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Metallic materials — Measurement of fracture toughness at impact loading rates using precracked Charpy-type test pieces

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National foreword

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INTERNATIONAL STANDARD

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Metallic materials — Measurement of fracture toughness at impact loading rates using precracked Charpy-type test pieces

Matériaux métalliques — Mesure de la ténacité d'éprouvettes type Charpy préfissurées soumises à un chargement d'impact

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing — Fracture (F), Pendulum (P), Tear (T)*.

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Introduction

This International Standard is closely related to ISO 14556 and was derived from a draft procedure prepared by the Working Party "European Standards on Instrumented Precracked Charpy Testing" of the European Structural Integrity Society (ESIS) Technical Subcommittee on Dynamic Testing at Intermediate Strain Rates (TC5).

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INTERNATIONAL STANDARD ISO 26843:2015(E)

Metallic materials — Measurement of fracture toughness at impact loading rates using precracked Charpy-type test pieces

1 Scope

This International Standard specifies requirements for performing and evaluating instrumented precracked Charpy impact tests on metallic materials using a fracture mechanics approach. Minimum requirements are given for measurement and recording equipment such that similar sensitivity and comparable measurements are achieved.

Dynamic fracture mechanics properties determined using this International Standard are comparable with conventional large-scale fracture mechanics results when the corresponding validity criteria are met. Because of the small absolute size of the Charpy specimen, this is often not the case. Nevertheless, the values obtained can be used in research and development of materials, in quality control, and to establish the variation of properties with test temperature under impact loading rates.

Fracture toughness properties determined through the use of this International Standard may differ from values measured at quasistatic loading rates. Indeed, an increase in loading rate causes a decrease in fracture toughness when tests are performed in the brittle or ductile-to-brittle regimes; the opposite is observed (i.e. increase in fracture toughness) in the fully ductile regime. More information on the dependence of fracture toughness on loading (or strain) rate is given in Reference [1]. In addition, it is generally acknowledged that fracture toughness also depends on test temperature. For these reasons, the user is required to report the actual test temperature and loading rate for each test performed.

In case of cleavage fracture of ferritic steels in the ductile-to-brittle transition region, variability can be very large and cannot be adequately described by simple statistics. In this case, additional tests are required and the analysis is to be performed using a statistical procedure applicable to this type of test, see for example Reference [2].

NOTE Modifications to the analytical procedures prescribed in Reference [2] might be necessary to account for the effect of elevated (impact) loading rates.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

ISO 12135, *Metallic materials — Unified method of test for the determination of quasistatic fracture toughness*

ISO 14556, *Steel — Charpy V-notch pendulum impact test — Instrumented test method*

ISO 26203-2, *Metallic materials — Tensile testing at high strain rates — Part 2: Servo-hydraulic and other test systems*

3 Symbols

For the purposes of this International Standard, the following symbols given in Table 1 apply.

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Table 1 — Symbols and definitions used in this International Standard

Symbol	Definition	Unit
a	Nominal crack length (for the purposes of fatigue precracking, an assigned value less than a_0)	mm
a_f	Final crack length ($a_0 + \Delta a$)	mm
a_m	Length of machined notch	mm
a_0	Initial crack length	mm
Δa	Crack extension ($a - a_0$)	mm
Δa_{max}	Crack extension limit for J-controlled crack extension	mm
Δa_s	Crack extension corresponding to displacement s	mm
B	Specimen thickness	mm
B_e	Specimen effective thickness as defined in Formula (E.7)	mm
B_N	Specimen net thickness after side-grooving	mm
C_M	Compliance of the test machine	m/N
C_0	Specimen elastic compliance	m/N
C_S	Specimen theoretical compliance	m/N
E	Young's modulus of elasticity	GPa
$d\varepsilon/dt$	Strain rate	s^{-1}
f_g	Output frequency limit	Hz
F	Applied force	N
F_{cd}	Applied force at onset of unstable crack extension in Figure 1	N
F_f	Maximum fatigue precracking force during the final precracking stage	N
F_{gy}	Applied force at onset of general yielding as defined in ISO 14556	N
F_m	Maximum applied force as defined in ISO 14556	N
F_s	Applied force corresponding to a displacement s	N
J_d	Dynamic J-integral	MJ/m^2
J_{cd}	Dynamic equivalent of $J_{c(B)}$ in ISO 12135 (with B = 10 mm)	MJ/m^2
J_g	J at upper limit of J-controlled crack extension	MJ/m^2
$J_{d,max}$	Limit of J_d-R material behaviour defined by this test method	MJ/m^2
J_{ud}	Dynamic equivalent of $J_{u(B)}$ in ISO 12135 (with B = 10 mm)	MJ/m^2
$J_{0,2Bd}$	Dynamic equivalent of $J_{0,2BL(B)}$ in ISO 12135 (with B = 10 mm)	MJ/m^2
dJ_d/dt	Rate of change of dynamic J-integral	$MJ/m^2\ s^{-1}$
K_d	Dynamic stress intensity factor	$MPa\ m^{0,5}$
K_{Jd}	Dynamic stress intensity factor calculated from J-integral	$MPa\ m^{0,5}$
$K_I^{dyn}(t)$	Stress intensity factor – time history from the impact response curve method	$MPa\ m^{0,5}$
K_{Id}	Dynamic plane strain fracture toughness	$MPa\ m^{0,5}$
K_{Jcd}	Dynamic stress intensity factor calculated from J-integral at the onset of cleavage	$MPa\ m^{0,5}$
dK_d/dt	Rate of change of dynamic stress intensity factor	$MPa\ m^{0,5}\ s^{-1}$
KV	Absorbed energy as defined in ISO 148-1	J
KV_0	Available potential energy corresponding to a reduced pendulum impact velocity v_0	J
M	Total mass of the moving striker of the pendulum	kg
n	Strain hardening exponent of the Ramberg-Osgood material law	—
N	Number of available test specimens	—

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Table 1 *(continued)*

Symbol	Definition	Unit
R_{fd}	Dynamic flow stress, defined as the average of dynamic yield strength and dynamic tensile strength	MPa
R_{md}	Dynamic tensile strength determined at the strain rate of the fracture toughness test	MPa
R_{pd}	Dynamic yield (proof) strength determined at the strain rate of the fracture toughness test	MPa
R_p	Yield (proof) strength measured at quasistatic strain rate	MPa
s	Specimen displacement (calculated according to ISO 14556)	mm
s_{pl}	Plastic component of specimen displacement	mm
S	Span between outer loading points	mm
T	Temperature	°C
t	Time	s
t_f	Time to fracture	s
t_i	Time at the onset of crack propagation	s
t_r	Signal rise time	s
t_o	Time at striker impact	s
τ	Period of force oscillation	s
v_0	Initial striker impact velocity	m s^{-1}
v_{0s}	Striker impact velocity corresponding to the maximum available energy of the pendulum	m s^{-1}
W	Specimen effective width	mm
W_m	Energy at maximum force as defined in ISO 14556	J
W_p	Plastic component of the area under the force-displacement test record up to displacement s	J
W_s	Total fracture energy under the force-displacement test record up to displacement s	J
W_t	Calculated energy from area under complete force-displacement test record up to $F = 0{,}02\ F_m$ as defined in ISO 14556	J
W_o	Available impact energy	J
ν	Poisson's ratio	—

4 Principle

This International Standard prescribes impact bend tests which may be performed on fatigue precracked Charpy-type specimens to obtain dynamic fracture mechanics properties of metallic materials. This International Standard extends the procedure for V-notch impact bend tests in accordance with ISO 148-1, and may be used for the evaluation of the master curve reference temperature in accordance with Reference [2] provided that the corresponding validity requirements are met. Instrumented testing machines are required together with ancillary instrumentation and recording equipment in accordance with ISO 14556.

Fracture toughness properties depend on material response reflected in the force-time diagrams described in Table 2 and Figure 1. The logical structure for fracture property determination and validation is shown in the flow chart of Figure 2.

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Table 2 — Fracture toughness properties to be determined

Material response/fracture behaviour	Corresponding diagram type (see Figure 1)	R-curve	Characteristic parameters
Linear-elastic	I	—	J_{cd}, K_{Jcd}, K_{Id} (B, dK_d/dt, dJ_d/dt)
Elastic-plastic, unstable fracture with $\Delta a < 0{,}2$ mm	II	—	J_{cd}, K_{Jcd} (B,dJ_d/dt)
Elastic-plastic, unstable fracture with $0{,}2\ \text{mm} \leq \Delta a \leq 0{,}15\ (W - a_0)$	II	—	J_{ud} (B,Δa,dJ_d/dt)
Elastic-plastic, unstable fracture with $\Delta a > 0{,}15\ (W - a_0)$	III	J_d-Δa	$J_{0,2Bd}$ (dJ_d/dt)
Elastic-plastic; no unstable fracture	IV	J_d-Δa	$J_{0,2Bd}$ (dJ_d/dt)

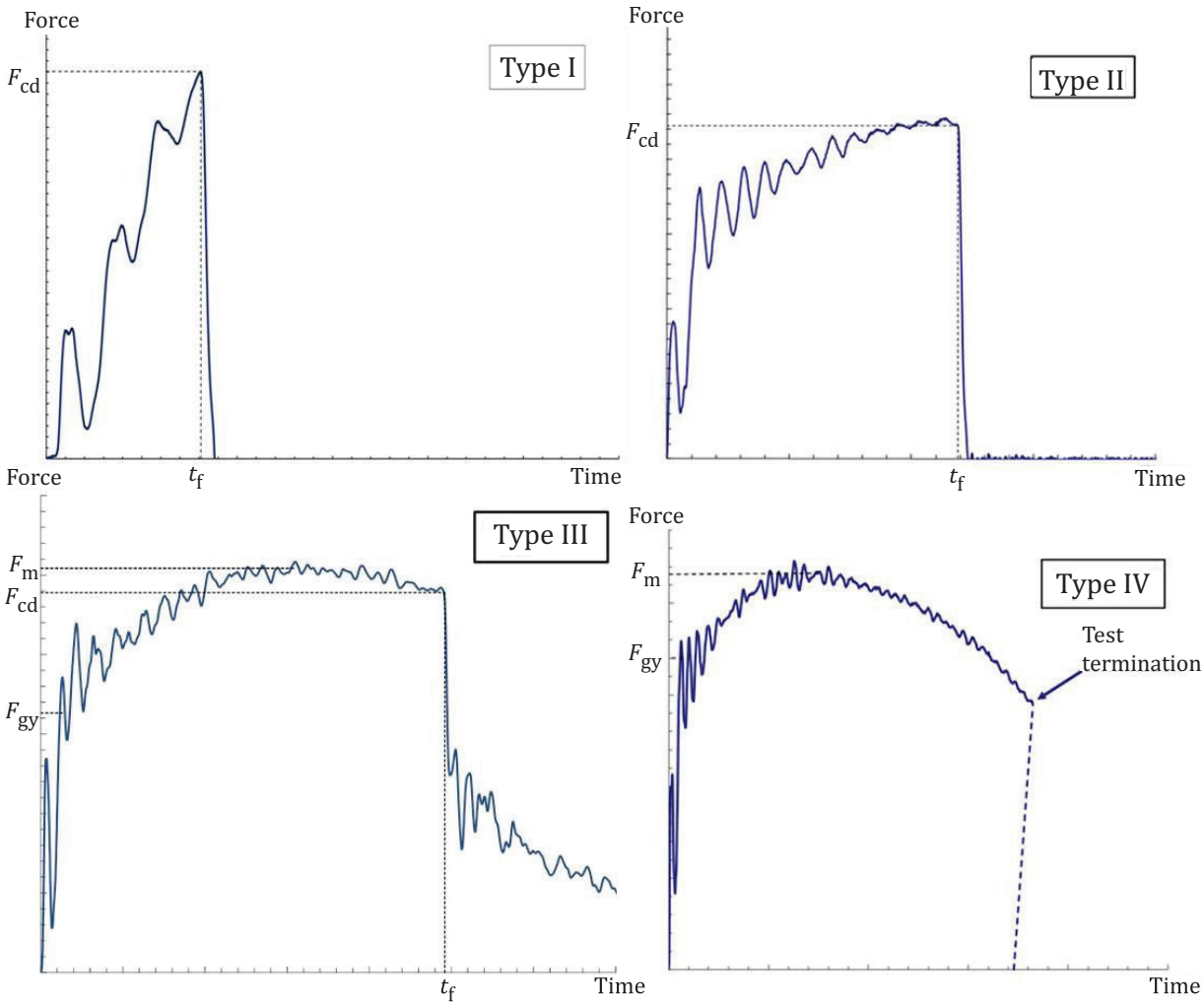

Figure 1 — Typical force-time diagrams (schematic)

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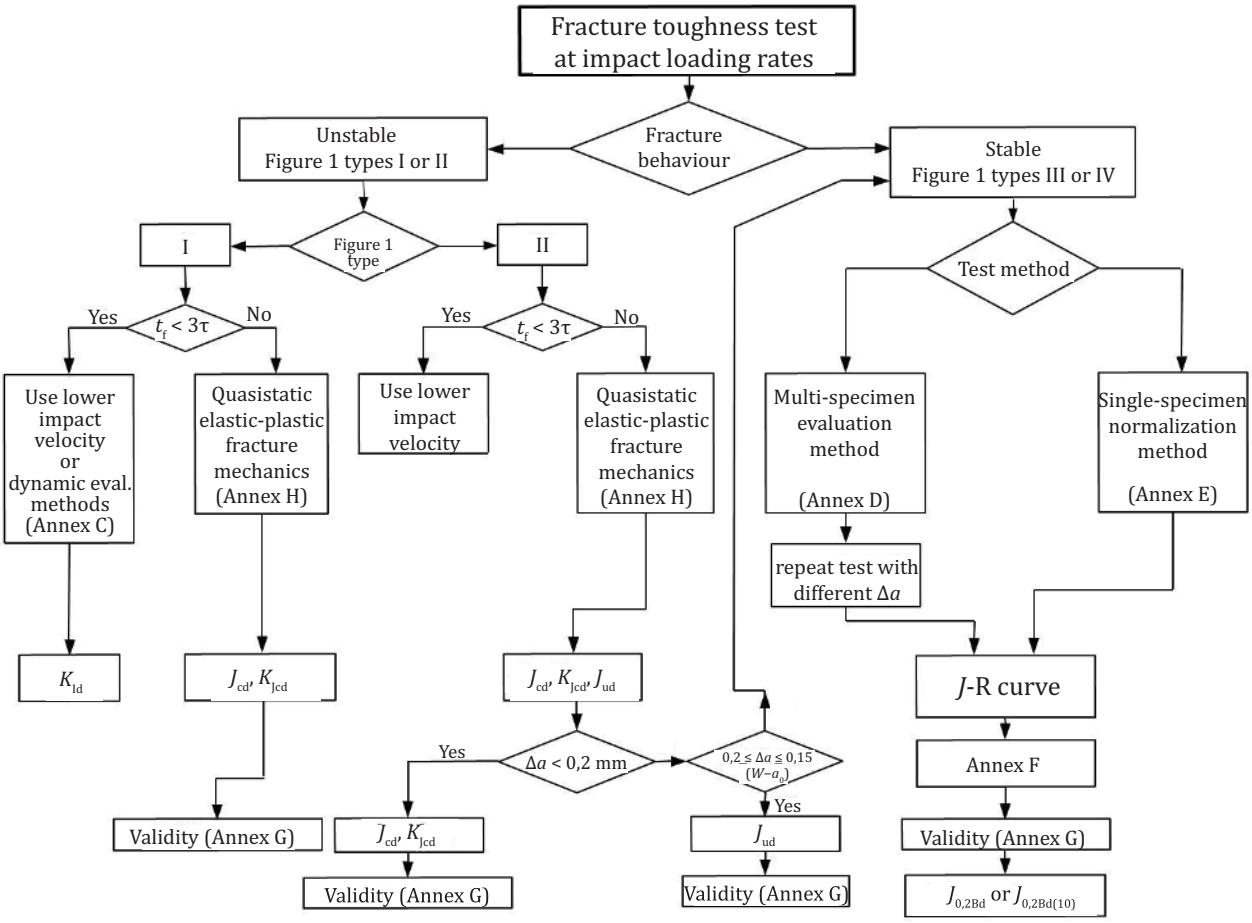

Figure 2 — Flow chart for the application of the test method

5 Test specimens

5.1 Specimens shall be prepared in accordance with the standard specimens of ISO 148-1, with or without the 2,0 mm V-notch, followed by fatigue precracking.

5.2 Specimens shall be fatigue precracked in bending to produce an initial crack length, a_0, in the range $0{,}30 \le a_0/W \le 0{,}70$.

If the results in terms of J are to be directly comparable with full-size standard fracture toughness values such as $J_{0,2BL}$ (as defined in ISO 12135), then a_0/W shall be in the range $0{,}45 < a_0/W < 0{,}70$. Shorter crack lengths may be more advantageous, as a stiffer test piece increases the probability of a successful test.

5.3 To initiate fatigue precracking, machine or spark erode a slot into the specimen. For specimens with an existing V-notch, fatigue precracking may initiate at the bottom of the notch. The length of the machined notch, a_m, shall be at least 1,0 mm shorter than the desired initial crack length, a_0.

5.4 During the final 1,3 mm or 50 % of precrack extension, whichever is less, the maximum fatigue precracking force shall be the lower of:

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$$F_f = \frac{0{,}8B\left(W - a_0\right)^2}{S} R_p \tag{1}$$

or

$$F_f = \xi \times E \left[\frac{\sqrt{WBB_N}}{f\left(\frac{a_0}{W}\right)} \right] \left(\frac{W}{S}\right) \tag{2}$$

where $\xi = 1{,}6 \times 10^{-4}\ \mathrm{m}^{1/2}$ and the function $f\left(\frac{a_0}{W}\right)$ is given in Formula (H.2).

The ratio of minimum-to-maximum fatigue precracking force shall be in the range 0 to 0,1 except that to expedite crack initiation one or more cycles of –1,0 may be first applied.

NOTE For plain-sided specimens, $B_N = B$.

5.5 When fatigue precracking is performed at temperature T_1 and testing is performed at temperature T_2, F_f in Formula (2) shall be factored by the ratio $R_p\ [T_1]\ /\ R_{pd}\ [T_2]$, where $R_p\ [T_1]$ is the quasistatic yield strength at temperature T_1 and $R_{pd}\ [T_2]$ is the dynamic yield strength at temperature T_2. In addition, F_f determined from Formula (1) shall be evaluated using the smaller value of $R_p\ [T_1]$ and $R_{pd}\ [T_2]$.

5.6 Specimens may be side grooved, preferably after fatigue precracking, using a V-notch cutter in accordance with ISO 148-1 to a depth of 1,0 mm on each side. Side grooving is recommended for all J_d-Δa R-curve tests. For details of crack length measurement, see 9.4.2.

6 Testing machines

6.1 The tests may be carried out using testing machines of the general types specified in Annex A. Not all machines can perform all types of test (see Annex A for more details). In all cases, the striker and anvil dimensions shall conform to ISO 148-2.

6.2 Details of machine instrumentation and calibration procedures are specified in ISO 14556.

6.3 For every test in which the entire force signal has been recorded (i.e. the force returns to the baseline), the difference between KV and W_t shall be within ±15 % of KV or ±1 J, whichever is larger. If this requirement is not met but the difference does not exceed ±25 % of KV or ±2 J, whichever is larger, force values may be adjusted until $KV = W_t$.[3] If the difference exceeds ±25 % of KV or ±2 J, whichever is larger, the test shall be discarded and the calibration of the instrumented striker user shall be checked and if necessary repeated. If recording of the entire force signal is not possible (for example due to the specimen being ejected from the machine without being fully broken), conformance to the requirements stated earlier shall be demonstrated by testing, using the same experimental apparatus, at least five Charpy specimens (precracked, non-precracked, or a mix of precracked and non-precracked) of similar absorbed energy level, for which the entire force signal is recorded. In all cases, the difference between KV and W_t shall be within ±15 % of KV or ±1 J, whichever is larger.

7 Test procedures and measurements

7.1 General

Tests are performed in general accordance with the standard Charpy impact test of ISO 148-1, with allowance for other types of machines, as specified in Annex A.

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