INTERNATIONAL STANDARD

ISO 14556

Third edition
2023-05

Metallic materials — Charpy V-notch pendulum impact test — Instrumented test method

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

Reference number
ISO 14556:2023(E)

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Fatigue, fracture and toughness testing*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 459/SC 1, *Test methods for steel (other than chemical analysis)*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 14556:2015), which has been technically revised.

The main changes are as follows:

- in Clause 1, a sentence was added to state that results shall not be directly used in design calculations;
- in Clause 4, the symbol K_p (potential energy of the pendulum hammer) was added; the symbol *KV* (absorbed energy) was changed to K_V;
- in 6.1 and D.2.1, the application of the "dynamic force adjustment" was added;
- in 6.2.3, a generic statement about the stiffness of the support block was removed;
- in 6.2.5, the possibility of directly determining characteristic values from printed graphs was removed;
- in Clauses 7 and 8, statements referring to Annex D when testing miniature test pieces were added;
- in 9.2, the characteristic values of force that can be evaluated from curves of Type A and B were changed;
- in 9.3, it is now specified that F_m is determined after general yield;
- in Figure 2, force-displacement curves in columns 3 (actual recording) were replaced with better-quality ones;

— in Clause 10, a requirement to report the type of test piece (standard, subsize, or miniature) was added;

— in Annex A, it was clarified that those shown are examples of instrumented strikers;

— in Annex D, alternative miniature test pieces were removed;

— in D.2.1, the deviation range between W_t and K_V was changed from ±0,5 J to ±10 % of K_V;

— in D.3.1, dimensions for the standard miniature test piece were added; test temperature requirements were removed; the test report section was removed;

— in the Bibliography, a new reference, [8], was added.

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.

Metallic materials — Charpy V-notch pendulum impact test — Instrumented test method

1 Scope

This document specifies a method of instrumented Charpy V-notch pendulum impact testing on metallic materials and the requirements concerning the measurement and recording equipment.

With respect to the Charpy pendulum impact test described in ISO 148-1, this test provides further information on the fracture behaviour of the product under impact testing conditions.

The results of instrumented Charpy test analyses are not directly transferable to structures or components and shall not be directly used in design calculations or safety assessments.

NOTE General information about instrumented impact testing can be found in References [1] to [5].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 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 testing machines*

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 Characteristic values of force (see Figure 2)

3.1.1
general yield force
F_{gy}
force at the transition point from the linearly increasing part, discarding inertia peak(s), to the curved increasing part of the force-displacement curve

Note 1 to entry: It represents an approximation of the force at which yielding occurs across the entire test piece ligament (see 9.3).

3.1.2
maximum force
F_m
maximum force in the course of the force-displacement curve

3.1.3
unstable crack initiation force
F_{iu}
force at the beginning of a steep drop in the force-displacement curve (unstable crack initiation)

3.1.4
crack arrest force
F_a
force at the end (arrest) of unstable crack propagation

3.2 Characteristic values of displacement (see Figure 2)

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
displacement at unstable crack initiation
s_{iu}
displacement corresponding to the force at unstable crack initiation, F_{iu}

3.2.4
crack arrest displacement
s_a
displacement corresponding to the force at the end (arrest) of unstable crack propagation, F_a

3.2.5
total displacement
s_t
displacement at the end of the force-displacement curve

3.3 Characteristic values of impact energy

3.3.1
energy at maximum force
W_m
partial impact energy from $s = 0$ to $s = s_m$

Note 1 to entry: Calculated as the area under the force-displacement curve from $s = 0$ to $s = s_m$.

3.3.2
energy at unstable crack initiation
W_{iu}
partial impact energy from $s = 0$ to $s = s_{iu}$

Note 1 to entry: Calculated as the area under the force-displacement curve from $s = 0$ to $s = s_{iu}$.

3.3.3
crack arrest energy
W_a
partial impact energy from $s = 0$ to $s = s_a$

Note 1 to entry: Calculated as the area under the force-displacement curve from $s = 0$ to $s = s_a$.

3.3.4
total impact energy
W_t
energy absorbed by the test piece during the test

Note 1 to entry: Calculated as the area under the force-displacement curve from $s = 0$ to $s = s_t$.

4 Symbols and abbreviated terms

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}	Unstable crack initiation force	N
F_m	Maximum force	N
g	Local acceleration due to gravity	m/s^2
h	Height of fall of the centre of strike of the pendulum (see ISO 148-2)	m
K_p	Initial potential energy (potential energy), as specified in ISO 148-1	J
K_V	Absorbed energy for a V-notch test piece, as specified in ISO 148-1	J
m	Effective mass of the pendulum corresponding to its effective weight	kg
s	Displacement	m
s_a	Crack arrest displacement	m
s_{gy}	General yield displacement	m
s_{iu}	Displacement at unstable crack initiation	m
s_m	Displacement at maximum force	m
s_t	Total displacement	m
$s(t)$	Displacement of the test piece at time t	m
t	Time	s
t_o	Time at the beginning of deformation of the test piece	s
t_r	Signal rise time	s
v_0	Initial striker impact velocity	m/s
$v(t)$	Striker impact velocity at time t	m/s
W_a	Crack arrest energy	J
W_{iu}	Energy at unstable crack initiation	J
W_m	Energy at maximum force	J
W_t	Total impact energy	J

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 is a measure of 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 can be deduced which provide considerable information about the behaviour of the test piece at impact loading rates.

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 between the total impact energy, W_t, from the instrumentation (see 9.5) and the absorbed energy indicated by the machine dial or encoder, K_V, shall be made.

NOTE The instrumentation and the machine dial or encoder measure similar but different quantities. Differences are to be expected (see Reference [6]).

If deviations between K_V and W_t exceed the larger between 10 % of K_V or 2 J, the following should be checked:

a) friction of the machine;

b) calibration of the measuring system;

c) software used;

d) the possibility of applying the so-called “dynamic force adjustment”, see Reference [7], whereby forces are adjusted until W_t and K_V become equal.

6.2 Instrumentation and calibration

6.2.1 Traceable measurement

The equipment used for all calibration measurements shall be metrologically 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. Examples of 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 Alternatively, any other instrumentation to form a force transducer, which meets the required performance levels, can 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.

A simple dynamic assessment of the force measuring chain can be performed by measuring the value of the first inertia 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 shall be adequate to give the required nominal force range. The instrumented striker shall be designed to minimize its sensitivity to non-symmetric loading.

NOTE 2 Experience shows that with the V-notch test piece, nominal impact forces up to 40 kN can occur for most steel types.

6.2.3 Calibration

Calibration of the recorder and measuring system may 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.

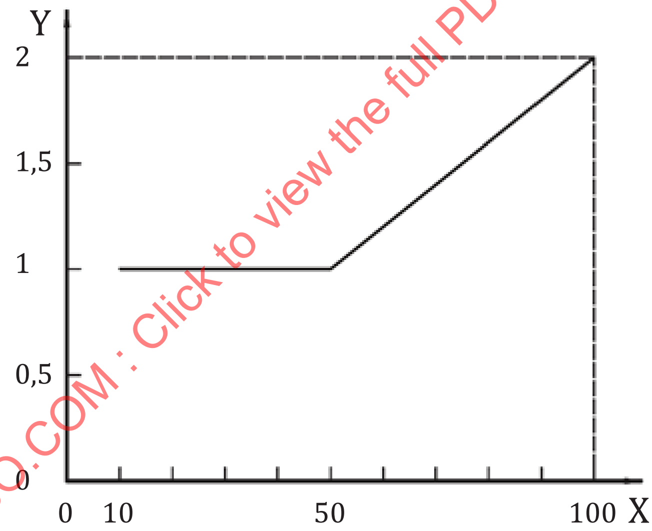
Force is applied to the striker through a special load frame equipped with a calibrated load cell and using a special support block in the position of the test piece.

The contact conditions shall be approximately equal to those of the test and give reproducible results.

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

The static linearity 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).

For the instrumented striker and the measuring system alone (without hammer assembly), it is recommended that the accuracy be ±1 % of the recorded value between 10 % and 100 % of the nominal range.



Key

X recorded value as percentage of nominal range

Y absolute error as percentage of nominal range

Figure 1 — Maximum permissible error of recorded values within the nominal force range

6.2.4 Displacement measurement

Displacement is normally determined from force-time measurements. 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 Formula (1):

$$v_0 = \sqrt{2gh} \tag{1}$$

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

It is recommended that displacements between 0 mm and 1 mm be determined from time measurements and the striker impact velocity, using double numerical integration as described in 9.1.

6.2.5 Recording apparatus

Recording of the dynamic signals is preferably achieved by digital storage recorders. 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 required; however, 12 bit and 1 MHz are recommended. A minimum 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; however, 8 000 data points are recommended. For signals less than 8 ms, the required storage capacity may be reduced in proportion.

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 with a previously calibrated striker, 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, in accordance with ISO 148-1. Miniature test pieces can also be tested in accordance with Annex D.

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 various characteristic deformation and fracture stages. For miniature test pieces, the additional provisions of Annex D shall apply.

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, $s(t)$, is calculated by double numerical integration using Formulae (2) and (3):

$$v(t) = v_0 - \frac{1}{m}\int_{t_0}^{t} F(t)\,\mathrm{d}t \tag{2}$$

$$s(t) = \int_{t_0}^{t} v(t)\,\mathrm{d}t \tag{3}$$

9.2 Evaluation of the force-displacement curve

Characteristic force-displacement curves of various types are shown in Figure 2, in order to simplify evaluation and reporting. These can be classified in the following categories:

— Type A and B (lower shelf);

— Type C, D, and E (ductile-to-brittle 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 (column 2). With force-displacement curves of Type A, no characteristics values of force can be evaluated. With curves of Type B, only F_a can 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, yields reliable characteristic values.

9.3 Determination of the characteristic values of force

Determine the general yield force, F_{gy}, as the force at the intersection between the linear elastic part of the force-displacement curve, discarding the initial inertia peak(s), 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 Type C to Type F).

Determine the maximum force, F_m, as the maximum value of the fitted curve through the oscillations, after the occurrence of general yield.

Determine the unstable crack initiation force, F_{iu}, as the force at the intersection between the fitted curve through the oscillations, after the occurrence of general yield, 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 Type C or Type D).

Determine the crack arrest force, F_a, as the force at the intersection between 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 Type B, Type D, or Type E).

9.4 Determination of the characteristic values of displacement

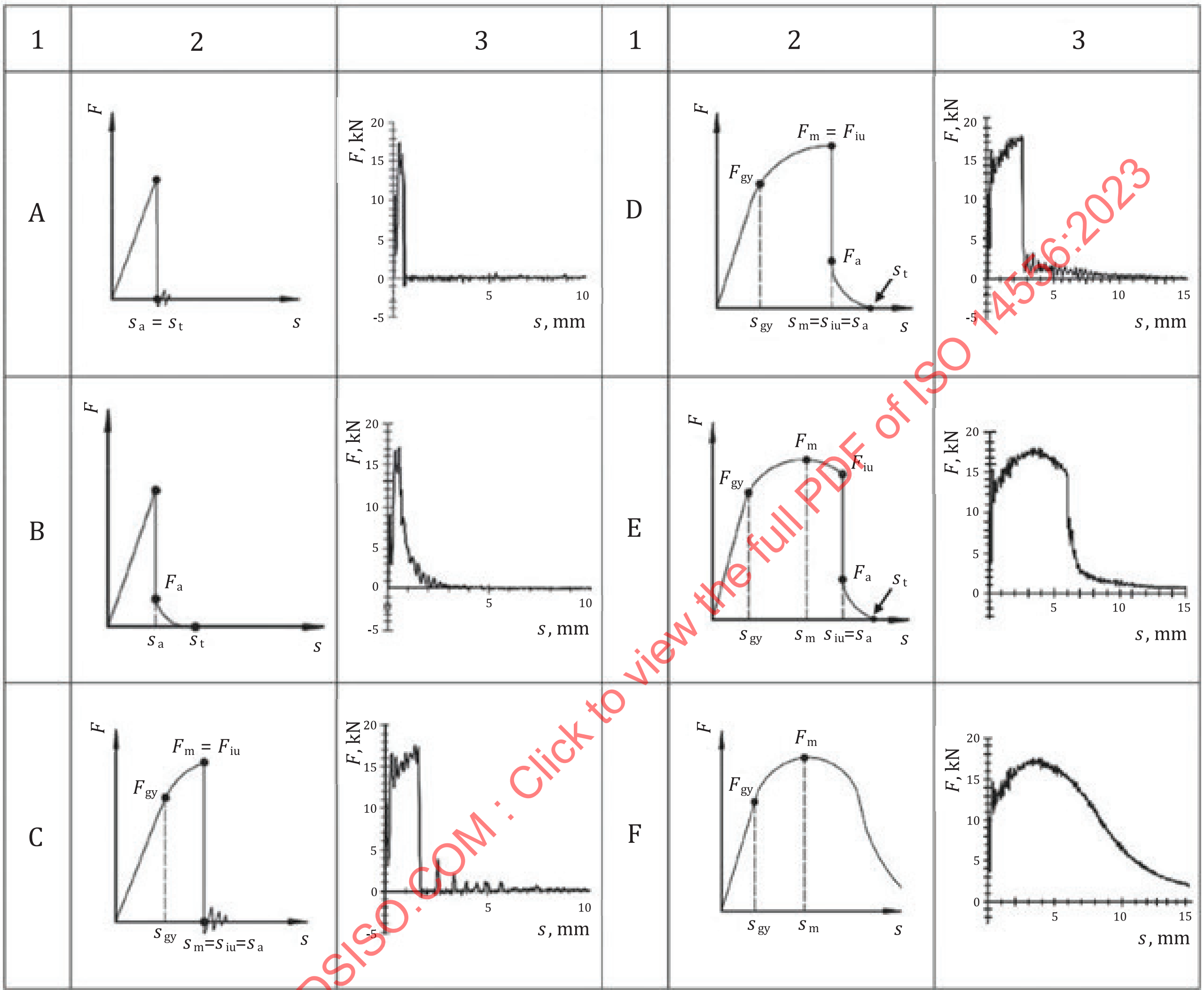
The characteristic values of displacement given in 3.2 are the abscissa values of the characteristic values of force determined according to 9.3 (see Figure 2).

NOTE 1 The general yield displacement, s_{gy}, can only be approximately determined using common measuring apparatus. Consequently, 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 corresponding to $F = 0$.

NOTE 3 If the force does not return to the baseline (*i.e.*, $F = 0$) within the testing time selected but approaches asymptotically a value $F > 0$, the total displacement, s_t, can be identified as the abscissa value of the fitted curve through the oscillations corresponding to $F = 0{,}02\ F_m$.



Key

1 type of force-displacement curve (see 9.2)

2 schematic representation

3 actual recording

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

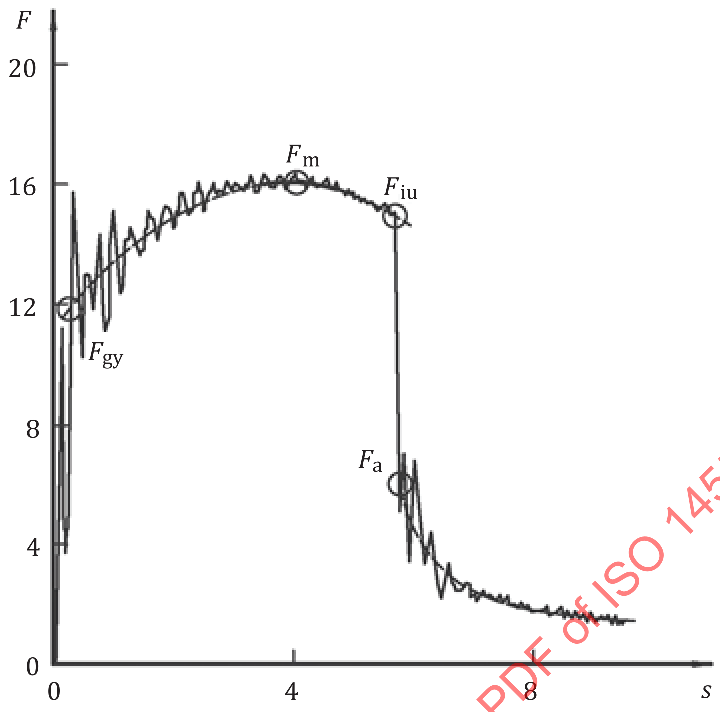


Figure 3 — Determination of the characteristic values of force

9.5 Determination of the characteristic values of impact energy

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

Determine the unstable crack initiation energy, W_{iu}, by integrating the force-displacement curve from $s = 0$ to $s = s_{iu}$.

Determine the crack arrest energy, W_a, by integrating 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 integrating the force-displacement curve from $s = 0$ to $s = s_t$.

10 Test report

The test report shall include the following information:

a) a reference to this document, i.e. ISO 14556 (including its year of publication) and any deviations from its procedures;

b) type of test piece (standard, subsize, or miniature). If subsize test pieces have been used, the thickness of the test piece shall be reported. If miniature test pieces have been used, the cross-section dimensions (width and thickness) of the test piece shall be reported;

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

d) direction and location of sampling;

e) striker geometry (2 mm striker or 8 mm striker, see ISO 148-1);

f) identification and nominal energy of testing machine;

g) test temperature, in °C;

h) effective energy absorbed, K_{V2} or K_{V8}, according to ISO 148-1, in J. If a test piece is removed from the machine without 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 (A to F) according to 9.2 and an illustration of the force-time and/or force-displacement curve;

j) the characteristic values of force, displacement, and impact energy determined in accordance with 9.3, 9.4, and 9.5;

k) if required, the estimated value of the proportion of ductile fracture surface, with an indication of the formula used (see Annex C);

l) any unusual features observed;

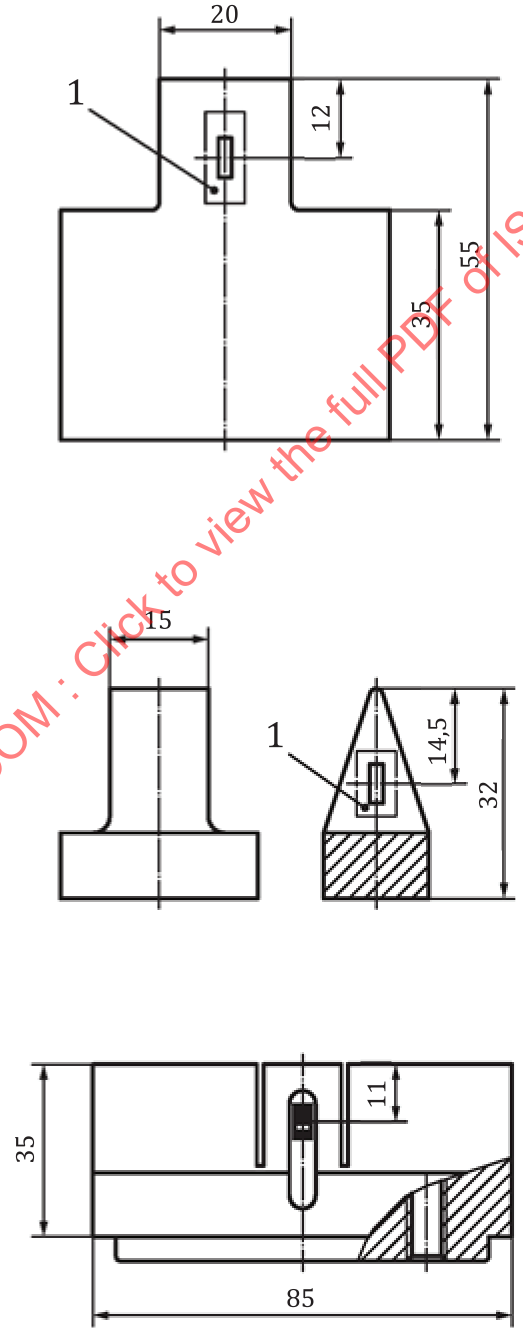
m) the date(s) of the test(s).

Annex A
(informative)

Examples of instrumented strikers

See Figure A.1 for examples of designs of instrumented strikers.

Dimensions in millimetres



Key

1 strain gauge

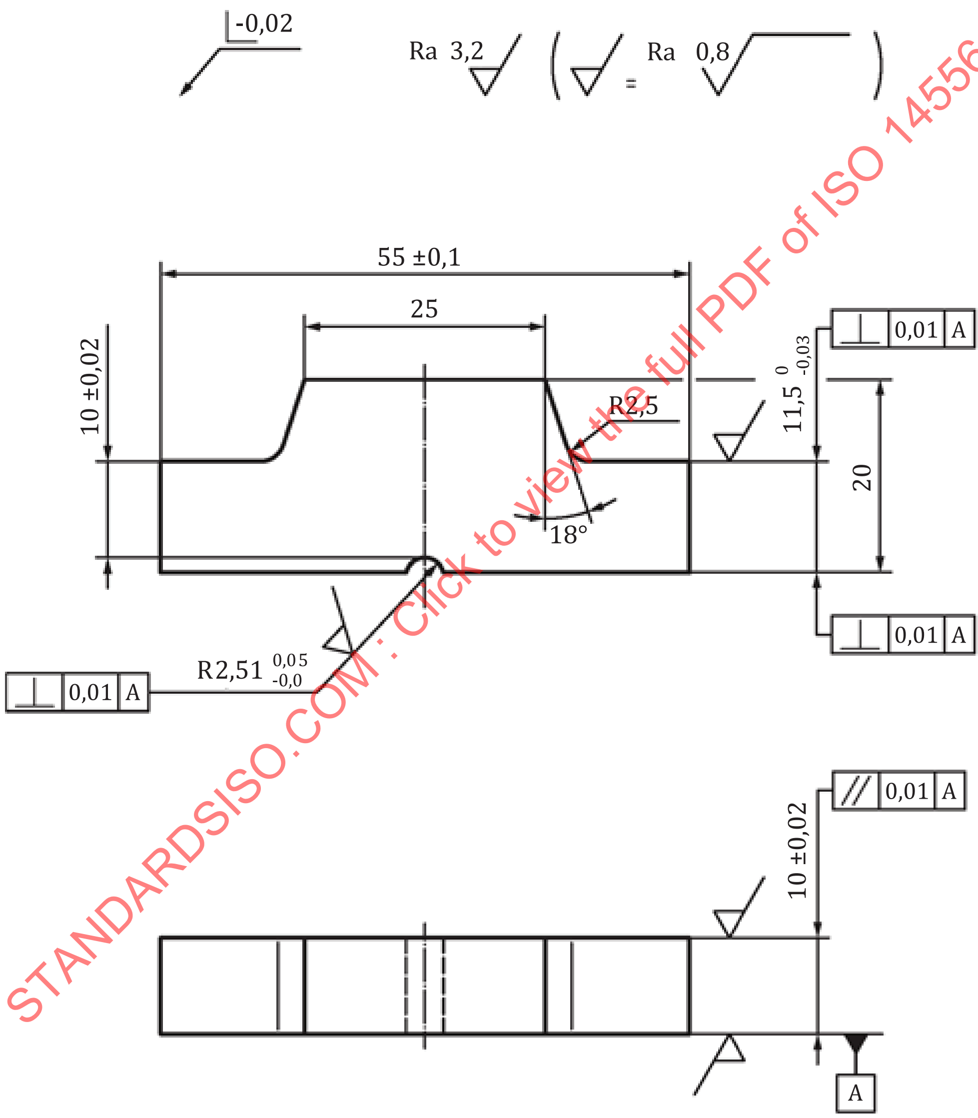
Figure A.1 — Examples of designs of instrumented strikers

Annex B
(informative)

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

See Figure B.1 for an example of support block for the calibration of a 2 mm striker.

Dimensions in millimetres
Surface roughness in micrometres



NOTE Minimum level of hardness = 56 HRC.

Figure B.1 — Example of support block for the calibration of a 2 mm striker

Annex C
(informative)

Formulae for the estimation 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 can 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 magnitude 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 any of the following formulae, which allow estimating the proportion of ductile fracture surface within ±20 %.

$$\text{Proportion of ductile fracture surface} = \left[1 - \frac{F_{iu} - F_a}{F_m}\right] \times 100\,\% \qquad \text{(C.1)}$$

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

$$\text{Proportion of ductile fracture surface} = \left[1 - \frac{F_{iu} - F_a}{F_m + 0{,}5\left(F_m - F_{gy}\right)}\right] \times 100\,\% \qquad \text{(C.3)}$$

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

Formulae (C.1) to (C.4) have been developed by different laboratories and for different steels (see Reference [5]). The choice of the formula to be used should be based on previous experience. As an example, Formula (C.3) is appropriate for pressure vessel steels.

Annex D
(normative)

Instrumented Charpy V-notch pendulum impact testing of miniature test pieces

D.1 General

This annex describes the specific aspects concerning instrumented impact testing of miniature test pieces of steel products and the requirements concerning the measurement and recording equipment.

The provisions of this Annex can be applied, by agreement, to other metallic materials and to other impact testing machines, such as drop-weight towers or high-speed servo-hydraulic machines.

This instrumented test provides further information on the fracture behaviour of the tested product at impact loading rates.

The user should be aware that data obtained from miniature test pieces may not be directly comparable to those obtained from full-size standard Charpy V-notch test pieces and that suitable correlation procedures have to be employed.

D.2 Apparatus

D.2.1 Testing machine

If the test machine has a potential energy not greater than 50 J, the quality of the instrumentation can be assessed by comparing the total impact energy, W_t, from the instrumentation with the absorbed energy indicated by the machine dial, K_V. If deviations between the values exceed ±10 % of K_V, the following should be investigated:

a) friction of the machine;

b) calibration of the measuring system;

c) software used;

d) the possibility of applying the so-called "dynamic force adjustment", see Reference [7], whereby forces are adjusted until W_t and K_V become equal.

D.2.2 Force measuring system

Due to the more dynamic behaviour of miniature with respect to full-size test pieces, the force measuring system (transducer, amplifier, and recording system) shall have an upper frequency of at least 250 kHz. If only the absorbed energy is to be measured from the curve, an upper frequency limit of 100 kHz is sufficient.

NOTE 1 A simple dynamic assessment of the force measuring chain can be obtained by measuring the maximum force value of the first initial peak. By experience, the dynamics of the measurement chain can be considered satisfactory if a steel V-notch miniature test piece shows an initial peak greater than (0,23 × v_o) kN.

NOTE 2 Experience shows that with the miniature test piece shown in Figure D.1, nominal impact forces up to 4 kN can occur for most steel types.

