Designation: E1221 – 12a

Standard Test Method for Determining Plane-Strain Crack-Arrest Fracture Toughness, K_{Ia}, of Ferritic Steels[1]

This standard is issued under the fixed designation E1221; 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 employs a side-grooved, crack-line-wedge-loaded specimen to obtain a rapid run-arrest segment of flat-tensile separation with a nearly straight crack front. This test method provides a static analysis determination of the stress intensity factor at a short time after crack arrest. The estimate is denoted K_a. When certain size requirements are met, the test result provides an estimate, termed K_{Ia}, of the plane-strain crack-arrest toughness of the material.

1.2 The specimen size requirements, discussed later, provide for in-plane dimensions large enough to allow the specimen to be modeled by linear elastic analysis. For conditions of plane-strain, a minimum specimen thickness is also required. Both requirements depend upon the crack arrest toughness and the yield strength of the material. A range of specimen sizes may therefore be needed, as specified in this test method.

1.3 If the specimen does not exhibit rapid crack propagation and arrest, K_a cannot be determined.

1.4 The values stated in SI units are to be regarded as the standards. The values given in parentheses are provided for information only.

1.5 *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]

E8 Test Methods for Tension Testing of Metallic Materials
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E616 Terminology Relating to Fracture Testing (Discontinued 1996) (Withdrawn 1996)[3]
E1304 Test Method for Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions in Terminology E1823 are applicable to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *conditional value of the plane-strain crack-arrest fracture toughness, K_{Qa} ($FL^{-3/2}$)* —the conditional value of K_{Ia} calculated from the test results and subject to the validity criteria specified in this test method.

3.2.1.1 *Discussion*—In this test method, side-grooved specimens are used. The calculation of K_{Qa} is based upon measurements of both the arrested crack size and of the crack-mouth opening displacement prior to initiation of a fast-running crack and shortly after crack arrest.

3.2.2 *crack-arrest fracture toughness, K_A ($FL^{-3/2}$)*—the value of the stress intensity factor shortly after crack arrest as determined from dynamic methods of analysis.

3.2.2.1 *Discussion*—The in-plane specimen dimensions must be large enough for adequate enclosure of the crack-tip plastic zone by a linear-elastic stress field.

3.2.3 *crack-arrest fracture toughness, K_a ($FL^{-3/2}$)*—the value of the stress intensity factor shortly after crack arrest, as determined from static methods of analysis.

3.2.3.1 *Discussion*—The in-plane specimen dimensions must be large enough for adequate enclosure of the crack-tip plastic zone by a linear-elastic stress field.

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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 Subcommittee E08.07 on Fracture Mechanics.

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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] The last approved version of this historical standard is referenced on www.astm.org.

3.2.4 *plane-strain crack-arrest fracture toughness,* K_{Ia} *$(FL^{-3/2})$*—the value of crack-arrest fracture toughness, K_a, for a crack that arrests under conditions of crack-front plane-strain.

3.2.4.1 *Discussion*—The requirements for attaining conditions of crack-front plane-strain are specified in the procedures of this test method.

3.2.5 *stress intensity factor at crack initiation,* K_o *$(FL^{-3/2})$*—the value of K at the onset of rapid fracturing.

3.2.5.1 *Discussion*—In this test method, only a nominal estimate of the initial driving force is needed. For this reason, K_o is calculated on the basis of the original (machined) crack (or notch) size and the crack-mouth opening displacement at the initiation of a fast-running crack.

4. Summary of Test Method

4.1 This test method estimates the value of the stress intensity factor, K, at which a fast running crack will arrest. This test method is made by forcing a wedge into a split-pin, which applies an opening force across the crack starter notch in a modified compact specimen, causing a run-arrest segment of crack extension. The rapid run-arrest event suggests need for a dynamic analysis of test results. However, experimental observations (**1, 2**)[4] indicate that, for this test method, an adjusted static analysis of test results provides a useful estimate of the value of the stress intensity factor at the time of crack arrest.

4.2 Calculation of a nominal stress intensity at initiation, K_o, is based on measurements of the machined notch size and the crack-mouth opening displacement at initiation. The value of K_a is based on measurements of the arrested crack size and the crack-mouth opening displacements prior to initiation and shortly after crack arrest.

5. Significance and Use

5.1 In structures containing gradients in either toughness or stress, a crack may initiate in a region of either low toughness or high stress, or both, and arrest in another region of either higher toughness or lower stress, or both. The value of the stress intensity factor during the short time interval in which a fast-running crack arrests is a measure of the ability of the material to arrest such a crack. Values of the stress intensity factor of this kind, which are determined using dynamic methods of analysis, provide a value for the crack-arrest fracture toughness which will be termed K_A in this discussion. Static methods of analysis, which are much less complex, can often be used to determine K at a short time (1 to 2 ms) after crack arrest. The estimate of the crack-arrest fracture toughness obtained in this fashion is termed K_a. When macroscopic dynamic effects are relatively small, the difference between K_A and K_a is also small (**1-4**). For cracks propagating under conditions of crack-front plane-strain, in situations where the dynamic effects are also known to be small, K_{Ia} determinations using laboratory-sized specimens have been used successfully to estimate whether, and at what point, a crack will arrest in a structure (**5, 6**). Depending upon component design, loading compliance, and the crack jump length, a dynamic analysis of a fast-running crack propagation event may be necessary in order to predict whether crack arrest will occur and the arrest position. In such cases, values of K_{Ia} determined by this test method can be used to identify those values of K below which the crack speed is zero. More details on the use of dynamic analyses can be found in Ref (**4**).

5.2 This test method can serve at least the following additional purposes:

5.2.1 In materials research and development, to establish in quantitative terms significant to service performance, the effects of metallurgical variables (such as composition or heat treatment) or fabrication operations (such as welding or forming) on the ability of a new or existing material to arrest running cracks.

5.2.2 In design, to assist in selection of materials for, and determine locations and sizes of, stiffeners and arrestor plates.

6. Apparatus

6.1 The procedure involves testing of modified compact specimens that have been notched by machining. To minimize the introduction of additional energy into the specimen during the run-arrest event, the loading system must have a low compliance compared with the test specimen. For this reason a wedge and split-pin assembly is used to apply a force on the crack line. This loading arrangement does not permit easy measurement of opening forces. Consequently, opening displacement measurements in conjunction with crack size and compliance calibrations are used for calculating K_o and K_a.

6.2 *Loading Arrangement:*

6.2.1 A typical loading arrangement is shown in Fig. 1. The specimen is placed on a support block whose thickness should be adequate to allow completion of the test without interference between the wedge and the lower crosshead of the testing machine. The support block should contain a hole that is aligned with the specimen hole, and whose diameter should be between 1.05 and 1.15 times the diameter of the hole in the specimen. The force that pushes the wedge into the split-pin is transmitted through a force transducer.

6.2.1.1 The surfaces of the wedge, split-pin, support block, and specimen hole should be lubricated. Lubricant in the form of thin (0.13 mm or 0.005 in.) strips of TFE-fluorocarbon is preferred. Molybdenum disulfide (both dry and in a grease vehicle) and high-temperature lubricants can also be used.

6.2.1.2 A low-taper-angle wedge and split-pin arrangement is used. If grease or dry lubricants are used, a matte finish (grit blasted) on the sliding surfaces may be helpful in avoiding galling. The split-pin must be long enough to contact the full specimen thickness, and the radius must be large enough to avoid plastic indentations of the test specimen. In all cases it is recommended that the diameter of the split-pin should be 0.13 mm (0.005in.) less than the diameter of the specimen hole. The wedge must be long enough to develop the maximum expected opening displacement. Any air or oil hardening tool steel is suitable for making the wedge and split-pins. A hardness in the range from R_C 45 to R_C 55 has been used successfully. With the recommended wedge angle and proper lubrication, a loading machine producing ⅕ to 1⁄10 the expected maximum opening force is adequate. The dimensions of a wedge and split-pin

[4] The boldface numbers in parentheses refer to the list of references at the end of this test method.

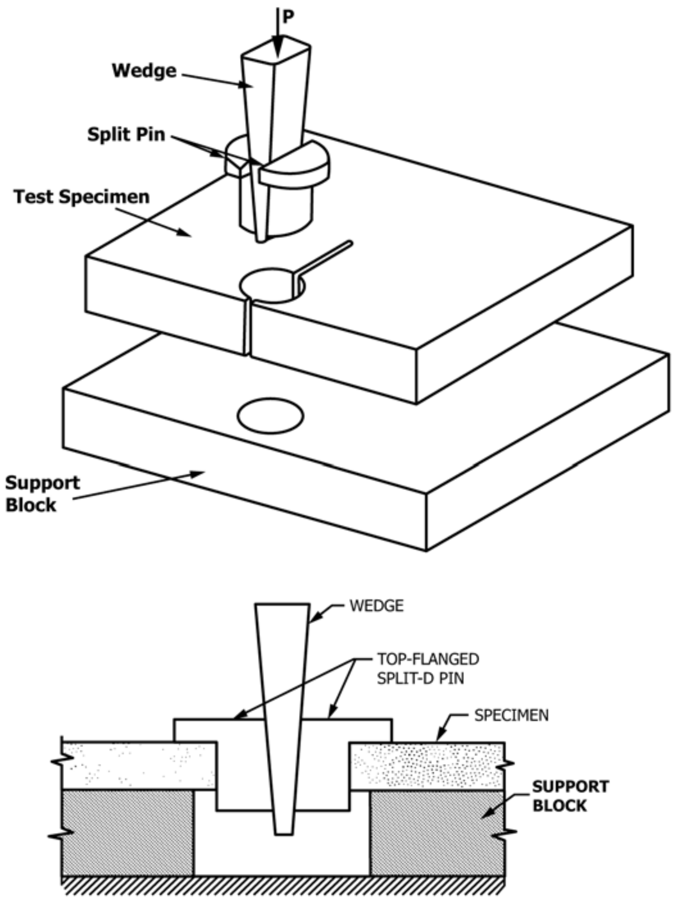

FIG. 1 Schematic Pictorial and Sectional Views Showing the Standard Arrangement of the Wedge and Split-Pin Assembly, the Test Specimen, and the Support Block

assembly suitable for use with a 25.4-mm (1.0-in.) diameter loading hole are shown in Fig. 2. The dimensions should be scaled when other hole diameters are used. A hole diameter of 1.0 in. has been found satisfactory for specimens having 125 < W < 170 mm (5 < W < 6.7 in.).

NOTE 1—Specimens tested with the arrangement shown in Fig. 1 may not exhibit an adequate segment of run-arrest fracturing, for example, at testing temperatures well above the NDT temperature. In these circumstances, the use of the loading arrangement shown in Fig. 3 has been found to be helpful (**2, 7**) and may be employed.

6.3 *Displacement Gages*—Displacement gages are used to measure the crack-mouth opening displacement at 0.25W from the load-line. Accuracy within 2 % over the working range is required. Either the gage recommended in Test Method E399 or a similar gage modified to accommodate conical seats is satisfactory. It is necessary to attach the gage in a fashion such that seating contact with the specimen is not altered by the jump of the crack. Two methods that have proven satisfactory for doing this are shown in Fig. 4. Other gages can be used so long as their accuracy is within 2 %.

7. Specimen Configuration, Dimensions, and Preparation

7.1 *Standard Specimen:*

7.1.1 The configuration of a compact-crack-arrest (CCA) specimen that is satisfactory for low- and intermediatestrength steels is shown in Fig. 5. (In this context, an intermediate-strength steel is considered to be one whose static yield stress, σ_{YS}, is of the order of 700 MPa (100 ksi) or less.)

7.1.1.1 The thickness, B, shall be either full product plate thickness or a thickness sufficient to produce a condition of plane-strain, as specified in 9.3.3.

7.1.1.2 Side grooves of depth B/8 per side shall be used. For alloys that require notch-tip embrittlement (see 7.1.3.2) the side grooves should be introduced after deposition of the brittle weld.

7.1.1.3 The specimen width, W, shall be within the range $2B \leq W \leq 8B$.

7.1.1.4 The displacement gage shall measure opening displacements at an offset from the load line of 0.25W, away from the crack tip.

7.1.2 *Specimen Dimensions:*

7.1.2.1 In order to limit the extent of plastic deformation in the specimen prior to crack initiation, certain size requirements must be met. These requirements depend upon the material yield strength. They also depend upon K_a, and therefore the K_o needed to achieve an appropriate run-arrest event.

7.1.2.2 The in-plane specimen dimensions must be large enough to allow for the linear elastic analysis employed by this test method. These requirements are given in 9.3.2 and 9.3.4, in terms of allowable crack jump lengths.

7.1.2.3 For a test result to be termed plane-strain (K_{Ia}) by this test method, the specimen thickness, B, should meet the requirement given in 9.3.3.

7.1.3 *Starting Notch:*

7.1.3.1 The function of the starting notch is to produce crack initiation at an opening displacement (or wedging force) that will permit an appropriate length of crack extension prior to crack arrest. Different materials require different starter notch preparation procedures.

7.1.3.2 The recommended starter notch for low- and intermediate-strength steels is a notched brittle weld, as shown in Fig. 6. It is produced by depositing a weld across the specimen thickness. Guidelines on welding procedures are given in Appendix X1.

7.1.3.3 Alternative crack starter configurations (**8**) and embrittlement methods may also be used. Examples of both alternative configurations and alternative test methods are also described in Appendix X1.

7.1.3.4 While it is expected that a_o values for the starting notch will typically lie in the range 0.30 W ≤ a_o ≤ 0.40 W, it is sometimes useful to utilize values as low as 0.20 W. The lower initial value of a_o /W results in a greater and quicker drop in the crack driving force as the crack extends. This may aid in arresting the running crack at a shorter final crack length and could be useful for conditions where the crack extension is too great with larger initial a_o /W values.

8. Procedure

8.1 *Number of Tests*—It is recommended that at least three valid test results be obtained at a single test temperature.