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StandardTest Method for Instrumented Impact Testing of Metallic Materials[1]

This standard is issued under the fixed designation E2298; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method establishes the requirements for performing instrumented Charpy V-Notch (CVN) and instrumented Miniaturized Charpy V-Notch (MCVN) impact tests on metallic materials. This method, which is based on experience developed testing steels, provides further information (in addition to the total absorbed energy) on the fracture behavior of the tested materials. Minimum requirements are given for measurement and recording equipment such that similar sensitivity and comparable total absorbed energy measurements to those obtained in Test Methods E23 and E2248 are achieved.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products
E4 Practices for Force Verification of Testing Machines
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2248 Test Method for Impact Testing of Miniaturized Charpy V-Notch Specimens

2.2 *ISO Standard:*

ISO 14556 Steel—Charpy V-notch Pendulum Impact Tests—Instrumented Test Method[3]

3. Terminology

3.1 *Definitions*—The symbols and definitions applicable to instrumented impact testing are indicated in Table 1.

4. Summary of Test Method

4.1 This test method prescribes the requirements for instrumented CVN and MCVN impact tests in accordance with Test Methods E23 and E2248. The E23 and E2248 tests consist of breaking by one blow from a swinging pendulum, under conditions defined hereafter, a specimen notched in the middle and supported at each end. In order to establish the impact force-displacement diagram, it is necessary to instrument the striker with strain gages[4] and measure the voltage as a function of time during the impact event. The voltage-time curve is converted to the force-time curve through a suitable static calibration. The force-displacement relationship is then obtained by double integration of the force-time curve. The area under the force-displacement curve corresponds to the energy absorbed by the specimen during the test.

4.2 Force-displacement curves for different steels and different temperatures can vary even though the areas under the curves and the absorbed energies are identical. If the force-displacement curves are divided into a number of characteristic parts, various phases of the test with characteristic forces, displacements, and energies can be deduced. These characteristic values provide additional information about the fracture behavior of the specimen.

4.3 Application of instrumented test data to the evaluation of material behavior is the responsibility of the user of this test method.

5. Significance and Use

5.1 Instrumented impact testing provides an independent measurement of the total absorbed energy associated with

[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.07 on Impact Testing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] This test method refers to strikers instrumented with strain gages. However, the use of piezoelectric load cells or accelerometers is not excluded, provided their temperature sensitivity is properly accounted for.

TABLE 1 Symbols and Designations Related to Instrumented Impact Testing

Symbol	Definition	Unit
F_a	Force at end of unstable crack propagation (arrest force)	N
F_{gy}	General yield force	N
F_m	Maximum force	N
F_{bf}	Force at initiation of brittle fracture (unstable crack propagation)	N
g	Local acceleration due to gravity	m/s^2
h_0	Initial falling height of the striker	m
KV	Absorbed energy measured from the machine dial or encoder	J
m	Total effective mass of moving striker	kg
s_a	Displacement at end of unstable crack propagation (arrest force)	m
s_{gy}	Displacement at general yield	m
s_m	Displacement at maximum force	m
s_{bf}	Displacement at initiation of brittle fracture	m
s_t	Displacement at end of force-displacement curve	m
t_0	Time at the beginning of deformation of the specimen	s
v_0	Initial striker impact velocity	ms^{-1}
W_a	Partial impact energy from $F = 0$ to $F = F_a$	J
W_{bf}	Partial impact energy from $F = 0$ to $F = F_{bf}$	J
W_m	Partial impact energy from $F = 0$ to $F = F_m$	J
W_t	Total impact energy	J

fracturing CVN or MCVN specimens for test machines equipped with a dial and/or optical encoder.

5.2 Instrumented impact testing is particularly effective in MCVN testing since the resolution of a calibrated strain-gaged striker does not necessarily decrease with the magnitude of the measured energy.

5.3 In addition to providing an measure of total absorbed energy (W_t), instrumented testing enables the determination of characteristic force, energy, and displacement parameters. Depending on the material and test temperature, these parameters can provide very useful information (in addition to total absorbed energy) on the fracture behavior of materials such as: the temperature which corresponds to the onset of the lower shelf; the temperature which corresponds to the onset of the upper shelf; the pre-maximum force energy (W_m); the post-maximum force energy; the energy associated with shear lip tearing after brittle fracture; the general yield force (F_{gy}); the force at brittle fracture initiation (F_{bf}); the arrest force (F_a). The instrumented data may also be used to highlight test results which should be discarded on the basis of misalignment or other critical test factors.

6. Precautions in Operation of the Machine

6.1 Safety precautions should be taken to protect personnel from electric shock, the swinging pendulum, flying broken specimens, and hazards associated with specimen warming and cooling media. See also 1.3.

7. Apparatus

7.1 The test shall be carried out in accordance with Test Methods E23 or E2248 using a pendulum impact testing machine which is instrumented to determine force-time or force-displacement curves.

7.1.1 For instrumented CVN testing, the use of an instrumented striker conforming to the specifications of ISO 14556 (i.e., 2 mm radius of striking edge) is allowed. Available data (**1, 2**)[5] indicate that the influence of striker geometry on instrumented CVN forces is not very significant.

7.2 *Force Measurement:*

7.2.1 Force measurement is achieved by using an electronic sensor (piezoelectric load cell, strain gage load cell or a force measurement derived from an accelerometer).

7.2.2 The force measuring system (including strain gages, wiring, and amplifier) shall have an upper frequency bound of at least 100 kHz for CVN tests and 250 kHz for MCVN tests. For MCVN tests, if only absorbed energy has to be measured from the curve, an upper frequency limit of 100 kHz is sufficient. The upper frequency bound for the system shall be verified by measurement or analysis. Measurements can be made using a function generator which is wired directly to the strain gage bridge.

7.2.3 The signal shall be recorded without filtering. Post-test filtering, however, is allowed.

7.2.4 Calibration of the recorder and measurement system may be performed statically in accordance with the accuracy requirements given below. It is recommended that the force calibration be performed with the striker attached to the pendulum assembly. The strain gage signal conditioning equipment, cables, and recording device shall be used in the calibration. In most cases, a computer is used for data acquisition and the calibration shall be performed with the voltage read from the computer. The intent is to calibrate through the electronics and cables which are used during actual testing. Force is applied to the striker by using a suitable load frame with a load cell verified in accordance with Practices E4.

7.2.4.1 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 Fig. 1).

7.2.4.2 The instrumented striker system shall be calibrated to ensure accurate force readings are obtained over the nominal force range which will be encountered in testing. The strain gaged system shall be designed to minimize its sensitivity to non-symmetric loading.

7.2.5 Calibration shall be performed if the instrumented striker has undergone dismantling or repair, unless it can be shown that removal of the striker from the test machine, and subsequent reattachment to the machine, does not affect the calibration. Calibration shall also be performed under the circumstances described below.

7.2.6 *Requirements on Absorbed Energy*—For each test in which the entire force signal has been recorded (i.e., until the force returns to the baseline), the difference between absorbed energy given by the dial and/or optical encoder KV and the total impact energy W_t shall be within 15 % or 1 J, whichever is larger. If this requirement is not met but the difference does not exceed 25 % or 2 J, whichever is larger, force values shall

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

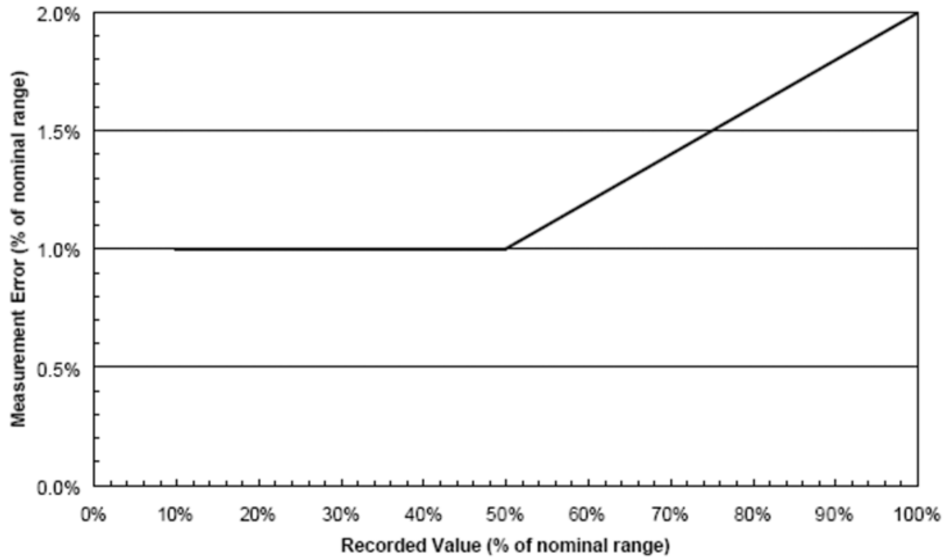

FIG. 1 Allowable Errors in Force Measurements

be adjusted until $KV = W_t$ within 0.01 J (**3**). If the difference exceeds 25 % or 2 J, whichever is larger, the test shall be discarded and the user shall check and if necessary repeat the calibration of the instrumented striker. 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), the user shall demonstrate conformance to the requirements above by testing at least five Charpy specimens of any equivalent material.

7.2.7 In order to verify the accuracy of the force values measured by the instrumented striker, dynamic impact force verification specimens are available, corresponding to maximum force (F_m) levels of 24 kN and 33 kN. These specimens are supplied by NIST in Boulder, CO as SRM 2112 (24 kN) and SRM 2113 (33 kN), and can also be used to verify the absorbed energy scale of the impact machine in accordance with Test Methods E23 at -40 °C ± 1 °C (low and high energy specimens) and room temperature (21 °C ± 1 °C, super-high energy specimens). The certified F_m values have been established at room temperature through an interlaboratory study (**4**) involving six international laboratories, see also 13.1.3.

7.3 *Displacement Determination:*

7.3.1 Displacement is normally determined by converting a strain gage voltage-time measurement to a force-time measurement. The force-time relationship is proportional to the acceleration as a function of time. Given an assumed rigid striker of mass *m*, the initial impact velocity v_0, the time *t* following the beginning of the deformation at t_0, and expressing the velocity as a function of time by $v(t)$, the specimen bending displacement $s(t)$ is calculated by double numerical integration as follows:

$$v(t) = v_0 - \frac{1}{m}\int_{t_0}^{t} F(t)dt \quad (1)$$

$$s(t) = \int_{t_0}^{t} v(t)dt \quad (2)$$

7.3.2 The initial impact velocity needed to perform the above integrations may be calculated from:

$$v_0 = \sqrt{2gh_0} \quad (3)$$

where:

g = the local acceleration due to gravity, and
h_0 = the falling height of the striker.

7.3.2.1 Alternatively, the velocity signal registered when the pendulum passes through its lowest position and strikes the specimen can be optically measured directly to determine v_0.

7.3.3 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 must correspond to that of the force measuring system in order to make the two recordings synchronous. The displacement measuring system shall be designed for nominal values of up to 30 mm. Linearity errors in the measuring system shall yield measured values to within +2 % in the range 1–30 mm. Measurements between zero and 1 mm may not be sufficiently accurate to determine the displacement. In such cases, it is recommended that the displacement of the specimen be determined from time measurement and the striker impact velocity as indicated in Eq 1 and 2.

7.4 *Recording Apparatus:*

7.4.1 The minimum data acquisition requirement is a 10-bit analog-digital converter with a minimum sampling rate of 1000 data points per millisecond. However, 12-bit or more is recommended. A minimum storage capacity of 8000 data points is required.

7.4.2 The total absorbed energy measured using instrumentation shall be compared with that shown by the machine dial (only for CVN testing), or preferably, by comparison with an optical encoder (for both CVN and MCVN testing). If total absorbed energy is measured using a machine dial or optical encoder, then this data shall be reported along with the instrumented striker energy. For requirements on absorbed energy based on the comparison between KV and W_t, refer to 7.2.6.

8. Test Specimens

8.1 The CVN specimens shall be in accordance with Test Method E23. The MCVN specimens shall be in accordance with Test Method E2248.

9. Procedure

9.1 *Specimen Testing*—The test is performed in the same way as the CVN or MCVN impact test according to Test Methods E23 or E2248, respectively. In addition, the voltage-time curve is measured and evaluated to give the force-displacement curve. The force-displacement curve is evaluated with respect to the characteristic phases of the deformation and fracture stages.

9.2 *Data Acquisition*—The high speed acquisition system (the portion of the system which is capable of storing the dynamic response signal) shall be triggered such that baseline data before loading and after fracture (or release of the specimen from the anvils) is retained in computer memory.

10. Characteristics of the Force-Displacement Curve

10.1 *Type of Force-Displacement Curve*—Representative force-displacement curves and their characteristic force values are illustrated in Fig. 2.

10.2 *Characteristic Values of Force:*

10.2.1 The general yield force F_{gy} is the force at the transition point from the initial linear elastic part, discarding the inertia peaks (normally one, unless the specimen was not fully in contact with the anvils), to the curved increasing part of the force-displacement curve. It serves, to a first approximation, as an indication of yielding across the entire ligament.

10.2.2 The maximum force F_m corresponds to the maximum value of the curve fitted through the oscillations of the force-displacement curve following the onset of yield of the entire ligament.

10.2.3 The force at the initiation of unstable crack propagation F_{bf} is the force at the beginning of the steep drop in the force-displacement curve. It characterizes the beginning of unstable crack propagation.

10.2.4 The force at the end (arrest) of unstable crack propagation is F_a.

10.3 *Characteristic Values of Displacement*—The forces defined in 10.2 have corresponding displacements which are given the same subscripts as the forces. In addition, a displacement corresponding to the end of the force-displacement curve, s_t, is defined.

10.3.1 The displacement at the onset of general yielding of the ligament is s_{gy}.

10.3.2 The displacement at maximum force is s_m.

10.3.3 The displacement at the initiation of unstable crack propagation is s_{bf}.

10.3.4 The displacement at the end (arrest) of unstable crack propagation is s_a (generally, s_a is approximately equal to s_{bf} due to the steep drop in the force-displacement curve between F_{bf} and F_a).

10.3.5 The displacement at the end of the force-displacement curve is s_t. This point is defined as the displacement at which the force has decreased to the pre-test baseline value.

10.4 *Characteristic Values of Impact Energy:*

10.4.1 Given the force definitions in 10.1, the force-displacement curve may be partitioned and corresponding energies may be determined. The values of the partial impact energies are given the same subscript as the force at the end of the appropriate part of the force-displacement curve.

10.4.2 The area under the complete force-displacement curve up to s_t is the total impact energy with the abbreviation W_t.

10.4.3 The impact energy up to maximum force is W_m.

10.4.4 The impact energy up to the force at the initiation of unstable crack propagation is W_{bf}.

10.4.5 The impact energy up to the force at the arrest of unstable crack propagation is W_a (on account of the steep drop in the force-displacement curve between F_{bf} and F_a, it is generally the case that W_{bf} is approximately equal to W_a).

11. Evaluation of the Force-Displacement Curve

11.1 The force-displacement curve is determined by double numerical integration of the force-time curve.

11.2 Representative force-displacement curves of various types are given in Fig. 2. These can be grouped as the following types:

Type A	Lower shelf (brittle fracture)
Type B	Ductile-to-Brittle Transition Region (mixed mode fracture)
Type C	Upper shelf (ductile fracture)

NOTE 1—The type of force-displacement curve may be determined by comparison with the examples shown in Fig. 2.

11.2.1 With force-displacement curves of type A, typically only unstable (brittle) crack propagation occurs. For type B, various amounts of stable and unstable crack propagation can occur. For type C, only stable (ductile) crack propagation occurs.

11.3 A condition for further evaluation of the force-displacement curve is the occurrence of a well defined general yield force F_{gy}. It should be noted that force oscillations are