3.2.21 *plane-strain fracture toughness,* J_{Ic} *[FL^{-1}],* K_{JIc} *[$FL^{-3/2}$]* , *n*—the crack-extension resistance under conditions of crack-tip plane-strain.

3.2.21.1 *Discussion*—For example, in Mode I for slow rates of loading and substantial plastic deformation, plane-strain fracture toughness is the value of the *J*-integral designated J_{Ic} [FL^{-1}] as measured using the operational procedure (and satisfying all of the qualification requirements) specified in this test method, that provides for the measurement of crack-extension resistance near the onset of stable crack extension.

3.2.21.2 *Discussion*—For example, in Mode I for slow rates of loading, plane-strain fracture toughness is the value of the stress intensity designated K_{JIc} calculated from J_{Ic} using the equation (and satisfying all of the qualification requirements) specified in this test method, that provides for the measurement of crack-extension resistance near the onset of stable crack extension under dominant elastic conditions (**2**).

3.2.21.3 *Discussion*—The dynamic equivalent of J_{Ic} is $J_{Icd,X}$, with X = order of magnitude of *J*-integral rate.

3.2.22 *pop-in, n*—a discontinuity in the force versus clip gage displacement record. The record of a pop-in shows a sudden increase in displacement and, generally a decrease in force. Subsequently, the displacement and force increase to above their respective values at pop-in.

3.2.23 *R-curve or J-R curve, n*—a plot of crack extension resistance as a function of stable crack extension, Δa_p or Δa_e.

3.2.23.1 *Discussion*—In this test method, the *J*-R curve is a plot of the far-field *J*-integral versus the physical crack extension, Δa_p. It is recognized that the far-field value of *J* may not represent the stress-strain field local to a growing crack.

3.2.24 *remaining ligament, b [L], n*—distance from the physical crack front to the back edge of the specimen, that is ($b = W - a_p$).

3.2.25 *specimen center of pin hole distance, H* [L], n*—the distance between the center of the pin holes on a pin-loaded specimen.

3.2.26 *specimen gage length, d [L], n*—the distance between the points of displacement measure (for example, clip gage, gage length).

3.2.27 *specimen span, S [L], n*—the distance between specimen supports.

3.2.28 *specimen thickness, B [L], n*—the distance between the parallel sides of a test specimen.

3.2.28.1 *Discussion*—For side-grooved specimens, the net thickness, B_N, is the distance between the roots of the side grooves.

3.2.29 *specimen width, W [L], n*—a physical dimension on a test specimen measured from a reference position such as the front edge in a bend specimen or the load-line in the compact specimen to the back edge of the specimen.

3.2.30 *stable crack extension [L], n*—a displacement-controlled crack extension beyond the stretch-zone width (see 3.2.34). The extension stops when the applied displacement is held constant.

3.2.31 *strain rate,* $\dot{\varepsilon}$—derivative of strain ε with respect to time.

3.2.32 *stress-intensity factor, K,* K_1, K_2, K_3, K_I, K_{II}, K_{III} *[$FL^{-3/2}$], n*—the magnitude of the ideal-crack-tip stress field (stress-field singularity) for a particular mode in a homogeneous, linear-elastic body.

3.2.32.1 *Discussion*—Values of *K* for the Modes 1, 2, and 3 are given by the following equations:

$$K_1 = \lim_{r \to 0} \left[\sigma_{yy} (2\pi r)^{1/2} \right] \tag{3}$$

$$K_2 = \lim_{r \to 0} \left[\tau_{xy} (2\pi r)^{1/2} \right] \tag{4}$$

$$K_3 = \lim_{r \to 0} \left[\tau_{yz} (2\pi r)^{1/2} \right] \tag{5}$$

where r = distance directly forward from the crack tip to a location where the significant stress is calculated.

3.2.32.2 *Discussion*—In this test method, Mode 1 or Mode I is assumed. See Terminology E1823 for definition of mode.

3.2.33 *stress-intensity factor rate,* $\dot{K}$ *[$FL^{-3/2}T^{-1}$]*—derivative of *K* with respect to time.

3.2.34 *stretch-zone width, SZW [L], n*—the length of crack extension that occurs during crack-tip blunting, for example, prior to the onset of unstable brittle crack extension, pop-in, or slow stable crack extension. The *SZW* is in the same plane as the original (unloaded) fatigue precrack and refers to an extension beyond the original crack size.

3.2.35 *time to fracture,* t_f *[T]*—time corresponding to specimen fracture.

3.2.36 *unstable crack extension [L], n*—an abrupt crack extension that occurs with or without prior stable crack extension in a standard test specimen under crosshead or clip gage displacement control.

3.3 *Symbols:*

3.3.1 t_i *[T]*—time corresponding to the onset of crack propagation.

3.3.2 v_0 *[LT^{-1}]*—in an instrumented impact test, striker velocity at impact.

3.3.3 W_m *[FL]*—in an instrumented impact test, absorbed energy at maximum force.

3.3.4 W_t *[FL]*—in an instrumented impact test, total absorbed energy calculated from the complete force/displacement test record.

3.3.5 W_0 *[FL]*—in an instrumented impact test, available impact energy.

4. Summary of Test Method

4.1 The objective of this test method is to load a fatigue precracked test specimen to induce either or both of the following responses (*1*) unstable crack extension, including significant pop-in, referred to as "fracture instability" in this test method; (*2*) stable crack extension, referred to as "stable tearing" in this test method. Fracture instability results in a single point-value of fracture toughness determined at the point of instability. Stable tearing results in a continuous fracture toughness versus crack-extension relationship (R-curve) from which significant point-values may be determined. Stable tearing interrupted by fracture instability results in an R-curve up to the point of instability.

4.2 This test method requires continuous measurement of force versus load-line displacement or crack mouth opening displacement, or both. If any stable tearing response occurs, then an R-curve is developed and the amount of slow-stable crack extension shall be measured.

4.3 Two alternative procedures for measuring crack extension are presented, the basic procedure and the resistance curve procedure. The basic procedure involves physical marking of the crack advance and multiple specimens used to develop a plot from which a single point initiation toughness value can be evaluated. The resistance curve procedure is an elastic-compliance method where multiple points are determined from a single specimen. In the latter case, high precision of signal resolution is required. These data can also be used to develop an R-curve. Other procedures for measuring crack extension are allowed.

4.4 The commonality of instrumentation and recommended testing procedure contained herein permits the application of data to more than one method of evaluating fracture toughness. Annex A4 and Annex A6 – Annex A11 define the various data treatment options that are available, and these should be reviewed to optimize data transferability.

4.5 Data that are generated following the procedures and guidelines contained in this test method are labeled qualified data. Data that meet the size criteria in Annex A4 and Annex A6 – Annex A11 are insensitive to in-plane dimensions.

4.6 Supplementary information about the background of this test method and rationale for many of the technical requirements of this test method are contained in (**3**). The formulas presented in this test method are applicable over the range of crack size and specimen sizes within the scope of this test method.

5. Significance and Use

5.1 Assuming the presence of a preexisting, sharp, fatigue crack, the material fracture toughness values identified by this test method characterize its resistance to: *(1)* fracture of a stationary crack, *(2)* fracture after some stable tearing, *(3)* stable tearing onset, and *(4)* sustained stable tearing. This test method is particularly useful when the material response cannot be anticipated before the test. Application of procedures in Test Method E1921 is recommended for testing ferritic steels that undergo cleavage fracture in the ductile-to-brittle transition.

5.1.1 These fracture toughness values may serve as a basis for material comparison, selection, and quality assurance. Fracture toughness can be used to rank materials within a similar yield strength range.

5.1.2 These fracture toughness values may serve as a basis for structural flaw tolerance assessment. Awareness of differences that may exist between laboratory test and field conditions is required to make proper flaw tolerance assessment.

5.2 The following cautionary statements are based on some observations.

5.2.1 Particular care must be exercised in applying to structural flaw tolerance assessment the fracture toughness value associated with fracture after some stable tearing has occurred. This response is characteristic of ferritic steel in the transition regime. This response is especially sensitive to material inhomogeneity and to constraint variations that may be induced by planar geometry, thickness differences, mode of loading, and structural details.

5.2.2 The *J*-R curve from bend-type specimens recommended by this test method (SE(B), C(T), and DC(T)) has been observed to be conservative with respect to results from tensile loading configurations.

5.2.3 The values of δ_c, δ_u, J_c, and J_u may be affected by specimen dimensions.

6. Apparatus

6.1 Apparatus is required for measurement of applied force, load-line displacement, and crack-mouth opening displacement. Force versus load-line displacement and force versus crack-mouth opening displacement may be recorded digitally for processing by computer or autographically with an *x-y* plotter. Test fixtures for each specimen type are described in the applicable Annex.

6.2 *Displacement Gages:*

6.2.1 Displacement measurements are needed for the following purposes: to evaluate *J* from the area under the force versus load-line displacement record, *CTOD* from the force versus crack-mouth opening displacement record and, for the elastic compliance method, to infer crack extension, Δa_p, from elastic compliance calculations.

6.2.2 The recommended displacement gage has a working range of not more than twice the displacement expected during the test. When the expected displacement is less than 3.75 mm (0.15 in.), the gage recommended in Fig. 2 may be used. When a greater working range is needed, an enlarged gage such as the one shown in Fig. 3 is recommended. Accuracy shall be within ±1 % of the full working range. In calibration, the maximum deviation of the individual data points from a fit (linear or curve) to the data shall be less than ±0.2 % of the working range of the gage when using the elastic compliance method and ±1 % otherwise. Knife edges are required for seating the gage. Parallel alignment of the knife edges shall be maintained to within 1°. Direct methods for measuring load-line displacement are described in Refs (**3-6**).

6.2.2.1 *Gage Attachment Methods*—The specimen shall be provided with a pair of accurately machined knife edges that support the gage arms and serve as the displacement reference points. These knife edges can be machined integral with the specimen or they may be attached separately. Experience has shown that razor blades serve as effective attachable knife edges. The knife edges shall be positively attached to the specimen to prevent shifting of the knife edges during the test method. Experience has shown that machine screws or spot welds are satisfactory attachment methods.

6.2.3 For the elastic compliance method, the recommended signal resolution for displacement should be at least 1 part in 32 000 of the transducer signal range, and signal stability should be ±4 parts in 32 000 of the transducer signal range measured over a 10-min period. Signal noise should be less than ±2 parts in 32 000 of the transducer signal range.