Designation: E1681 – 23

Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials[1]

This standard is issued under the fixed designation E1681; 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 the environment-assisted cracking threshold stress intensity factor parameters, K_{IEAC} and K_{EAC}, for metallic materials from constant-force testing of fatigue precracked beam or compact fracture specimens and from constant-displacement testing of fatigue precracked bolt-load compact fracture specimens.

1.2 This test method is applicable to environment-assisted cracking in aqueous or other aggressive environments.

1.3 Materials that can be tested by this test method are not limited by thickness or by strength as long as specimens are of sufficient thickness and planar size to meet the size requirements of this test method.

1.4 A range of specimen sizes with proportional planar dimensions is provided, but size may be variable and adjusted for yield strength and applied force. Specimen thickness is a variable independent of planar size.

1.5 Specimen configurations other than those contained in this test method may be used, provided that well-established stress intensity calibrations are available and that specimen dimensions are of sufficient size to meet the size requirements of this test method during testing.

1.6 *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.*

1.7 *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]

D1141 Practice for Preparation of Substitute Ocean Water

E8/E8M Test Methods for Tension Testing of Metallic Materials

E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials

E647 Test Method for Measurement of Fatigue Crack Growth Rates

E1823 Terminology Relating to Fatigue and Fracture Testing

G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to fracture testing used in this test method, refer to Terminology E1823.

3.1.2 For definitions of terms relating to corrosion testing used in this test method, refer to Terminology G15.

3.1.3 *stress-corrosion cracking (SCC)*—a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress.

3.1.4 *stress intensity factor threshold for plane strain environment-assisted cracking (K_{IEAC} [$FL^{-3/2}$])*—the highest value of the stress intensity factor (K) at which crack growth is not observed for a specified combination of material and environment and where the specimen size is sufficient to meet requirements for plane strain as described in Test Method E399.

3.1.5 *stress intensity factor threshold for environment-assisted cracking (K_{EAC} [$FL^{-3/2}$])*—the highest value of the

[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.06 on Crack Growth Behavior.

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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.

stress intensity factor (K) at which crack growth is not observed for a specified combination of material and environment and where the measured value may depend on specimen thickness.

3.1.6 *physical crack size ($a_p[L]$)*—the distance from a reference plane to the observed crack front. This distance may represent an average of several measurements along the crack front. The reference plane depends on the specimen form, and it is normally taken to be either the boundary or a plane containing either the loadline or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

3.1.7 *original crack size ($a_o[L]$)*—the physical crack size at the start of testing.

3.1.8 *original uncracked ligament ($b_o[L]$)*—distance from the original crack front to the back edge of the specimen ($b_o = W - a_o$).

3.1.9 *specimen thickness (B[L])*—the side-to-side dimension of the specimen being tested.

3.1.10 *tensile strength (σ_{TS} $[FL^{-2}]$)*—the maximum tensile stress that a material is capable of sustaining. Tensile strength is calculated from the maximum force during a tension test carried to rupture and the original cross-section area of the specimen.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *environment-assisted cracking (EAC)*—a cracking process in which the environment promotes crack growth or higher crack growth rates than would occur without the presence of the environment.

3.2.2 *normalized crack size (a/W)*—the ratio of crack size, *a*, to specimen width, *W*. Specimen width is measured from a reference position such as the front edge in a bend specimen or the loadline in the compact specimen to the back edge of the specimen.

3.2.3 *yield strength ($\sigma_{YS}[FL^{-2}]$)*—the stress at which a material exhibits a specific limiting deviation from the proportionality of stress to strain. This deviation is expressed in terms of strain.

NOTE 1—In this test method, the yield strength determined by the 0.2 % offset method is used.

3.2.4 *effective yield strength ($\sigma_Y[FL^{-2}]$)*—an assumed value of uniaxial yield strength that represents the influences of plastic yielding upon fracture test parameters. For use in this method, it is calculated as the average of the 0.2 % offset yield strength σ_{YS}, and the ultimate tensile strength, σ_{TS}, or

$$\sigma_Y = (\sigma_{YS} + \sigma_{TS})/2 \quad (1)$$

3.2.5 *notch length ($a_n(L)$)*—the distance from a reference plane to the front of the machined notch. The reference plane depends on the specimen form and normally is taken to be either the boundary or a plane containing either the loadline or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

4. Summary of Test Method

4.1 This test method involves testing of single-edge notched [SE(B)] specimens, compact [C(T)] specimens, or bolt-load compact [MC(W)] specimens, precracked in fatigue. The single-edge notched beam specimen is tested by dead weight loading. An environmental chamber is either attached to the specimen, or the specimen is contained within the chamber. The chamber must enclose the portion of the specimen where the crack tip is located. Prescribed environmental conditions must be established and maintained within the chamber at all times during the test.

4.1.1 Specimens shall be deadweight loaded or otherwise held under constant force or held under constant displacement (defined in 6.2) for a prescribed length of time, during which failure by crack growth leading to fracture may or may not occur. K_{IEAC} and K_{EAC} are defined as the highest value of stress intensity factor at which neither failure nor crack growth occurs. The stress intensity factor (K) is calculated from an expression based on linear elastic stress analysis. To establish a suitable crack-tip condition for constant force tests, the stress-intensity level at which the fatigue precracking of the specimen is conducted is limited to a value substantially less than the measured K_{IEAC} or K_{EAC} values. For constant displacement tests, the stress-intensity level at which the fatigue precracking of the specimen is conducted is limited to the requirements of Test Method E399. The validity of the K_{IEAC} value determined by this test method depends on meeting the size requirements to ensure plane strain conditions, as stated in Test Method E399. The validity of the K_{EAC} value depends on meeting the size requirements for linear elastic behavior, as stated in the Test Method E647.

4.1.2 This test method can produce information on the onset of environment-assisted crack growth. Crack growth rate information can be obtained after crack nucleation, but the method for obtaining this information is not part of this test method (**1**).[4]

4.2 The mechanisms of environment-assisted cracking are varied and complex. Measurement of a K_{EAC} or K_{IEAC} value for a given combination of material and environmental provides no insight into the particular cracking mechanism that was either operative or dominant. Two prominent theories of environment-assisted cracking are anodic reaction and hydrogen embrittlement (**2**). The data obtained from this test method may be interpreted by either theory of environment-assisted cracking.

4.3 Specimen thickness governs the proportions of plane strain and plane stress deformation local to the crack tip, along with the environmental contribution to cracking. Since these chemical and mechanical influences cannot be separated in some material/environment combinations, thickness must be treated as a variable. In this test method, however, the stress in the specimen must remain elastic. For these reasons, two threshold values of EAC are defined by this test method. The measurement of K_{IEAC} requires that the thickness requirements of plane strain constraint are met. The less restrictive requirements of K_{EAC} are intended for those conditions in which the results are a strong function of the thickness of the specimen

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

and the application requires the testing of specimens with thickness representative of the application.

4.4 A variety of environmental (temperature, environment composition, and electrode potential, for example) and metallurgical (yield strength, alloy composition, and specimen orientation) variables affect K_{EAC} and K_{IEAC}.

5. Significance and Use

5.1 The parameters K_{EAC} or K_{IEAC} determined by this test method characterize the resistance to crack growth of a material with a sharp crack in specific environments under loading conditions in which the crack-tip plastic region is small compared with the crack depth and the uncracked ligament. The less restrictive thickness requirements of K_{EAC} are intended for those conditions in which the results are a strong function of the thickness of the specimen and the application requires the testing of specimens with thickness representative of the application. Since the chemical and mechanical influences cannot be separated, in some material/environment combinations, the thickness must be treated as a variable. A K_{EAC} or K_{IEAC} value is believed to represent a characteristic measurement of environment-assisted cracking resistance in a precracked specimen exposed to an environment under sustained tensile loading. A K_{EAC} or K_{IEAC} value may be used to estimate the relationship between failure stress and defect size for a material under any service condition, where the combination of crack-like defects, sustained tensile loading and the same specific environment would be expected to occur. (Background information concerning the development of this test method can be found in Refs (**3-18**).

5.1.1 The apparent K_{EAC} or K_{IEAC} of a material under a given set of chemical and electrochemical environmental conditions is a function of the test duration. It is difficult to furnish a rigorous and scientific proof for the existence of a threshold (**4, 5**). Therefore, application of K_{EAC} or K_{IEAC} data in the design of service components should be made with awareness of the uncertainty inherent in the concept of a true threshold for environment-assisted cracking in metallic materials (**6, 18**). A measured K_{EAC} or K_{IEAC} value for a particular combination of material and environment may, in fact, represent an acceptably low rate of crack growth rather than an absolute upper limit for crack stability. Care should be exercised when service times are substantially longer than test times.

5.1.2 The degree to which force deviations from static tensile stress will influence the apparent K_{EAC} or K_{IEAC} of a material is largely unknown. Small-amplitude cyclic loading, well below that needed to produce fatigue crack growth, superimposed on sustained tensile loading was observed to significantly lower the apparent threshold for stress corrosion cracking in certain instances (**7, 8**). Therefore, caution should be used in applying K_{EAC} or K_{IEAC} data to service situations involving cyclic loading. In addition, since this standard is for static loading, small-amplitude cyclic loading should be avoided during testing.

5.1.3 In some material/environment combinations, the smaller the specimen, the lower the measured K_{EAC} value, while in other material/environment combinations the measured K_{IEAC} value will be the lowest value (**5, 9, 10, 11, 12**). If, for the material/environment combination of interest, it is not known which specimen size will result in the lower measured value, then it is suggested that the use of both specimen sizes should be considered; that is, specimens with thicknesses representative of the application and specimens in which the thickness meets the requirements (see 7.2.1) of a K_{IEAC} value.

5.1.3.1 The user may optionally determine and report a K_{EAC} value or a K_{IEAC} value. The specimen size validity requirements for a K_{EAC} value meet the size requirements developed for Test Method E647 to achieve predominately elastic behavior in the specimen. Test Method E647 size requirements for compact specimens should be applied to both the compact specimen and the beam specimen. The specimen size validity requirements for a K_{IEAC} value meet the size requirements developed for plane strain conditions for Test Method E399.

5.1.4 Evidence of environment-assisted crack growth under conditions that do not meet the validity requirements of 7.2 may provide an important indication of susceptibility to environmental cracking but cannot be used to determine a valid K_{EAC} value (**14**).

5.1.5 Environment-assisted cracking is influenced by both mechanical and electrochemical driving forces. The latter can vary with crack depth, opening, or shape and may not be uniquely described by the fracture mechanics stress intensity factor. As an illustrative example, note the strong decrease reported in K_{ISCC}[5] with decreasing crack size below 5 mm for steels in 3 % NaCl in water solution (**15**). Geometry effects on *K* similitude should be experimentally assessed for specific material/environment systems. Application modeling based on K_{EAC} similitude should be conducted with caution when substantial differences in crack and specimen geometry exist between the specimen and the component.

5.1.6 Not all combinations of material and environment will result in environment-assisted cracking. In general, susceptibility to aqueous stress-corrosion cracking decreases with decreasing material strength level. When a material in a certain environment is not susceptible to environment-assisted cracking, it will not be possible to measure K_{EAC} or K_{IEAC}. This method can serve the following purposes:

5.1.6.1 In research and development, valid K_{EAC} or K_{IEAC} data can quantitatively establish the effects of metallurgical and environmental variables on the environment-assisted cracking resistance of materials.

5.1.6.2 In service evaluation, valid K_{EAC} or K_{IEAC} data can be utilized to establish the suitability of a material for an application with specific stress, flaw size, and environmental conditions.

5.1.6.3 In acceptance and quality control specifications, valid K_{EAC} or K_{IEAC} data can be used to establish criteria for material processing and component inspection.

5.1.7 Test results will be affected by force relaxation in constant displacement bolt-loaded compact specimens for

[5] K_{ISCC} has been used in the literature as a special case of K_{IEAC} in which the crack growth is known to be due to the simultaneous action of a stress and a corrodent.