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Steel — Charpy V-notch pendulum impact test — Instrumented test method

Aciers — Essai de flexion par choc sur éprouvette Charpy à entaille en V — Méthode d'essai instrumenté

Reference number
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Tel. + 41 22 749 01 11
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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 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 14556 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing*.

Annexes A to C of this International Standard are for information only.

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Steel — Charpy V-notch pendulum impact test — Instrumented test method

1 Scope

This International Standard specifies a method of instrumented Charpy V-notch pendulum impact testing on steel products and the requirements concerning the measurement and recording equipment.

This International Standard can be applied to other metallic materials by agreement.

This test provides further information on the fracture behaviour of the tested product.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated reference, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test Method.*

ISO 148-2, *Metallic materials — Charpy pendulum impact test — Part 2: Verification of test machines.*

3 Terms and definitions

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

3.1 Characteristic values of force

NOTE Characteristic values of force are expressed in newtons.

3.1.1
general yield force
F_{gy}
force at the transition point from the linearly increasing part to the curved increasing part of the force-displacement curve

NOTE It represents a first approximation of the force at which yielding has occurred across the entire uncracked-test-piece ligament (see 9.3).

3.1.2
maximum force
F_{m}
maximum force in the course of the force-displacement curve

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3.1.3

crack initiation force

F_{iu}

force at the beginning of the steep drop in the force-displacement curve

NOTE It characterizes the beginning of unstable crack propagation.

3.1.4

crack arrest force

F_{a}

force at the end (arrest) of unstable crack propagation

3.2 Characteristic values of displacement

NOTE Characteristic values of displacement are expressed in metres.

3.2.1

general yield displacement

s_{gy}

displacement corresponding to the general yield force, F_{gy}

3.2.2

displacement at maximum force

s_{m}

displacement corresponding to the maximum force, F_{m}

3.2.3

crack initiation displacement

s_{iu}

displacement at the initiation of unstable crack propagation

3.2.4

crack arrest displacement

s_{a}

displacement at the end (arrest) of unstable crack propagation

3.2.5

total displacement

s_{t}

displacement at the end of the force-displacement curve

3.3 Characteristic values of impact energy

NOTE Characteristic values of impact energy are expressed in joules.

3.3.1

energy at maximum force

W_{m}

partial impact energy from $s= 0$ to $s = s_{\mathrm{m}}$

3.3.2

crack initiation energy

W_{iu}

partial impact energy from $s = 0$ to $s = s_{\mathrm{iu}}$

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3.3.3

crack arrest energy

W_a

partial impact energy from $s = 0$ to $s = s_a$

3.3.4

total impact energy

W_t

energy absorbed during the breaking of the specimen calculated from area under the force-displacement curve from $s = 0$ to $s = s_t$

4 Symbols and abbreviated terms

For the purposes of this International Standard, the symbols and abbreviations given in Table 1 are applicable (see also Figures 2 and 3).

Table 1 — Symbols and designations

Symbol	Designation	Unit
f_g	Output frequency limit	Hz
F	Force	N
F_a	Crack arrest force	N
F_{gy}	General yield force	N
F_{iu}	Crack initiation force	N
F_m	Maximum force	N
g_n	Acceleration due to gravity	m/s^2
h	Height of fall of the centre of strike of the pendulum (see ISO 148-2)	m
KV	Absorbed energy as defined in ISO 148-1	J
m	Effective mass of the pendulum corresponding to its effective weight (see ISO 148-2)	kg
s	Displacement	m
s_a	Crack arrest displacement	m
s_{gy}	General yield displacement	m
s_{iu}	Crack initiation displacement	m
s_m	Displacement at maximum force	m
s_t	Total displacement	m
t	Time	s
t_o	Time at the beginning of deformation of the test piece	s
t_r	Signal rise time	s
v_o	Initial striker impact velocity	m/s
v_t	Striker impact velocity at time t	m/s
W_a	Crack arrest energy	J
W_{iu}	Crack initiation energy	J
W_m	Energy at maximum force	J
W_t	Total impact energy	J

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5 Principle

5.1 This test consists of measuring the impact force, in relation to the test piece bending displacement, during an impact test, carried out in accordance with ISO 148-1. The area under the force-displacement curve defines the energy absorbed by the test piece.

5.2 Force-displacement curves for different steel products and different temperatures can be quite different, even though the areas under the curves and the absorbed energies are identical. If the force-displacement curves are divided into characteristic parts, various phases of the test with characteristic appearances can be deduced which provide considerable information about the fracture behaviour of the test piece.

NOTE The force displacement curve cannot be used in strength calculations of structures. It is not possible to directly determine the lowest permissible operating temperature for a material in a construction.

6 Apparatus

6.1 Testing machine

A pendulum impact testing machine, in accordance with ISO 148-2, and instrumented to determine the force-time or force-displacement curve shall be used.

Comparisons of the total impact energy, W_t, from the instrumentation with the absorbed energy indicated by the machine dial, KV, shall be made.

NOTE 1 The instrumentation and the dial measure similar but different quantities. Differences in the readings are to be expected (see [5] in the bibliography).

NOTE 2 If deviations between the values exceed ± 5 J, the following should be investigated:

a) the friction of the machine;

b) the calibration of the measuring system;

c) the software used.

6.2 Instrumentation and calibration

6.2.1 Traceable measurements

The equipment used for all calibration measurements shall be traceable to national or international standards of measurement.

6.2.2 Force measurement

Force measurement is usually achieved by using two active electric resistance strain gauges attached to the standard striker to form a force transducer. Suitable designs are shown in annex A.

A full bridge circuit is made by two equally stressed (active) strain gauges bonded to opposite sides of the striker and by two compensating (passive) strain gauges, or by substitute resistors. Compensating strain gauges shall not be attached to any part of the testing machine which experiences impact or vibration effects.

NOTE 1 Alternately, any other instrumentation to form a force transducer, which meets the required performance levels, may be used.

The force measuring system (instrumented striker, amplifier, recording system) shall have a response of at least 100 kHz, which corresponds to a rise time, t_r, of no more than 3,5 µs.

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NOTE 2 The dynamic assessment of the force measuring chain can be simplified by measuring the value of the first initial peak. By experience, the dynamics of the measuring chain can be considered satisfactory if a steel V-notch test piece shows an initial peak greater than 8 kN when using an impact velocity between 5 m/s and 5,5 m/s. This is valid if the centres of the active strain gauges are 11 mm to 15 mm away from the striker contact point.

The instrumentation of the striker should be arranged to give the required nominal force range. The instrumented striker shall be designed to minimize its sensitivity to non-symmetric loading.

NOTE 3 Experience shows that with the V-notch test piece, nominal impact forces between 10 kN and 40 kN occur for all steel types.

6.2.3 Calibration

Calibration of the recorder and measuring system may, in practice, be performed statically in accordance with the accuracy requirements given below and in 6.2.4.

It is recommended that the force calibration be performed with the striker built into the hammer assembly.

Force is applied to the striker via a special load frame equipped with a calibrated load cell and using a special support block in the position of the test piece.

This support block shall have a high stiffness and its relevant parameters shall be in accordance with the Charpy V-notch test piece. The contact conditions shall be approximately equal to those of the test and give reproducible results.

NOTE 1 An example of the support block for the calibration of a 2 mm striker is given in annex B.

The static linearity and hysteresis error of the built-in, instrumented striker, including all parts of the measurement system up to the recording apparatus (printer, plotter, etc.), shall be within ± 2 % of the recorded force, between 50 % and 100 % of the nominal force range, and within ± 1 % of the full scale force value between 10 % and 50 % of the nominal force range (see Figure 1).

NOTE 2 For the instrumented striker alone, it is recommended that the accuracy be ± 1 % of the recorded value between 10 % and 100 % of the nominal range.

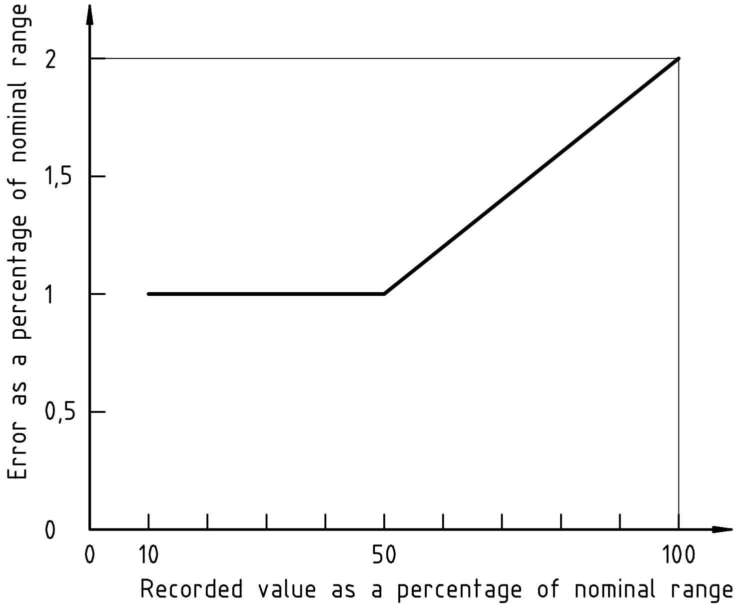

Figure 1 — Permissible errror of recorded values within the nominal force range

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6.2.4 Displacement measurement

Displacement is normally determined from force-time measurement. See clause 9.

Displacement can also be determined by non-contacting measurement of the displacement of the striker, relative to the anvil, using optical, inductive or capacitive methods. The signal transfer characteristics of the displacement measurement system shall correspond to that of the force measuring system in order to make the two recording systems synchronous.

The displacement measuring system shall be designed for nominal values up to 30 mm; linearity errors in the measuring system shall yield measured values to within ± 2 % in the range 1 mm to 30 mm. A dynamic calibration of the displacement system can be achieved by releasing the pendulum without a test piece in place, when the velocity is determined by:

$$v_0 = \sqrt{2g_\mathrm{n}h} \qquad (1)$$

The velocity signal registered when the pendulum passes through the lowest position should correspond to velocity v_0.

It is recommended that displacements between 0 mm and 1 mm be determined from time measurement and the striker impact velocity. In such a case, the following simplified relationship may be used:

$$s = v_0(t - t_0) \qquad (2)$$

The uncertainty of this approximation is less than 2 %, if the corresponding partial impact energy is less than 4 % of the effective potential energy of the striker.

6.2.5 Recording apparatus

Recording of the dynamic signals is preferably achieved by digital storage recorders, with output of the test results to an X-Y printer or plotter. In order to meet the accuracies required in 6.2.3 and 6.2.4 with digital measurement and recording systems, at least an 8 bit analogue-digital converter, with a sampling rate of 250 kHz (4 µs), is necessary; however, 12 bit is recommended. A storage capacity of 2 000 data points is required for each signal over an 8 ms time period, if the recording is to be adequate. For signals less than 8 ms, the required storage capacity may be reduced in proportion.

When values are determined from force-displacement graphs, sufficient precision is achieved by producing graphs at least 100 mm high by 100 mm wide.

6.2.6 Calibration interval

It is recommended that calibration of the instrumentation be performed at intervals not exceeding 12 months, or whenever the pendulum impact machine or instrumentation has undergone dismantling, moving, repair or adjustment. In the case of striker replacement, it is recommended that a calibration be performed, unless it can be demonstrated that it is not necessary.

7 Test Piece

The test piece is a Charpy V-notch test piece, which shall be in accordance with ISO 148-1.

8 Test procedure

Perform the Charpy V-notch pendulum impact test, in accordance with ISO 148-1. In addition, determine and evaluate the force-displacement curve with respect to the characteristic phases of the deformation and fracture stages.

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9 Expression of results

9.1 General

If the displacement is not directly measured, calculate the force-displacement curve as follows. The force-time relationship measured on the striker is proportional to the acceleration characteristic. Given an assumed rigid pendulum of effective mass m, the initial impact velocity v_0, and the time t following the beginning of the deformation at t_0, the test piece bending displacement is calculated by double numerical integration:

$$v(t) = v_0 - \frac{1}{m}\int_{t_0}^{t} F(t)\mathrm{d}t \tag{3}$$

$$s(t) = \int_{t_0}^{t} v(t)\mathrm{d}t \tag{4}$$

9.2 Evaluation of the force-displacement curve

Characteristic force-displacement curves of various types are given in Figure 2, in order to simplify evaluation and reporting. These can be arranged in an approximate order in relation to the impact energy curve;

— Type A and B	Lower shelf
— Type C, D, and E	Transition
— Type F	Upper shelf

With force-displacement curves of Type A, only unstable crack propagation occurs. For Types B, C, D and E, various amounts of stable and unstable crack propagation can occur. With Type F curves, only stable crack propagation occurs.

Determine the type of force-displacement curve by comparison with the schematic representations given in Figure 2. A condition for further evaluation of the force-displacement curve is the occurrence of a clear yield force, F_{gy}. Force-displacement curves of Type A and B cannot be evaluated.

In the following sections, the evaluation of the force-displacement curve is explained. It should be noted that vibrations are superimposed on the force-displacement signal, which arise from force interaction between the instrumented striker and the test piece. Generally, a fitted curve through the oscillations, as shown in Figure 3, yield reproducible characteristic values.

9.3 Determination of the characteristic values of force

Determine the general yield force, F_{gy}, as the force at the intersection of the steeply rising part of second peak of the force-displacement curve and the fitted curve through the oscillations of the force-displacement curve following the onset of yield of the entire ligament (Figure 2: force-displacement curves of Types C — F).

Determine the maximum force, F_m, as the maximum value of the fitted curve through the oscillations.

Determine the crack initiation force, F_{iu}, as the force at the intersection of the fitted curve through the oscillations and the steeply dropping part of the force-displacement curve. If the steep drop coincides with the maximum recorded force, then $F_{iu} = F_m$ (force-displacement curves of Types C or D).

Determine the crack arrest force, F_a, as the force at the intersection of the steep drop of the force-displacement curve and the fitted curve through the oscillations of the subsequent part of the force-displacement curve (force-displacement curves of Types D and E). If the unstable crack is not arrested, $F_a = 0$ (force-displacement curve type C).

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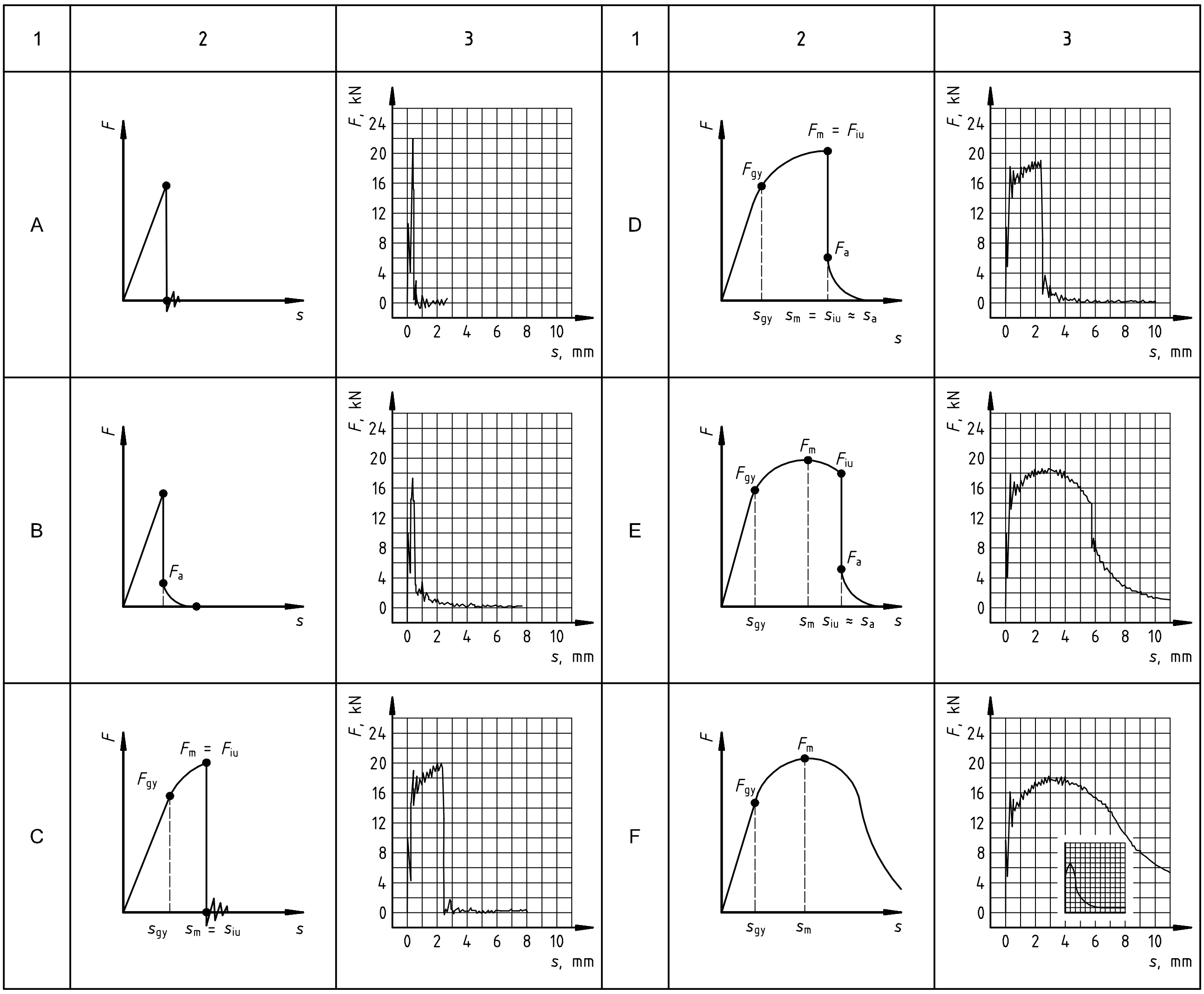
9.4 Determination of the characteristic values of displacement

The characteristic values of displacement given in 3.2 are the abscissa values of the characteristic values of force determined according to 9.3 (see Figures 2 and 3).

NOTE 1 The general yield displacement, s_{gy}, can only be approximately determined using common measuring apparatus. Consequently the specification of s_{gy} is not generally used.

NOTE 2 Due to the steep drop in the force-displacement curve between F_{iu} and F_a, it is generally the case that $s_{iu} \approx s_a$.

The total displacement, s_t, is only determined if the test piece becomes completely fractured during the test and the force-displacement curve up to the fracture of the test piece is available. In such a case, the fitted curve through the oscillations of the force-displacement curve approaches asymptotically the force $F = 0$. The total displacement, s_t, is given as the abscissa value of the fitted curve through the oscillations at $F = 0{,}02\ F_m$.



Key

1 Type

2 Schematic representation

3 Actual recording

Figure 2 — Characteristic force-displacement curves and definition of values of force and displacement

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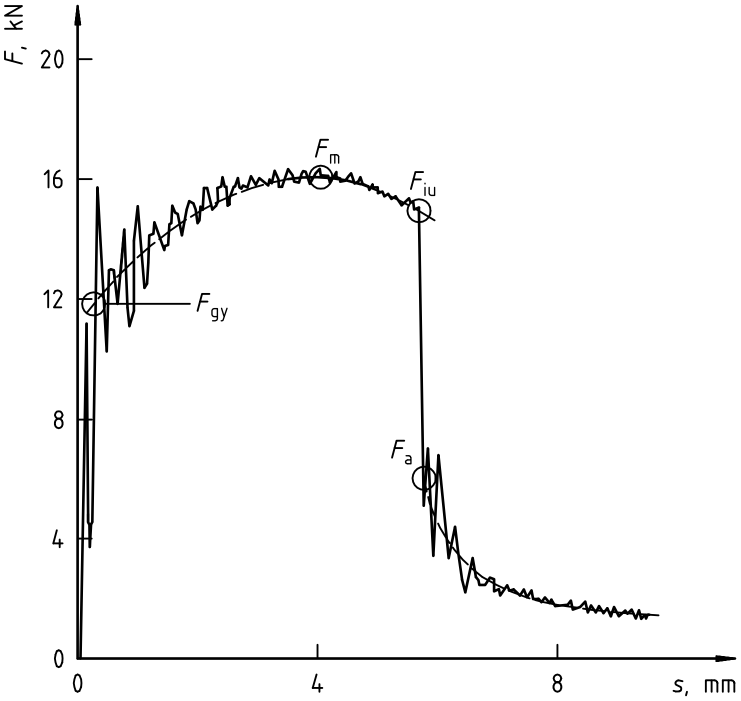

Figure 3 — Determination of the characteristic values of force

9.5 Determination of the characteristic values of impact energy

Determine the energy at maximum force, W_m, by finding the surface area under the force-displacement curve from $s = 0$ to $s = s_m$.

Determine the crack initiation energy, W_{iu}, by finding the surface area under the force-displacement curve from $s = 0$ to $s = s_{iu}$.

Determine the crack arrest energy, $W_{a,}$ by finding the surface area under the force-displacement curve from $s = 0$ to $s = s_a$.

NOTE Due to the steep drop in the force-displacement curve between F_{iu} and F_a, it is generally the case that $W_{iu} \approx W_a$.

Determine the total impact energy, W_t, by finding the surface area under the force-displacement curve from $s = 0$ to $s = s_t$.

9.6 Determination of the proportion of ductile fracture surface

If, in the course of the force-displacement or force-time curve, there is no steep drop of force occurring (curves of type F in Figure 2), it may indicate that the ductile proportion of the fracture surface amounts to 100 % of the total fracture surface. If a steep drop of force occurs, the amount of the drop, in relation to other characteristic force values, allows an approximate value of the proportion of ductile fracture surface to be obtained by using formulae such as those given in annex C.

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10 Test Report

The test report shall include the following information:

a) reference to this International Standard, i.e., ISO 14556;

b) dimensions of the test piece;

c) identification of the test piece (grade, cast No.);

d) direction and location of sampling;

e) the radius of the striker;

f) identification and nominal energy of testing machine;

g) test temperature in degrees Celsius;

h) effective energy absorbed, KV, according to ISO 148-1, in joules. If a test piece is removed from the machine without it being fractured, the test result shall be bracketed and the test piece should be described as “not fully broken”;

i) type of force-displacement curve according to 9.2. If the force-displacement curve cannot be assigned as one of the Types A to F given in Figure 2, the test report shall include an illustration of the curve;

j) the characteristic values of force, displacement, and impact energy determined in accordance with 9.3, 9.4 and 9.5 in so far as the force-displacement curve can be evaluated;

k) if required, the estimated value of the proportion of ductile fracture on the fracture surface, with an indication of the formula used.

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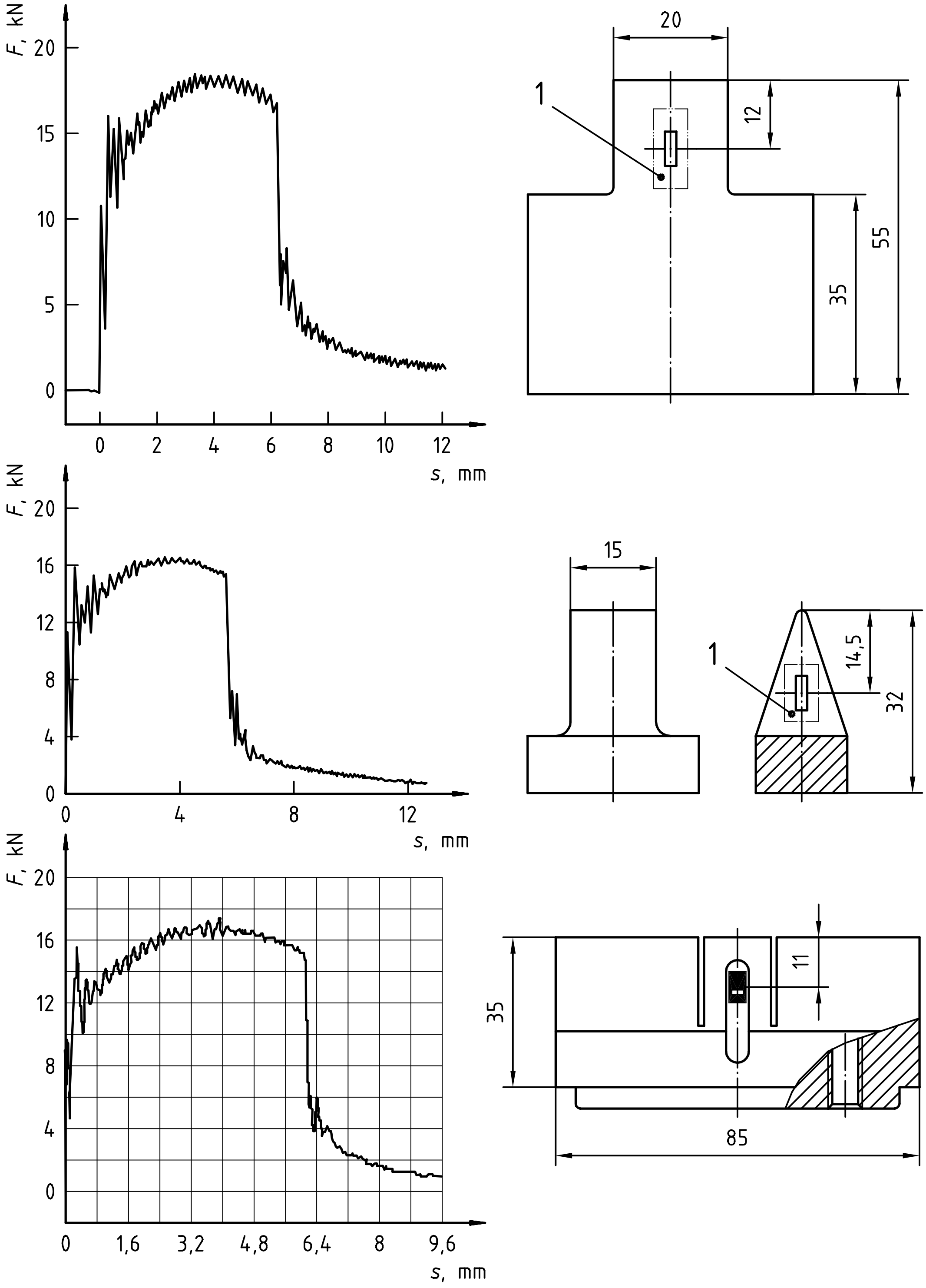
Annex A
(informative)

Designs of instrumented strikers and associated force-displacement curves

Dimensions in millimetres



Key

1 Strain gauge

Figure A.1

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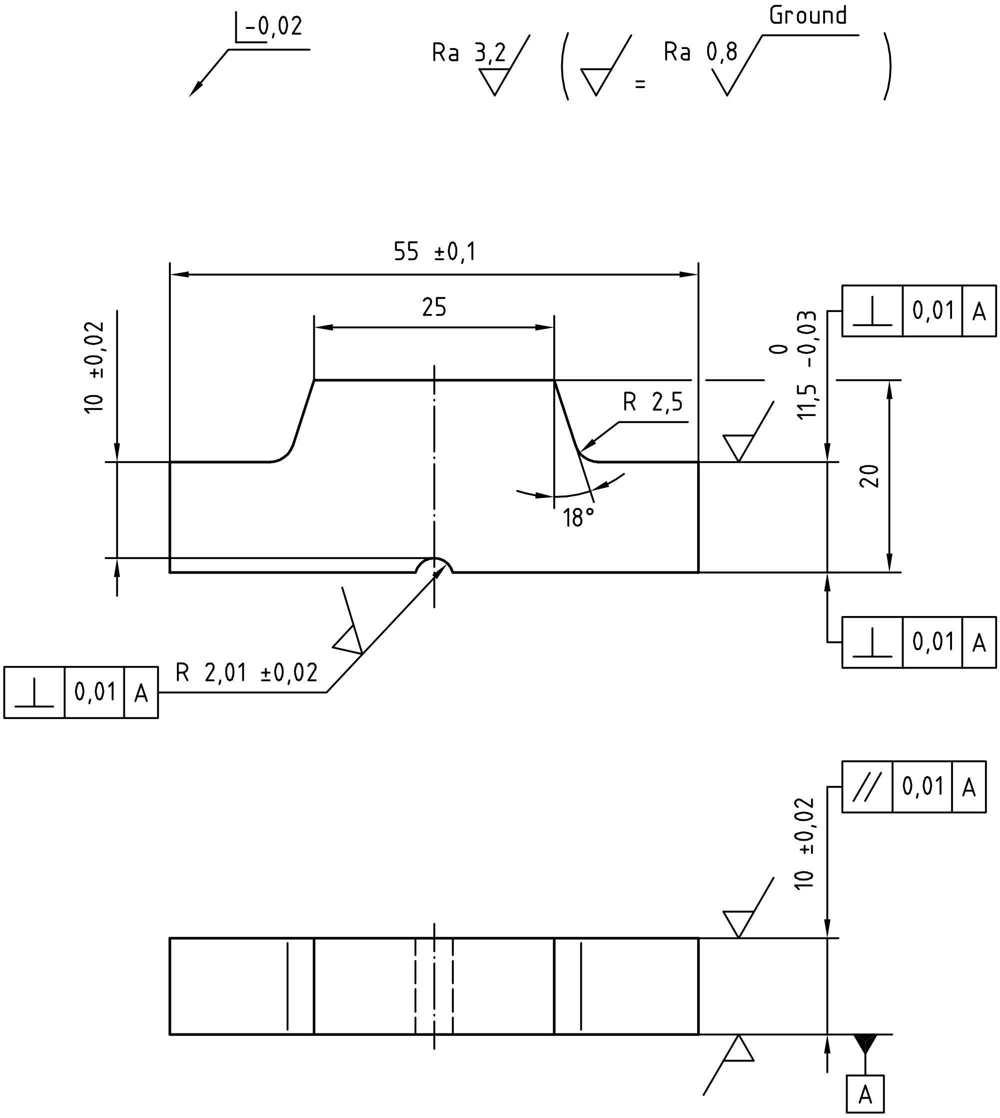
Annex B
(informative)

Example of support block for the calibration of a 2 mm striker

Dimension in millimetres
Surface roughness in micrometres



NOTE Minimum level of hardness = 56 HRC

Figure B.1

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Annex C
(informative)

Formulae for the calculation of the proportion of ductile fracture surface

The following formulae are used to find approximate values (of the order of 20 %) for the proportion of ductile fracture surface.

$$\text{Proportion of ductile fracture surface} = \left[1 - \frac{F_{\text{iu}} - F_{\text{a}}}{F_{\text{m}}}\right] \times 100\ \% \tag{C.1}$$

$$\text{Proportion of ductile fracture surface} = \left[1 - \frac{F_{\text{iu}} - F_{\text{a}}}{F_{\text{m}} + \left(F_{\text{m}} - F_{\text{gy}}\right)}\right] \times 100\ \% \tag{C.2}$$

$$\text{Proportion of ductile fracture surface} = \left[1 - \frac{F_{\text{iu}} - F_{\text{a}}}{F_{\text{m}} + K\left(F_{\text{m}} - F_{\text{gy}}\right)}\right] \times 100\ \% \tag{C.3}$$

where

$K \approx 1/2$

$$\text{Proportion of ductile fracture surface} = \left[1 - \sqrt{\frac{\left(\frac{F_{\text{gy}}}{F_{\text{m}}} + 2\right)}{3}} \times \left(\frac{\sqrt{F_{\text{iu}}}}{\sqrt{F_{\text{m}}}} - \frac{\sqrt{F_{\text{a}}}}{\sqrt{F_{\text{m}}}}\right)\right] \times 100\ \% \tag{C.4}$$

NOTE These formulae have been developed by different laboratories and for different steels with differing ranges of ductilities (see [5] in the Bibliography). The choice of the formula to be used should be based on previous experience. As an example, formula C.3 is appropriate for some pressure vessel steels.

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