress on the left-side (input-bar side) end section of the parallel length of the specimen (tensile specimen)
σ_{2t}	MPa	stress on the right-side (output-bar side) end section of the parallel length of the specimen (tensile specimen)
F_1	N	load acting on the left side of the specimen (three-point bending specimen)
F_2	N	total load acting on the right side of the specimen (three-point bending specimen)
σ	MPa	nominal stress (compression specimen)
$\dot{\varepsilon}$	s ⁻¹	nominal strain rate (compression specimen)
ε	—	nominal strain (compression specimen)
σ_t	MPa	nominal stress (tensile specimen)
$\dot{\varepsilon}_t$	s ⁻¹	nominal strain rate (tensile specimen)
ε_t	—	nominal strain (tensile specimen)
σ_b	MPa	bending stress (three-point bending specimen)
$\dot{\varepsilon}_b$	s ⁻¹	bending strain rate (three-point bending specimen)
ε_b	—	bending strain (three-point bending specimen)
P_1	N	axial load on the specimen at the input-bar side (see Annex A)
P_2	N	axial load on the specimen at the output-bar side (see Annex A)
NOTE 1 MPa = 1 N/mm ²		

5 Principle

An impact of a striker bar is used to generate an elastic stress wave in the assembly where a specimen is placed between the input bar and output bar. The relationship between the incident wave, reflected wave, and transmitted wave of the elastic stress wave through the specimen is analyzed to determine the stress, strain, and strain rate of the specimen using the one-dimensional elastic wave propagation theory^[1].

6 Compression test

6.1 Test apparatus

6.1.1 Basic configuration

A compression test apparatus for split Hopkinson bar method consists of a striker bar, input bar, and output bar (see Figure 1). The three bars are aligned coaxially, and a specimen is placed between the input bar and the output bar. All three bars shall be straight bars with a round cross-section. Restriction of the axial movement of the input and output bars shall be minimal.

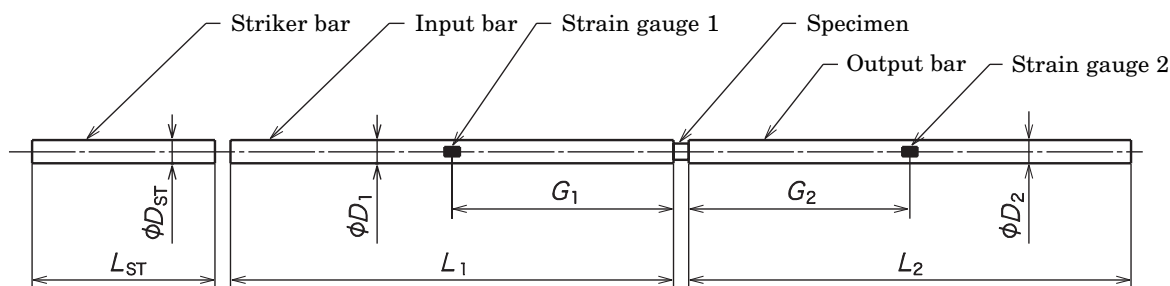


Figure 1 Basic configuration of compression test apparatus for split Hopkinson bar method

6.1.2 Components

The components of a compression test apparatus for Split Hopkinson bar method are as follows.

- a) **Striker bar**, typically propelled by compressed air or spring, either of which method may be used.

The material of the striker bar may differ from those of the input bar and output bar. The diameter of the striker bar, D_{ST} , shall be determined so that the mechanical impedance of the striker bar is equal to or smaller than that of the input bar.

The length of the striker bar, L_{ST} , is at least 10 times the diameter of the input bar, D_1 , as shown by Equation (1):

$$L_{ST} \geq 10D_1 \dots\dots\dots (1)$$

To increase the maximum strain generated in the specimen, either the length of the striker bar, L_{ST} , or the launch velocity of the striker bar shall be increased.

- b) **Input bar and output bar**, the former having Strain gauge 1 pasted at distance G_1 from the end in contact with the specimen for the purpose of measuring the incident wave and reflected wave, and the latter having Strain gauge 2 pasted at distance G_2 from the end in contact with the specimen for the purpose of measuring transmitted wave. The lengths of the input bar and output bar, L_1 and L_2 , and distances G_1 and G_2 (paste positions of Strain gauges 1 and 2) shall satisfy Equations (2) to (5):

$$\frac{G_1}{C_1} \geq 1.2 \frac{L_{ST}}{C_{ST}} \dots\dots\dots (2)$$

$$L_1 \geq 2G_1 \dots\dots\dots (3)$$

$$G_2 \geq 10D_2 \dots\dots\dots (4)$$

$$\frac{L_2 - G_2}{C_2} \geq 1.2 \frac{L_{ST}}{C_{ST}} \dots\dots\dots (5)$$

The input and output bars should preferably be of the same material and diameter unless required otherwise.

The parts of the input and output bars to be in contact with the specimen shall be capable of resisting plastic deformation.

- c) **Measuring equipment**, capable of satisfying the measuring conditions provided in Annex B.

6.1.3 Standard test apparatus

The types and dimensions of standard compression test apparatus for split Hopkinson bar method, of which the striker bar, input bar, and output bar are of the same material and diameter, are shown in Table 2.

The material for the striker bar, input bar, and output bar shall normally be steel (high yield strength steel such as SUJ2 specified in **JIS G 4805**); however, depending on the compressive stress generated in the specimen, aluminium alloy (2000 and 7000 series specified in **JIS H 4040**) may be used.

Table 2 Types and dimensions of standard compression test apparatus

Unit: mm

Dimension symbols	Types of test apparatus	
	C20	C10
D_1	20	10
D_2	20	10
L_1	2 500	2 500
L_2	1 600	1 500
G_1	1 250	1 250
G_2	300	150
D_{ST}	20	10
L_{ST}	1 000	1 000

6.1.4 Launch velocity of striker bar

The launch velocity of the striker bar, V_0 (velocity of collision with the input bar), shall be obtained by Equations (6) and (7) based on the absolute values of desired average nominal strain rate, $\dot{\epsilon}_{ave}$, and maximum nominal strain, ϵ_{max} , in the specimen: