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INTERNATIONAL

Designation: E1221 − 23

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

1.6 *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:*[2]

E8/E8M 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 of Metallic Materials
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.

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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.

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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.

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**)[3] 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 (0.005 in.) 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

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