Designation: E1921 – 23b

Standard Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range[1]

This standard is issued under the fixed designation E1921; 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 covers the determination of a reference temperature, T_0, which characterizes the fracture toughness of ferritic steels that experience onset of cleavage cracking at elastic, or elastic-plastic K_{Jc} instabilities, or both. The specific types of ferritic steels (3.2.2) covered are those with yield strengths ranging from 275 MPa to 825 MPa (40 ksi to 120 ksi) and weld metals, after stress-relief annealing, that have 10 % or less strength mismatch relative to that of the base metal.

1.2 The specimens covered are fatigue precracked single-edge notched bend bars, SE(B), and standard or disk-shaped compact tension specimens, C(T) or DC(T). A range of specimen sizes with proportional dimensions is recommended. The dimension on which the proportionality is based is specimen thickness.

1.3 Median K_{Jc} values tend to vary with the specimen type at a given test temperature, presumably due to constraint differences among the allowable test specimens in 1.2. The degree of K_{Jc} variability among specimen types is analytically predicted to be a function of the material flow properties (**1**)[2] and decreases with increasing strain hardening capacity for a given yield strength material. This K_{Jc} dependency ultimately leads to discrepancies in calculated T_0 values as a function of specimen type for the same material. T_0 values obtained from C(T) specimens are expected to be higher than T_0 values obtained from SE(B) specimens. Best estimate comparisons of several materials indicate that the average difference between C(T) and SE(B)-derived T_0 values is approximately 10°C (**2**). C(T) and SE(B) T_0 differences up to 15 °C have also been recorded (**3**). However, comparisons of individual, small data-sets may not necessarily reveal this average trend. Datasets which contain both C(T) and SE(B) specimens may generate T_0 results which fall between the T_0 values calculated using solely C(T) or SE(B) specimens. It is therefore strongly recommended that the specimen type be reported along with the derived T_0 value in all reporting, analysis, and discussion of results. This recommended reporting is in addition to the requirements in 11.1.1.

1.4 Requirements are set on specimen size and the number of replicate tests that are needed to establish acceptable characterization of K_{Jc} data populations.

1.5 T_0 is dependent on the K-rate. T_0 is evaluated for a quasi-static K-rate range with $0.5 < \bar{\dot{K}}_I < 2$ MPa√m/s. T_0 values for slowly loaded specimens ($\bar{\dot{K}}_I < 0.5$ MPa√m) can be considered valid if environmental effects are known to be negligible. Provision is also made for higher K-rates ($\bar{\dot{K}}_I > 2$ MPa√m/s) in Annex A1. Note that this threshold K-rate for application of Annex A1 is a much lower threshold than is required in other fracture toughness test methods such as E399 and E1820.

1.6 The statistical effects of specimen size on K_{Jc} in the transition range are treated using the weakest-link theory (**4**) applied to a three-parameter Weibull distribution of fracture toughness values. A limit on K_{Jc} values, relative to the specimen size, is specified to ensure high constraint conditions along the crack front at fracture. For some materials, particularly those with low strain hardening, this limit may not be sufficient to ensure that a single-parameter (K_{Jc}) adequately describes the crack-front deformation state (**5**).

1.7 Statistical methods are employed to predict the transition toughness curve and specified tolerance bounds for 1T specimens of the material tested. The standard deviation of the data distribution is a function of Weibull slope and median K_{Jc}. The procedure for applying this information to the establishment of transition temperature shift determinations and the establishment of tolerance limits is prescribed.

1.8 The procedures described in this test method assume that the data set represents a macroscopically homogeneous material, such that the test material has uniform tensile and toughness properties. Application of this test method to an inhomogeneous material will result in an inaccurate estimate of the transition reference value T_0 and nonconservative confidence bounds. For example, multi-pass weldments can create heat-affected and brittle zones with localized properties that are

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[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of E08.07 on Fracture Mechanics.

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

quite different from either the bulk or weld materials. Thick-section steels also often exhibit some variation in properties near the surfaces. Metallography and initial screening may be necessary to verify the applicability of these and similarly graded materials. Section 10.6 provides a screening criterion to assess whether the data set may not be representative of a macroscopically homogeneous material, and therefore, may not be amenable to the statistical analysis procedures employed in this test method. If the data set fails the screening criterion in 10.6, the homogeneity of the material and its fracture toughness can be more accurately assessed using the analysis methods described in Appendix X5.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E4 Practices for Force Calibration and Verification of Testing Machines
E8/E8M Test Methods for Tension Testing of Metallic Materials
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E74 Practices for Calibration and Verification for Force-Measuring Instruments
E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
E399 Test Method for Linear-Elastic Plan-Strain Fracture Toughness K_{Ic} of Metallic Materials
E436 Test Method for Drop-Weight Tear Tests of Ferritic Steels
E561 Test Method for K_R Curve Determination
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1820 Test Method for Measurement of Fracture Toughness
E1823 Terminology Relating to Fatigue and Fracture Testing

2.2 *ASME Standards:*[4]

ASME Boiler and Pressure Vessel Code, Section II, Part D

[3] 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.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

3. Terminology

3.1 Terminology given in Terminology E1823 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *effective yield strength, σ_Y [FL^{-2}]*— an assumed value of uniaxial yield strength that represents the influence of plastic yielding upon fracture test parameters.

3.2.1.1 *Discussion*—It is calculated as the average of the 0.2 % offset yield strength σ_{YS}, and the ultimate tensile strength, σ_{TS} as follows:

$$\sigma_Y = \frac{\sigma_{YS} + \sigma_{TS}}{2}$$

3.2.2 *ferritic steels*—typically carbon, low-alloy, and higher alloy grades. Typical microstructures are bainite, tempered bainite, tempered martensite, and ferrite and pearlite. All ferritic steels have body centered cubic crystal structures that display ductile-to-cleavage transition temperature fracture toughness characteristics. See also Test Methods E23, E208 and E436.

3.2.2.1 *Discussion*—This definition is not intended to imply that all of the many possible types of ferritic steels have been verified as being amenable to analysis by this test method.

3.2.3 *stress-intensity factor, K [$FL^{-3/2}$]*—the magnitude of the mathematically ideal crack-tip stress field coefficient (stress field singularity) for a particular mode of crack-tip region deformation in a homogeneous body.

3.2.3.1 *Discussion*—In this test method, Mode I is assumed. See Terminology E1823 for further discussion.

3.2.4 *J-integral, J [FL^{-1}]*—a mathematical expression; a line or surface integral that encloses the crack front from one crack surface to the other; used to characterize the local stress-strain field around the crack front (**6**). See Terminology E1823 for further discussion.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *average stress-intensity-factor rate $\bar{\dot{K}}_I$ [$FL^{-3/2}T^{-1}$]*—average rate of increase of applied stress-intensity factor up to K_{Jc}.

3.3.1.1 *Discussion*—It is evaluated as the ratio between K_{Jc} and the corresponding time to cleavage. For tests where partial unloading/reloading sequences are used to measure compliance, an equivalent time to cleavage (t_c) shall be used to calculate the stress-intensity-factor rate (that is, *K*-rate). The value of t_c is calculated as the ratio between the value of load-line displacement at cleavage and the load-line displacement rate applied during the monotonic loading portions of the test (that is, the periods between partial unloading/reloading sequences used for compliance measurement). Additionally, in such tests, the total time of unloading/loading sequences should be shorter than the total time of monotonic loading.

3.3.2 *control force, P_m [F]*—a calculated value of maximum force, used in 7.8.1 to stipulate allowable precracking limits.

3.3.3 *crack initiation*—describes the onset of crack propagation from a preexisting macroscopic crack created in the specimen by a stipulated procedure.