INTERNATIONAL STANDARD

ISO 148-1

Second edition
2009-11-15

Metallic materials — Charpy pendulum impact test —

Part 1: **Test method**

Matériaux métalliques — Essai de flexion par choc sur éprouvette Charpy —

Partie 1: Méthode d'essai

Reference number
ISO 148-1:2009(E)

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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 2.

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 148-1 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing — Fracture (F), Pendulum (P), Tear (T)*.

This second edition cancels and replaces the first edition (ISO 148-1:2006), which has been technically revised.

ISO 148 consists of the following parts, under the general title *Metallic materials — Charpy pendulum impact test*:

— *Part 1: Test method*

— *Part 2: Verification of testing machines*

— *Part 3: Preparation and characterization of Charpy V-notch test pieces for indirect verification of pendulum impact machines*

Annexes B and C are based on ASTM E23 (*Standard Test Methods for Notched Bar Impact Testing of Metallic Materials)*, copyright ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, USA.

Metallic materials — Charpy pendulum impact test —

Part 1:
Test method

1 Scope

This part of ISO 148 specifies the Charpy pendulum impact (V-notch and U-notch) test method for determining the energy absorbed in an impact test of metallic materials.

This part of ISO 148 does not apply to instrumented impact testing, which is specified in ISO 14556.

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 148-2:2008, *Metallic materials — Charpy pendulum impact test — Part 2: Verification of testing machines*

ISO 286-1, *Geometrical product specifications (GPS) — ISO code system for tolerances of linear sizes — Part 1: Basis of tolerances, deviations and fits*

3 Terms and definitions

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

3.1 Energy

3.1.1
initial potential energy
potential energy
K_p
difference between the potential energy of the pendulum hammer prior to its release for the impact test, and the potential energy of the pendulum hammer at the position of impact, as determined by direct verification

[ISO 148-2:2008, definition 3.2.2]

3.1.2
absorbed energy
K
energy required to break a test piece with a pendulum impact testing machine, after correction for friction

NOTE The letter V or U is used to indicate the notch geometry, that is: KV or KU. The number 2 or 8 is used as a subscript to indicate striker radius, for example KV_2.

3.2 Test piece

With the test piece placed in the test position on the supports of the machine, the following nomenclature shall apply (see Figure 1).

3.2.1
height
h
distance between the notched face and the opposite face

3.2.2
width
w
dimension perpendicular to the height that is parallel to the notch

3.2.3
length
l
the largest dimension at right angles to the notch

4 Symbols and abbreviated terms

The symbols and designations applicable to this part of ISO 148 are indicated in Tables 1 and 2, and are illustrated in Figure 2.

Table 1 — Symbols and their unit and designation

Symbol	Unit	Designation
K_p	J	Initial potential energy (potential energy)
FA	%	Shear-fracture appearance
h	mm	Height of test piece
KU_2	J	Absorbed energy for a U-notch test piece using a 2 mm striker
KU_8	J	Absorbed energy for a U-notch test piece using an 8 mm striker
KV_2	J	Absorbed energy for a V-notch test piece using a 2 mm striker
KV_8	J	Absorbed energy for a V-notch test piece using a 8 mm striker
LE	mm	Lateral expansion
l	mm	Length of test piece
T_t	°C	Transition temperature
w	mm	Width of test piece

5 Principle

This test consists of breaking a notched test piece with a single blow from a swinging pendulum, under the conditions defined in Clauses 6, 7 and 8. The notch in the test piece has specified geometry and is located in the middle between two supports, opposite to the location which is struck in the test. The energy absorbed in the impact test is determined.

Because the impact values of many metallic materials vary with temperature, tests shall be carried out at a specified temperature. When this temperature is other than ambient, the test piece shall be heated or cooled to that temperature, under controlled conditions.

6 Test pieces

6.1 General

The standard test piece shall be 55 mm long and of square section, with 10 mm sides. In the centre of the length, there shall be either a V-notch or a U-notch, as described in 6.2.1 and 6.2.2, respectively.

If the standard test piece cannot be obtained from the material, one of the subsidiary test pieces, having a width of 7,5 mm, 5 mm or 2,5 mm (see Figure 2 and Table 2), shall be used.

NOTE For low energies, the use of shims is important, as excess energy is absorbed by the pendulum. For high energies, this might not be important. Shims can be placed on or under the test piece supports, with the result that the mid-height of the specimen is 5 mm above the 10 mm specimen-support surface.

The test pieces shall have a surface roughness of better than Ra 5 µm except for the ends.

When a heat-treated material is being evaluated, the test piece shall be finish-machined, including notching, after the final heat treatment, unless it can be demonstrated that there is no difference when machined prior to heat treatment.

6.2 Notch geometry

The notch shall be carefully prepared so that the root radius of the notch is free of machining marks which could affect the absorbed energy.

The plane of symmetry of the notch shall be perpendicular to the longitudinal axis of the test piece (see Figure 2).

6.2.1 V-notch

The V-notch shall have an included angle of 45°, a depth of 2 mm, and a root radius of 0,25 mm [see Figure 2 a) and Table 2].

6.2.2 U-notch

The U-notch shall have a depth of 5 mm (unless otherwise specified) and a root radius of 1 mm [see Figure 2 b) and Table 2].

6.3 Tolerance of the test pieces

The tolerances on the specified test piece and notch dimensions are shown in Figure 2 and Table 2.

6.4 Preparation of the test pieces

Preparation shall be carried out in such a way that any alteration of the test piece, for example due to heating or cold working, is minimized.

6.5 Marking of the test pieces

The test piece may be marked on any face not in contact with supports, anvils or striker and at a position which avoids the effects of plastic deformation and surface discontinuities on the absorbed energy measured in the test (see 8.7).

7 Test equipment

7.1 General

The equipment used for all measurements shall be traceable to national or International Standards. They shall be calibrated within suitable intervals.

7.2 Installation and verification

The testing machine shall be installed and verified in accordance with ISO 148-2.

7.3 Striker

The striker geometry shall be specified as being either the 2 mm striker or the 8 mm striker. It is recommended that the striker radius be shown as a subscript as follows: KV_2 or KV_8.

Reference shall be made to the product specification for striker geometry guidance.

NOTE Some materials can yield significantly varying results (per cent difference) at low energy levels and the 2 mm results can be higher than the 8 mm results.

8 Test procedure

8.1 General

The test piece shall lie squarely against the anvils of the testing machine, with the plane of symmetry of the notch within 0,5 mm of the midplane between the anvils. It shall be struck by the striker in the plane of symmetry of the notch and on the side opposite the notch (see Figure 1).

8.2 Test temperature

8.2.1 Unless otherwise specified, tests shall be carried out at (23 ± 5) °C. If a temperature is specified, the test piece shall be conditioned to that temperature to within ± 2 °C.

8.2.2 For conditioning, either heating or cooling, using a liquid medium, the test piece shall be positioned in a container on a grid that is at least 25 mm above the bottom of the container and covered by at least 25 mm of liquid and be at least 10 mm from the sides of the container. The medium shall be constantly agitated and brought to the specified temperature by any convenient method. The device used to measure the temperature of the medium should be placed in the centre of the group of test pieces. The temperature of the medium shall be held at the specified temperature to within ± 1 °C for at least 5 min.

NOTE When a liquid medium is near its boiling point, evaporative cooling can dramatically lower the temperature of the test piece during the interval between removal from the liquid and fracture (see ASTM STP 1072 [5]).

8.2.3 For conditioning, either heating or cooling, using a gaseous medium, the test piece shall be positioned in a chamber at least 50 mm from the nearest surface. Individual test pieces shall be separated by at least 10 mm. The medium shall be constantly circulated and brought to the specified temperature by any convenient method. The device used to measure the temperature of the medium should be placed in the centre of the group of test pieces. The temperature of the gaseous medium shall be held at the specified temperature within ± 1 °C for at least 30 min.

8.3 Specimen transfer

When testing is performed at other than ambient temperature, not more than 5 s shall pass between the time the test piece is removed from the heating or cooling medium and the time it is struck by the striker.

The transfer device shall be designed and used in such a way that the temperature of the test piece is maintained within the permitted temperature range.

The parts of the device in contact with the specimen during transfer from the medium to the machine shall be conditioned with the specimens.

Care should be taken to ensure that the device used to centre the test piece on the anvils does not cause the fractured ends of low-energy, high-strength test pieces to rebound off this device into the pendulum and cause erroneously-high indicated energy. It has been shown that clearance between the end of a test piece in the test position and the centring device, or a fixed portion of the machine, shall be greater than approximately 13 mm or else, as part of the fracture process, the ends can rebound into the pendulum.

NOTE Self-centring tongs, similar to those for V-notched test pieces in Annex A, are often used to transfer the test piece from the temperature-conditioning medium to the proper test position. Tongs of this nature eliminate potential clearance problems due to interference between the fractured specimen halves and a fixed centring device.

8.4 Exceeding machine capacity

The absorbed energy, K, should not exceed 80 % of the initial potential energy, K_p. If the absorbed energy exceeds this value, the absorbed energy shall be reported as approximate and it shall be noted in the test report that it exceeded 80 % of the machine capacity.

NOTE Ideally, an impact test would be conducted at a constant impact velocity. In a pendulum-type test, the velocity decreases as the fracture progresses. For specimens with impact energies approaching the capacity of the pendulum, the velocity of the pendulum decreases during fracture to the point that accurate impact energies are no longer obtained.

8.5 Incomplete fracture

If a test piece is not completely broken in a test, the impact energy may be reported or averaged with the results of the completely broken test pieces.

8.6 Test piece jamming

If any test piece jams in the machine, the results shall be disregarded and the machine thoroughly checked for damage that would affect its calibration.

NOTE Jamming occurs when a broken test piece is caught between moving and non-moving parts of the testing machine. It can result in significant energy absorption. Jamming can be differentiated from secondary strike marks, because a jam is associated with a pair of opposing marks on the specimen.

8.7 Post-fracture inspection

If post-fracture inspection shows that any portion of the marking is in a portion of the test piece which is visibly deformed, the test result might not be representative of the material and this shall be noted in the test report.

9 Test report

9.1 Mandatory information

The test report shall include the following information:

a) a reference to this part of ISO 148, i.e. ISO 148-1:2009;

b) identification of the test piece (e.g. type of steel and cast number);

c) the type of notch;

d) the size of the test piece, if other than full size;

e) the conditioning temperature of the test piece;

f) the absorbed energy, KV_2, KV_8, KU_2 or KU_8, as appropriate;

g) any abnormalities that can affect the test.

9.2 Optional information

The test report may optionally include, in addition to the information in 9.1:

a) the test-piece orientation (see ISO 3785);

b) the nominal energy of the testing machine, in joules;

c) the lateral expansion (see Annex B);

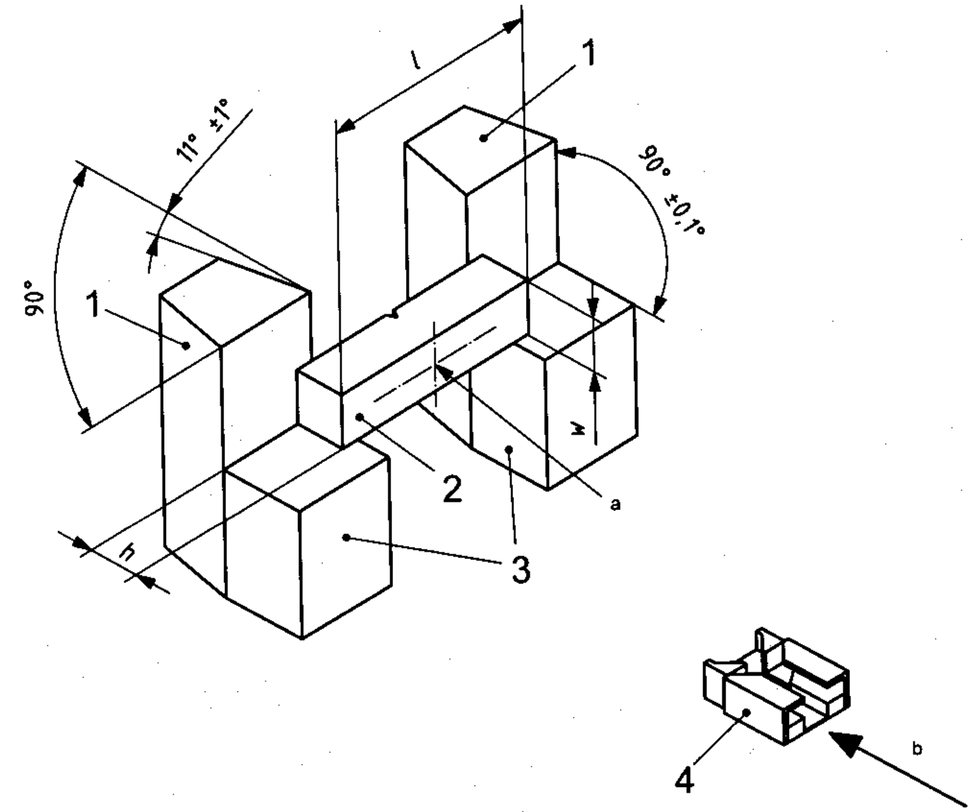
d) the fracture appearance, per cent shear (see Annex C);

e) the absorbed energy/temperature curve (see D.1);

f) the transition temperature and the criteria used (see D.2);

g) the number of test pieces which were not completely broken in the test;

h) the measurement uncertainty (see Annex E).

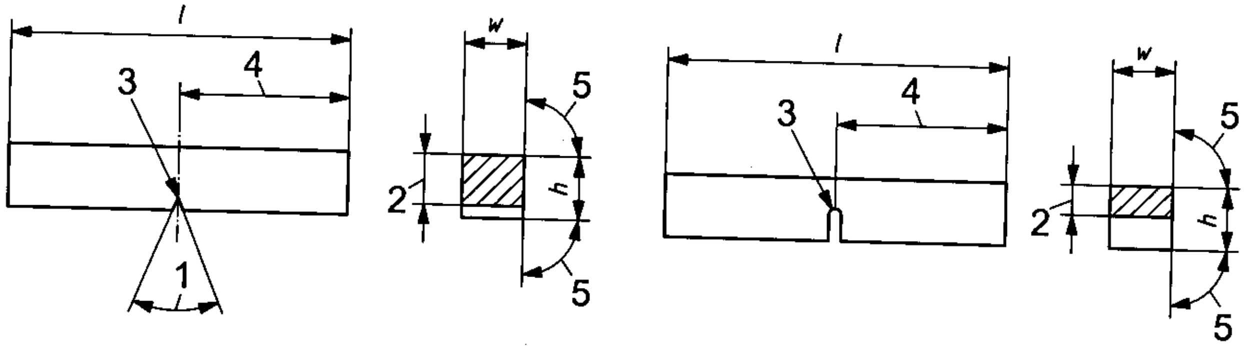


Key

1 anvil
2 standard-sized test piece
3 test piece supports
4 shroud

h height of test piece
l length of test piece
w width of test piece
a Centre of strike.
b Direction of pendulum swing.

Figure 1 — Test piece terminology showing configuration of test piece supports and anvils of a pendulum impact-testing machine



a) V-notch geometry

b) U-notch geometry

NOTE The symbols *l*, *h*, *w* and the numbers 1 to 5 refer to Table 2.

Figure 2 — Charpy pendulum impact test piece

Table 2 — Tolerances on specified test piece dimensions

Designation	Symbol and No.	V-notch test piece			U-notch test piece		
		Nominal dimension	Machining tolerance	Tolerance class [a]	Nominal dimension	Machining tolerance	Tolerance class [a]
Length	*l*	55 mm	± 0,60 mm	js15	55 mm	± 0,60 mm	js15
Height [b]	*h*	10 mm	± 0,075 mm	js12	10 mm	± 0,11 mm	js13
Width [b]:	*w*						
— standard test piece		10 mm	± 0,11 mm	js13	10 mm	± 0,11 mm	js13
— reduced-section test piece		7,5 mm	± 0,11 mm	js13	—	—	—
— reduced-section test piece		5 mm	± 0,06 mm	js12	—	—	—
— reduced-section test piece		2,5 mm	± 0,05 mm	js12	—	—	—
Angle of notch	1	45°	± 2°	—	—	—	—
Height below notch (height of test piece minus depth of notch)	2	8 mm	± 0,075 mm	js12	5 mm [c]	± 0,09 mm	js13
Radius of curvature at base of notch	3	0,25 mm	± 0,025 mm	—	1 mm	± 0,07 mm	js12
Distance of plane of symmetry of notch from ends of test piece [b]	4	27,5 mm	± 0,42 mm [d]	js15	27,5 mm	± 0,42 mm [d]	js15
Angle between plane of symmetry of notch and longitudinal axis of test piece		90°	± 2°	—	90°	± 2°	—
Angle between adjacent longitudinal faces of test piece	5	90°	± 2°	—	90°	± 2°	—

[a] In accordance with ISO 286-1.

[b] The test pieces shall have a surface roughness better than *Ra* 5 µm except for the ends.

[c] If another height (2 mm or 3 mm) is specified, the corresponding tolerances shall also be specified.

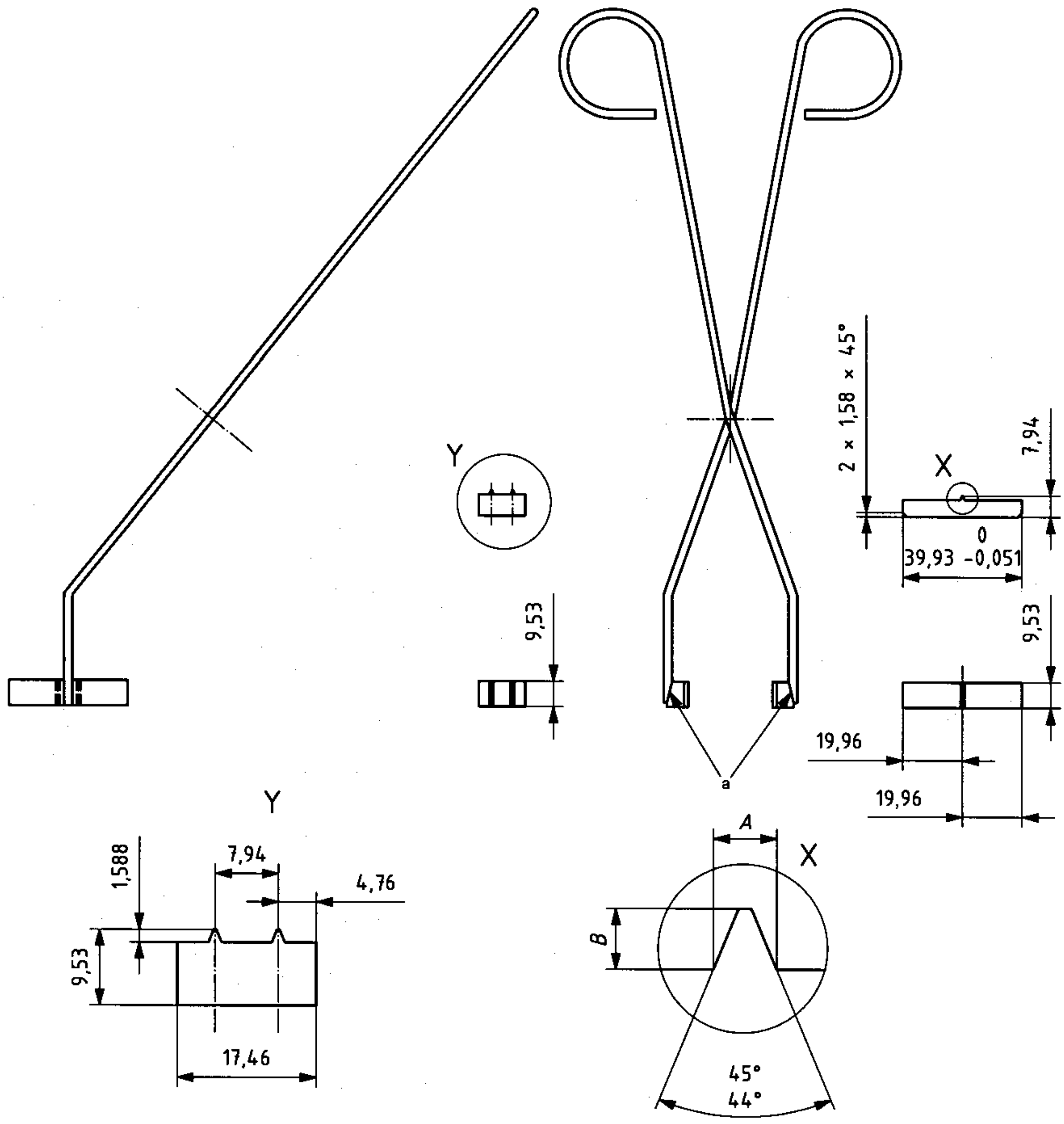
[d] For machines with automatic positioning of the test piece, it is recommended that the tolerance be taken as ± 0,165 mm instead of ± 0,42 mm.

Annex A
(informative)

Self-centring tongs

The tongs shown in Figure A.1 are often used to transfer the test piece from the temperature-conditioning medium and to properly position the test piece in the pendulum impact testing machine.

Dimensions in millimetres



Specimen width	Base width *A*	Height *B*
10	1,60 to 1,70	1,52 to 1,65
5	0,74 to 0,80	0,69 to 0,81
3	0,45 to 0,51	0,36 to 0,48

[a] Steel pieces silver-soldered to tongs parallel to each other.

Figure A.1 — Centring tongs for V-notched Charpy specimens

Annex B
(informative)

Lateral expansion

B.1 General

A measure of the ability of the material to resist fracture when subjected to triaxial stresses, such as those at the root of the notch in a Charpy test piece, is the amount of deformation that occurs at this location. The deformation in this case is contraction. Because of the difficulties in measuring this deformation, even after fracture, the expansion [1)] that occurs at the opposite end of the fracture plane is customarily measured and used as a proxy for the contraction.

B.2 Procedure

The method of measuring lateral expansion should take into account the fact that the fracture plane seldom bisects the point of maximum expansion on both sides of a test piece. One half of a broken test piece might include the maximum expansion for both sides, one side only, or neither. The techniques used should therefore provide an expansion value, equal to the sum of the higher of the two values obtained for each side, by measuring the two halves separately. The amount of expansion on each side of each half shall be measured relative to the plane defined by the undeformed portion of the side of the test piece (see Figure B.1). Expansion may be measured by using a gauge similar to that shown in Figures B.2 and B.3. Measure the two broken halves individually. First, however, check the sides perpendicular to the notch to ensure that no burrs were formed on these sides during impact testing; if such burrs exist, they shall be removed, for example by rubbing with an emery cloth, making sure that the protrusions to be measured are not rubbed during the removal of the burr. Next, place the half-specimens together so that the surfaces originally opposite the notch are facing one another. Take one of the half-specimens (see Figure B.1) and press it firmly against the reference supports, with the protrusions against the gauge anvil. Note the reading, and then repeat this step with the other half-specimen (see Figure B.1), ensuring that the same side is measured. The larger of the two values is the expansion of that side of the test piece. Repeat this procedure to measure the protrusions on the opposite side, and then add the larger values obtained for each side. For example if $A_1 > A_2$ and $A_3 = A_4$, consequently $LE = A_1 + (A_3 \text{ or } A_4)$. If $A_1 > A_2$ and $A_3 > A_4$, consequently, $LE = A_1 + A_3$.

If one or more protrusions of a test piece have been damaged by contacting the anvil, machine mounting surface, etc., the test piece shall not be measured and the condition shall be indicated in the test report.

Measure each test piece.

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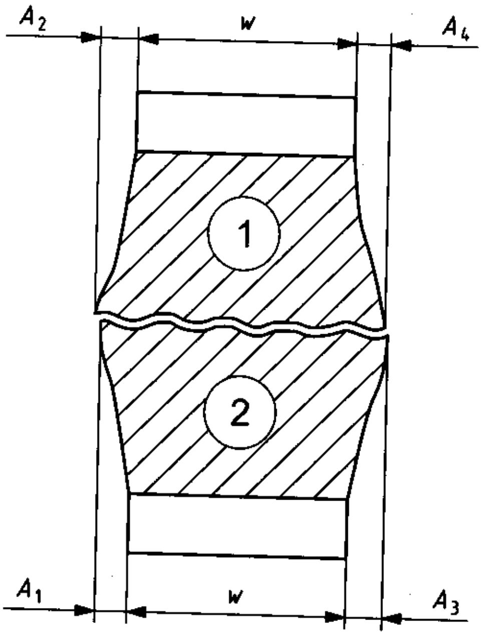


The halves are numbered 1 and 2.

Figure B.1 — Halves of broken Charpy V-notched impact specimen, illustrating the measurement of lateral expansion, dimensions A_1, A_2, A_3, A_4 and the original width, dimension w

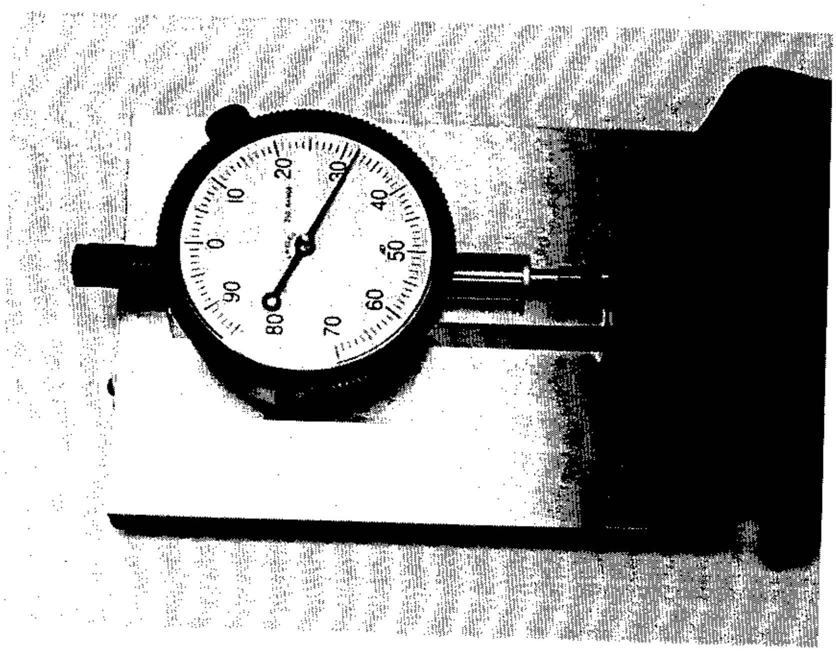
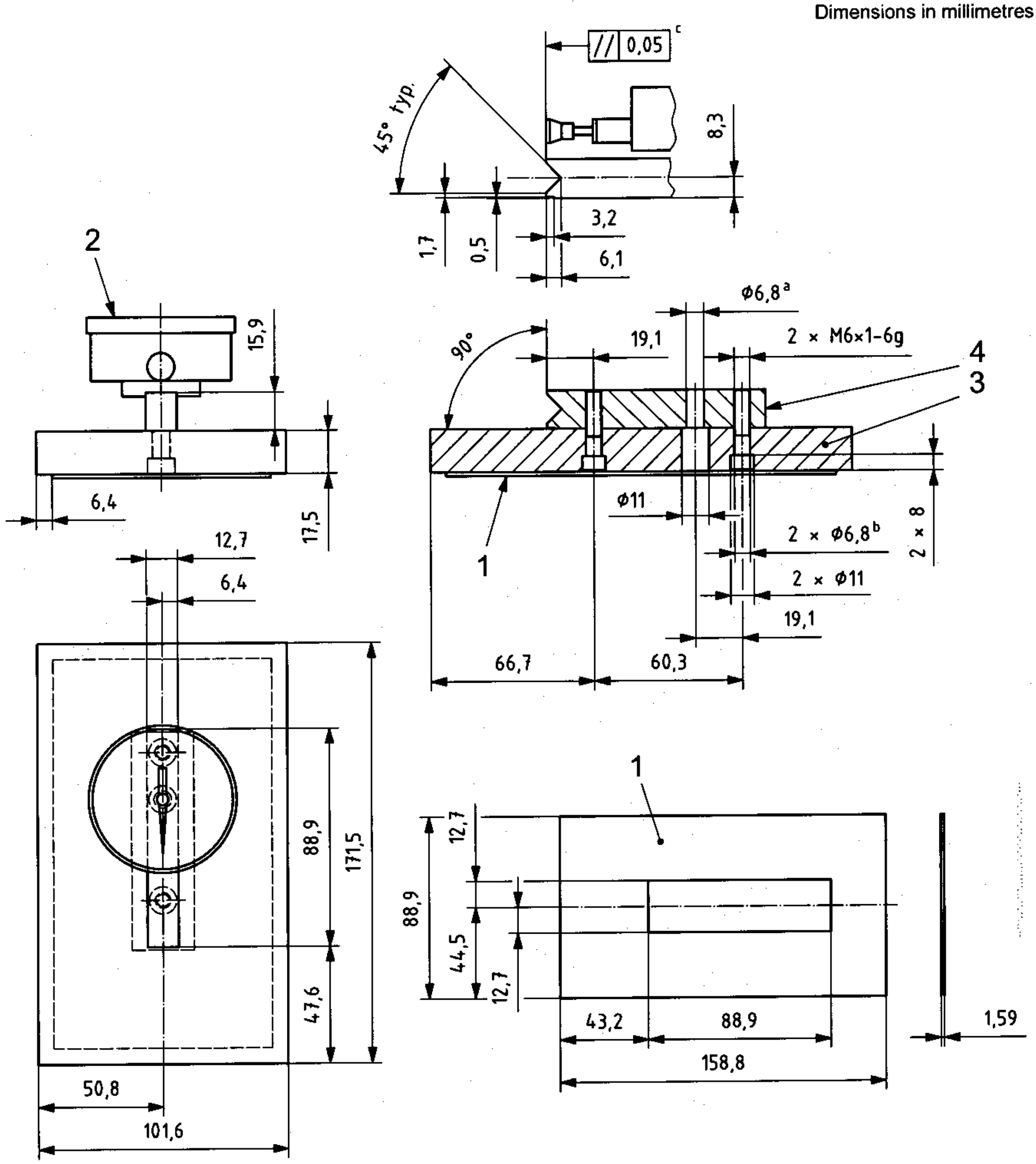


Figure B.2 — Lateral expansion gauge for Charpy specimens

Dimensions in millimetres



Key

1 pad made of rubber

2 indicator, 10 mm range, graduations in 1/100 mm

3 base plate made of stainless steel or chrome-plated steel

4 dial mount made of stainless steel or chrome-plated steel

a For 1/4-20 UNC screw with 7/8" long socket head to mount the indicator.

b For M6 × 1 screw with 25 mm socket head.

c Lap at assembly.

Figure B.3 — Assembly and details for lateral expansion gauge

Annex C
(informative)

Fracture appearance

C.1 General

The fracture surface of Charpy test pieces is often rated by the percentage of shear fracture which occurs[2]. The greater the percentage of shear fracture, the greater the notch toughness of the material. The fracture surface of most Charpy specimens exhibits a mixture of both shear and cleavage (brittle) fracture. Because the rating is extremely subjective, it is recommended that it not be used in specifications.

NOTE The term fibrous-fracture appearance is often used as a synonym for shear-fracture appearance. The terms cleavage-fracture appearance and crystallinity are often used to express the opposite of shear fracture. That is, 0 % shear fracture is 100 % cleavage fracture.

C.2 Procedures

The percentage of shear fracture is commonly determined by any one of the following methods:

a) measure the length and width of the cleavage portion (the "shiny" portion) of the fracture surface, as given in Figure C.1, and determine the per cent shear from Table C.1;

b) compare the appearance of the fracture of the test piece with a fracture-appearance chart, such as that given in Figure C.2;

c) magnify the fracture surface and compare it to a precalibrated overlay chart or measure the per cent cleavage fracture by means of a planimeter, then calculate per cent shear fracture (as 100 % – per cent cleavage fracture);

d) photograph the fracture surface at a suitable magnification and measure the per cent cleavage fracture by means of a planimeter, then calculate per cent shear fracture (as 100 % – per cent cleavage fracture);

e) measure the per cent shear fracture by image analysis techniques.

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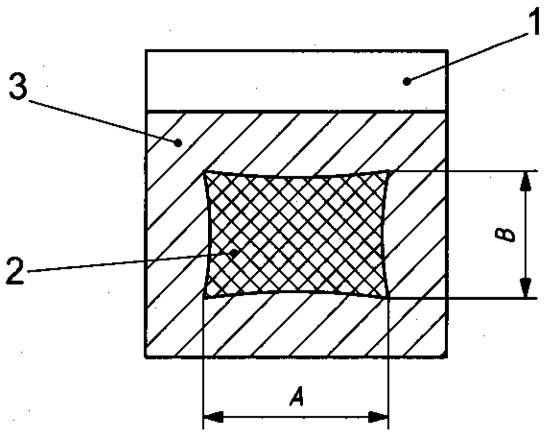


Key

1 notch
2 cleavage area (brittle)
3 shear area (dull)

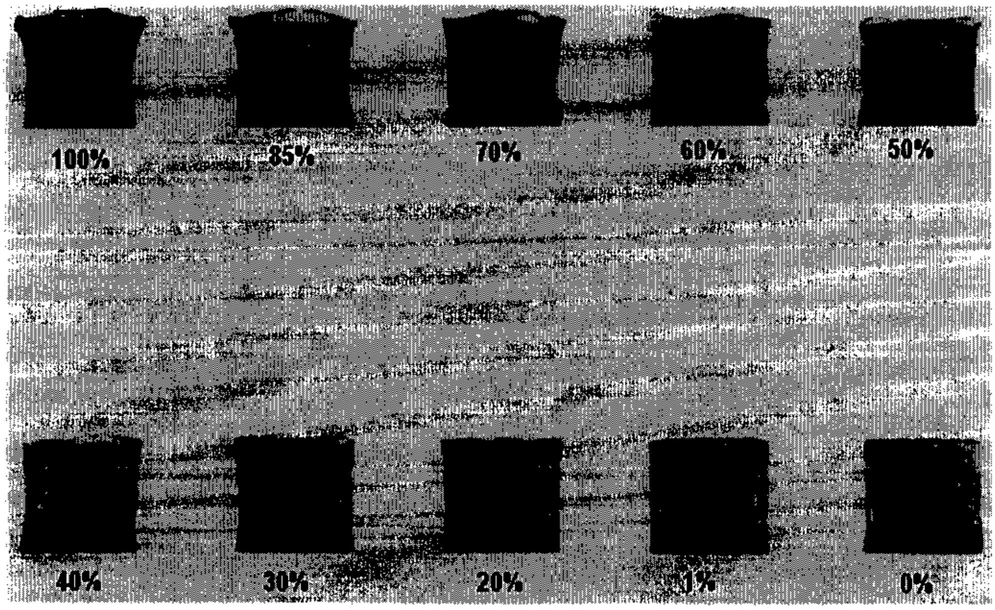
NOTE 1 Measure average dimensions A and B to the nearest 0,5 mm.

NOTE 2 Determine the per cent shear fracture using Table C.1.

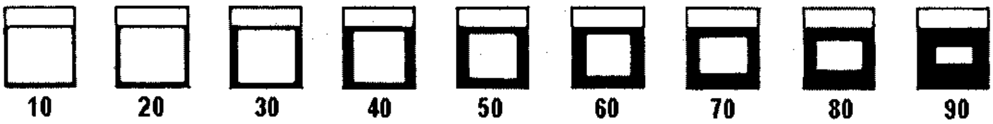
Figure C.1 — Determination of per cent shear fracture

Table C.1 — Per cent shear for measurements in millimetres

B mm	*A* mm																		
	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10
	Per cent shear																		
1,0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1,5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2,0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2,5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3,0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3,5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4,0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4,5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5,0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5,5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6,0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6,5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7,0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7,5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8,0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
100 % shear shall be reported when either A or B is zero.																			



a) Fracture appearance charts and per cent shear fracture comparator



b) Guide for estimating fracture appearance

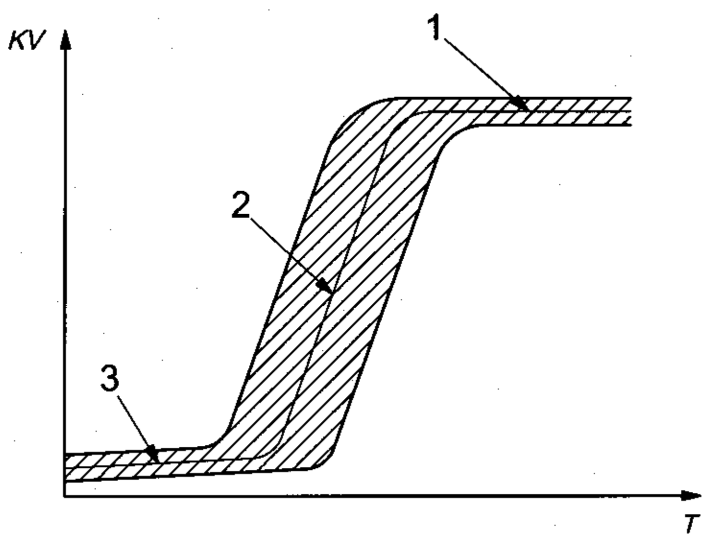
Figure C.2 — Fracture appearance

Annex D
(informative)

Absorbed energy vs. temperature and transition temperature

D.1 Absorbed energy/temperature curve

The absorbed energy/temperature curve (*KV/T* curve) shows the energy absorbed as a function of the test temperature for a given shape of specimen (see Figure D.1). In general, the curve is obtained by drawing a fitted curve through the individual values. The shape of the curve and the scatter of the test values are dependent on the material, the specimen shape and the impact velocity. In the case of a curve with a transition zone, a distinction is made between the upper-shelf zone, transition zone and the lower-shelf zone.



Key

T temperature

KV absorbed energy

1 upper-shelf zone

2 transition zone

3 lower-shelf zone

Figure D.1 — Absorbed energy/temperature curve shown schematically

D.2 Transition temperature

The transition temperature, T_t, characterizes the position of the steep rise in the absorbed energy/temperature curve. Since the steep rise usually extends over a fairly wide temperature range, there can be no generally applicable definition of the transition temperature. The following criteria have, among others, been found useful for determining the transition temperature:

The transition temperature, T_t, is the temperature at which

a) a particular value of absorbed energy is reached, e.g. $KV_8 = 27$ J,

b) a particular percentage of the absorbed energy of the upper-shelf value is reached, e.g. 50 %,

c) a particular portion of shear fracture occurs, e.g. 50 %, and

d) a particular amount of lateral expansion is reached, e.g. 0,9 mm.

The choice of the method used to define transition temperature should be specified in the product standard or specification, or by agreement.

Annex E
(informative)

Measurement uncertainty of an absorbed energy value, KV

E.1 Symbols and units

The symbols and units used in this annex are given in Table E.1.

Table E.1 — Symbols and units

Symbol	Unit	Definition
B_V	J	Bias of the pendulum impact testing machine, as determined through indirect verification
k		Coverage factor
KV	J	Absorbed energy as measured in accordance with this International Standard on V-notched sample
$\overline{KV}$	J	Reported average KV value of a set of samples from a test material
KV_R	J	Certified KV value of the reference material used in the indirect verification
$\overline{KV}_V$	J	Mean KV value of the reference test pieces tested for indirect verification
n		Number of tested samples
r	J	Instrument scale resolution
s_x	J	Standard deviation of the values obtained on the n test samples
T_x	J	Error of measured KV value due to temperature effects
$u(\overline{KV})$	J	Standard uncertainty of $\overline{KV}$
$U(\overline{KV})$	J	Expanded uncertainty of $\overline{KV}$ with a confidence level of about 95 %
u_T	K	Standard uncertainty of the test temperature
u_V	J	Standard uncertainty of the indirect verification result
$u(\bar{x})$	J	Standard uncertainty of $\bar{x}$
$\bar{x}$	J	Observed average KV value of a set of n samples from a test material
$\nu_{\overline{KV}}$		Degrees of freedom corresponding with $u(\overline{KV})$
ν_V		Degrees of freedom corresponding with u_V
ν_x		Degrees of freedom corresponding with $u(\bar{x})$

E.2 Determination of measurement uncertainty

E.2.1 General

This annex specifies a robust method for determining the uncertainty, $u(\overline{KV})$, associated with the mean absorbed energy, $\overline{KV}$, of a set of specimens of a test material. Other methods of assessing $u(\overline{KV})$ can be developed and are acceptable, if they meet the requirements of ISO/IEC Guide 98-3 [3].

This approach requires input from the "indirect verification" of the Charpy pendulum impact testing machine, which is a normative method of assessing the performance of the instrument with reference test pieces (see ISO 148-2:2008, Annex A).

NOTE 1 ISO 148 (all parts) requires Charpy pendulum impact testing machines to successfully meet the requirements for both indirect and direct verification. The latter consists of a check of all individual geometric and mechanical requirements imposed on the construction of the instrument (see ISO 148-2).

The roles of direct and indirect verification in the metrological traceability chain of Charpy measurements are given in Figure E.1. The chain starts at the international level with the definition of the measurand, KV, or absorbed energy, in the standard procedures described in ISO 148 (all parts). Global comparability relies on international comparisons of Charpy reference machines and of the certified values of the certified reference test pieces produced by national or international bodies using sets of reference machines.

Calibration laboratories use the certified reference test pieces to verify their reference machine and can use their pendulum to characterize and produce reference test pieces. At the user level, Charpy test laboratories can verify their pendulum with reference test pieces to obtain the desired reliable KV values.

NOTE 2 Users can choose to acquire certified reference test pieces from national or international organizations, by-passing the calibration laboratory level.

NOTE 3 For additional information on the difference between certified reference test pieces and reference test pieces, see ISO 148-3:2008, Annex A.

E.2.2 Uncertainty disclaimer

Measurement uncertainty analysis is useful in identifying major sources of inconsistencies in measured results.

Product standards and material property databases based on this part of ISO 148 have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk a product which fails compliance. For this reason, the estimates of uncertainty derived from following this procedure are for information only, unless specifically instructed otherwise by the customer.

The test conditions and limits defined in this part of ISO 148 shall not be adjusted to take account of uncertainties of measurement, unless specifically instructed otherwise by the customer. The estimated measurement uncertainties shall not be combined with measured results to assess compliance to product specifications, unless specifically instructed otherwise by the customer.

E.3 General procedure

E.3.1 Factors contributing to uncertainty

The principal factors contributing to uncertainty are associated with:

a) instrument bias deduced from the indirect verification;

b) homogeneity of the test material and the instrument repeatability;

c) test temperature.

The measurement equation for the mean absorbed energy $\overline{KV}$ is Equation (E.1):

$$\overline{KV} = \bar{x} - B_V - T_x \tag{E.1}$$

where

$\bar{x}$ is the observed mean absorbed energy of n test specimens;

B_V is the instrument bias based on the indirect verification;

T_x is the bias due to temperature.

E.3.2 Instrument bias

As a rule (see ISO/IEC Guide 98-3 [3]), measured values have to be corrected for known bias. Indirect verification is one way to establish the value of bias. The instrument bias determined by indirect verification is defined in ISO 148-2:2008, as given in Equation (E.2):

$$B_V = \overline{KV}_V - KV_R \tag{E.2}$$

where

$\overline{KV}_V$ is the mean value of the reference test pieces broken during the indirect verification;

KV_R is the certified value of the reference test pieces.

Depending on how well the value of B_V is known, different actions are proposed in ISO 148-2:2008, Annex A, which deals with the uncertainty associated with the results of indirect verification:

a) B_V is well known and stable - in this exceptional case, the observed value $\bar{x}$ is corrected by a term equal to B_V to obtain $\overline{KV}$.

b) Most often there is no firm evidence about the stability of the value of B_V; in this case, the bias is not corrected for, but it contributes to u_V, the uncertainty of the indirect verification result.

In both cases a) and b), an uncertainty, u_V, associated with the indirect verification result and the instrument bias is calculated in accordance with procedures described in ISO 148-2:2008, Annex A. The outcome of the uncertainty analysis of the indirect verification is the value u_V.

If there is a significant difference between the values of $\overline{KV}_V$ and $\overline{KV}$, then the values B_V and u_V should be multiplied by the ratio $\overline{KV}/\overline{KV}_V$.

E.3.3 Machine repeatability and material heterogeneity

The uncertainty of $\bar{x}$, the mean observed absorbed energy of n test specimens, is determined using Equation (E.2):

$$u(\bar{x}) = \frac{s_x}{\sqrt{n}} \tag{E.3}$$

where s_x is the standard deviation of the values obtained on the n test samples.

s_x is caused by two factors: the machine repeatability and the sample-to-sample material heterogeneity. These factors are confounded and therefore are both included in this term. It is recommended to report the total measurement uncertainty with the value of s_x as a conservative measure for the variation in KV due to material heterogeneity.

The value of $\nu_{\bar{x}}$, the number of degrees of freedom of $u(\bar{x})$, is calculated as n-1.

E.3.4 Temperature bias

The effect of temperature bias, T_x, on the absorbed energy is extremely material dependent. If steel is tested in the temperature region of the brittle-to-ductile transition, small changes in temperature can correspond with large differences in absorbed energy. At the time of publication, it is not possible to present a generic and accepted approach to the calculation of the contribution to absorbed energy uncertainty corresponding with the uncertainty of the measured test temperature. Instead, it is proposed to complement the statement of the measurement uncertainty in terms of absorbed energy with a separate statement on u_T, the uncertainty of the test temperature at which the absorbed energy was measured (see E.5 for example).

E.3.5 Machine resolution

The effect of machine resolution is in most cases negligible in comparison with the other factors contributing to uncertainty (see E.3.1 to E.3.4). An exception is the case where machine resolution is large and the measured energy is low. In that case, the corresponding uncertainty contribution is calculated using Equation (E.4):

$$u(r) = \frac{r}{\sqrt{3}} \qquad \text{(E.4)}$$

where r is the machine resolution. The corresponding number of degrees of freedom is ∞.

E.4 Combined and expanded uncertainty

To calculate $u\left(\overline{KV}\right)$, the factors contributing to uncertainty (see E.3) shall be combined. Since u_T is treated separately, and since the terms $u(\bar{x})$, u_V and $u(r)$ are independent of each other, the combined standard uncertainty is determined using Equation (E.5):

$$u(\overline{KV}) = \sqrt{u^2(\bar{x}) + u_V^2 + u^2(r)} \qquad \text{(E.5)}$$

To calculate the expanded uncertainty, the combined standard uncertainty is multiplied by the appropriate coverage factor, k. The value of k depends on $\nu_{\overline{KV}}$, the effective degrees of freedom of $u\left(\overline{KV}\right)$, which can be computed using the simple Welch-Satterthwaite [3] approximation, by combining the degrees of freedom, ν_V and ν_x, and evaluating the corresponding uncertainty contributions, u_V and $u(\bar{x})$. Since the value of the degrees of freedom corresponding with $u(r)$ is ∞, the instrument resolution does not contribute to $\nu_{\overline{KV}}$; see Equation (E.6):

$$\nu_{\overline{KV}} = \frac{u^4 u\left(\overline{KV}\right)}{\dfrac{u^4(\bar{x})}{\nu_{\bar{x}}} + \dfrac{u_V^4}{\nu_V}} \qquad \text{(E.6)}$$

NOTE In the case of Charpy tests, the number of samples is often limited to 5 or even 3. In addition, the heterogeneity of the samples often leads to a significant value of $u(\bar{x})$. This is why the number of effective degrees of freedom is most often not sufficiently large to use a coverage factor of k equal to 2.

The coverage factor, k, corresponding to a confidence level of about 95 % is obtained from ISO/IEC Guide 98-3 (GUM) t-table as $t_{95}\left(\nu_{\overline{KV}}\right)$. (For selected t-values, see Table E.5.) The expanded uncertainty of $\overline{KV}$ is determined using Equation (E.7):

$$U\left(\overline{KV}\right) = k \times u\left(\overline{KV}\right) = t_{95}\left(\nu_{\overline{KV}}\right) \times u\left(\overline{KV}\right) \tag{E.7}$$

E.5 Example

In this example, the measurement uncertainty is calculated for the mean value, $\bar{x}$, of a set of $n = 3$ samples from a particular test material. The results in Table E.2 were obtained on a pendulum which was successfully checked with both direct and indirect verification procedures. As a first step, the mean observed KV value, $\bar{x}$, is calculated, as well as the standard uncertainty, $\bar{x}$, $u(\bar{x})$, which is calculated using Equation (E.3).

Table E.2 — Raw Charpy test results

Dimensions in Joules

Test results	
KV, Sample 1	105,8
KV, Sample 2	109,3
KV, Sample 3	112,2
Mean KV, $\bar{x}$	109,1
Standard deviation of $n = 3$ KV-values, s_x	3,2
Standard uncertainty of the mean observed KV, $u(\bar{x})$, calculated according to Equation (E.3)	1,9

In the second step, the raw results were combined with the results of the most recent indirect verification test, for which reference test pieces of different energy levels (e.g. 20 J, 120 J and 220 J) were used. The test material had an absorbed energy level closest to the 120 J level ($\bar{x}$ = 109,1 J). Therefore, the indirect verification results obtained at this energy level were used in the uncertainty assessment. The bias value, B_V, met the verification criteria in accordance with ISO 148-2. Since there is no firm evidence about the stability of B_V, the measured value was not corrected for the bias. Therefore, the reported KV value, $\overline{KV}$, is equal to the measured mean value, $\bar{x}$.

Since the bias value was not corrected for, it contributed to the uncertainty of the indirect verification result, u_V. The resulting standard uncertainty of the indirect verification result at 120 J was $u_V = 5{,}2$ J, with a number of degrees of freedom equal to 7 (see ISO 148-2). These conclusions and values can be taken from the calibration or verification certificate of the pendulum used.

Table E.3 gives the measurement uncertainty calculation procedure.

Table E.3 — Calculation scheme of expanded measurement uncertainty, $U\left(\overline{KV}\right)$

Raw test results		Results from indirect verification at 120 J	
$u(\bar{x})$	1,9 J	u_V	5,2 J
Degrees of freedom ν_x for tests on $n = 3$ samples, calculated as $n - 1$	2	Degrees of freedom of indirect verification ν_V, taken from calibration certificate	7
Combined standard uncertainty $u\left(\overline{KV}\right)$, from Equation (E.5)			5,5 J
$\nu_{\overline{KV}}$, the effective degrees of freedom of $u\left(\overline{KV}\right)$, from Equation (E.6)			8
t-factor corresponding with a $\nu_{\overline{KV}}$ of 8 and a 95 % confidence level, $t_{95}\left(\nu_{\overline{KV}}\right)$			2,3
Expanded uncertainty $U\left(\overline{KV}\right)$			12,6 J

Table E.4 can be used to report the test results and measurement uncertainty.

Table E.4 — Summary table of the result, $\overline{KV}$, with expanded measurement uncertainty, $U\left(\overline{KV}\right)$

n	s_x [a]	$\overline{KV}$	$\nu_{\overline{KV}}$	$t_{95}\left(\nu_{\overline{KV}}\right)$	$U\left(\overline{KV}\right)$ [b, c]
	J	J			J
3	3,2	109,1	8	2,3	12,6

[a] This standard deviation is a conservative estimate of the test material heterogeneity (its value also contains a contribution from the instrument repeatability, which cannot be separately assessed).

[b] The expanded uncertainty, calculated in accordance with this procedure, corresponds to a confidence level of about 95 %.

[c] The uncertainty quoted is subject to an uncertainty of the test temperature, which was measured to an uncertainty of 2 K (confidence level of 95 %). The uncertainties quoted do not consider contributions that can be introduced by particular characteristics of the test material.

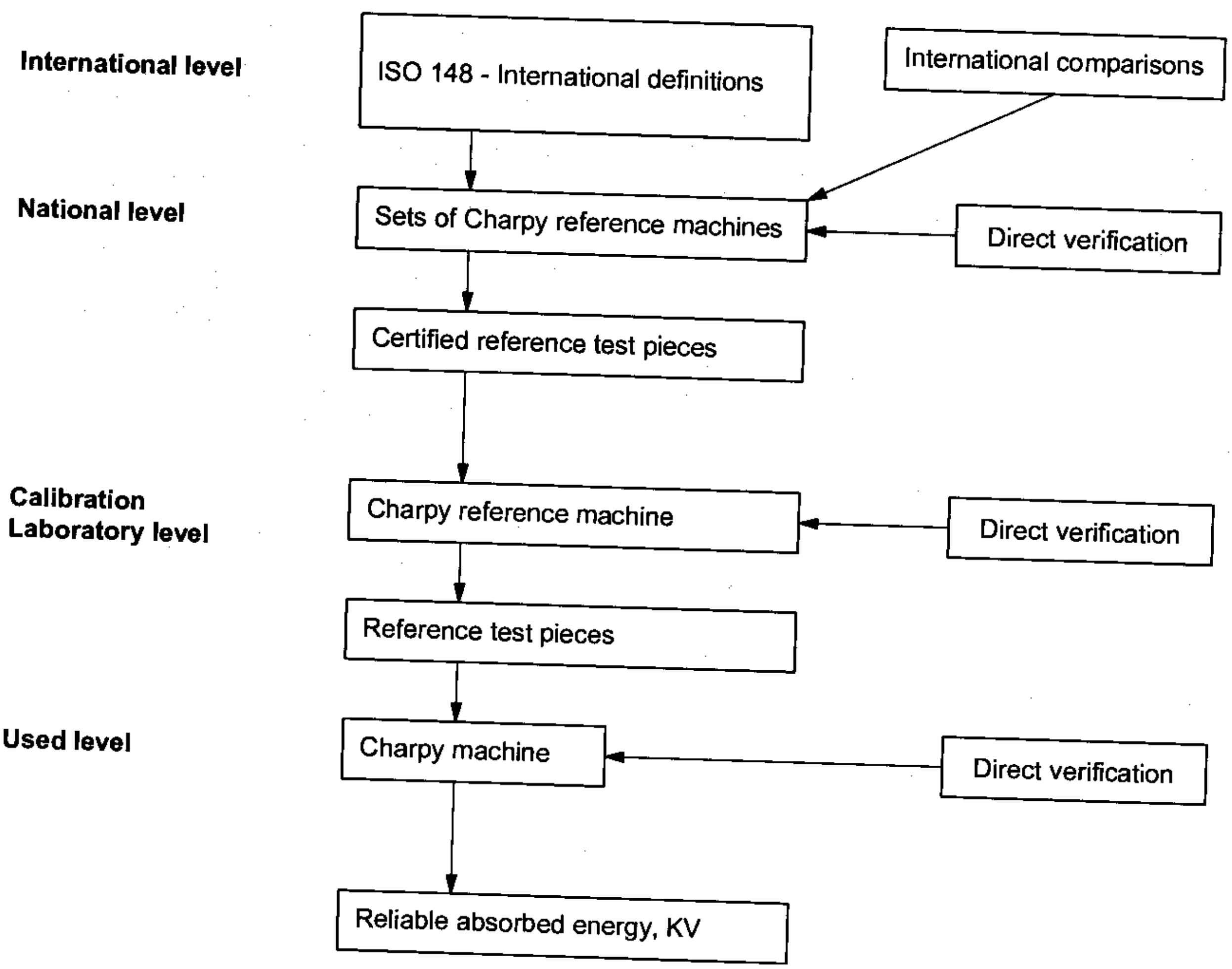


Figure E.1 — Structure of the metrological traceability chain for the definition and dissemination of the absorbed energy scales of the Charpy impact test

Table E.5 — Value of $t_p(\nu)$ from the t-distribution for ν degrees of freedom that defines an interval $-t_p(\nu)$ to $+t_p(\nu)$ that encompasses the fraction, p, of the distribution [3]

Degrees of freedom, ν	$t_p(\nu)$ for fraction $p = 95$ %
1	12,71
2	4,30
3	3,18
4	2,78
5	2,57
6	2,45
7	2,36
8	2,31
9	2,26
10	2,23
11	2,20
12	2,18
13	2,16
14	2,14
15	2,13
16	2,12
17	2,11
18	2,10
19	2,09
20	2,09
25	2,06
30	2,04
35	2,03
40	2,02
45	2,01
50	2,01
100	1,98
∞	1,96

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