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Standard Practice for Linear-Elastic ~~Plane–Strain~~Plane-Strain Fracture Toughness Testing of Aluminum Alloys[1]

This standard is issued under the fixed designation B645; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

INTRODUCTION

Linear-elastic plane-strain fracture toughness testing of aluminum alloys is performed essentially in accordance with Test Method E399. However, there is a need, in the application of Test Method E399 for quality assurance testing, to deal with the interpretation of the results for material qualification and release in cases where all requirements for valid measurements of plane-strain fracture toughness cannot be met. It is the purpose of this practice to provide consistent methods of dealing with those situations.

1. Scope*

1.1 This practice is applicable to the fracture toughness testing of all aluminum alloys, tempers, and products, especially in cases where the tests are being made to establish whether or not individual lots meet the requirements of specifications and should be released to customers.

1.2 Test Method E399 is the basic test method to be used for plane-strain fracture toughness testing of aluminum alloys. The purpose of this practice is to provide supplementary information for plane-strain fracture toughness of aluminum alloys in three main areas:

1.2.1 Specimen sampling,

1.2.2 Specimen size selection, and

1.2.3 Interpretation of invalid test results.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3.1 *Exception*—Certain inch-pound values given in parentheses are provided for information only.

1.4 This standard is currently written to accommodate only C(T) specimens.

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

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[1] This practice is under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.05 on Testing.

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***A Summary of Changes section appears at the end of this standard**

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]
B646 Practice for Fracture Toughness Testing of Aluminum Alloys
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
E561 Test Method for K_R Curve Determination
E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *General*—Terms, definitions, symbols, and orientation designations in Test Method E399 and Terminology E1823 are applicable herein.

3.2 *Definitions:*The following additional definitions are applicable:

3.2.1 *invalid plane-strain fracture toughness*—test result, K_Q, that does not meet one or more of the validity requirements in Test Method E399 and, where so characterized, is of no value in judging the true ~~plain-strain~~plane-strain fracture toughness of a material but may, under certain conditions, adequately guarantee the material's fracture toughness for lot release purposes.

3.2.2 *valid plane-strain, fracture toughness*—test result meeting all the validity requirements in Test Method E399, that is, a value of K_{Ic}.

4. Summary of Practice

4.1 This practice supplements Test Method E399 and Practice B646 in three main areas:

4.1.1 Specimen sampling,

4.1.2 Specimen size selection, and

4.1.3 Interpretation of results that fail the validity requirements in Test Method E399 in one of the following areas in order to determine if the invalid results are usable for lot release:

4.1.3.1 P_{max}/P_Q requirements,

4.1.3.2 Specimen size requirements, and

4.1.3.3 Fatigue precracking requirements.

5. Significance and Use

5.1 This practice for plane-strain fracture toughness testing of aluminum alloys may be used as a supplement to Test Method E399. The application of this practice is primarily intended for quality assurance and material release in cases where valid plane-strain fracture toughness data cannot be obtained per Test Method E399.

5.2 It must be understood that the interpretations and guidelines in this practice do not alter the validity requirements of Test Method E399 or promote the designation of data that are invalid according to Test Method E399 to a "valid" condition. This practice is primarily concerned with cases where it is not possible or practical to obtain valid data, but where material release judgments must be made against specified fracture toughness values. Where it is possible to obtain a valid plane-strain fracture toughness value by replacement testing according to Test Method E399, that is the preferred approach.

[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.

6. Apparatus

6.1 All apparatus shall be in conformance with Test Method E399.

7. Sampling

7.1 Sampling requirements stated in the individual material specifications shall be followed. In the absence of specific requirements in the individual material specifications, specimens shall be taken at the following locations:

7.1.1 Specimens from plate shall be from the mid-thickness, until the plate thickness is twice the standard specimen thickness for that particular product (that is, the specimen thickness selected for lot release and quality assurance testing which typically yields a valid K_{Ic} for that particular alloy and product), at and beyond which the specimen shall be centered at the quarter-thickness location.

7.1.2 Specimens from forgings, extrusions, and rod shall be taken from the center of the cross section as far as is practical.

NOTE 1—Considerable care should be taken in specifying the location of specimens within the thickness of the thick plate, forgings, extrusions, or rod because fracture toughness may vary appreciably with location through the thickness.

8. Test Specimen Configuration and Dimensions

8.1 Specimen size requirements stated in the individual material specifications shall be followed. In the absence of specific requirements, the specimen types, general configuration, and size requirements in Test Method E399 are applicable herein with the following supplemental recommendations and requirements:

8.1.1 For aluminum products, the recommended minimum specimen ligament length is:

$$(W-a) \geq 5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \quad (1)$$

rather than the required minimum of:

$$(W-a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \quad (2)$$

in Test Method E399.

NOTE 2—Experimental studies[3] have shown that more uniform values of K_Q are obtained for high toughness aluminum alloys when the conditions of Eq 1 are met.

8.1.2 In all cases, the specimen *W/B* ratio shall be greater than or equal to 2 and less than or equal to 4 based on nominal specimen dimensions. Other specimen dimensional proportions in Test Method E399 shall also be maintained.

NOTE 3—Specimens meeting this requirement correspond to the standard (*W/B* = 2) or alternative specimen geometries ($2 \leq W/B \leq 4$) in Test Method E399.

8.1.3 When the minimum size requirement of:

$$(W-a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \quad (3)$$

in Test Method E399 cannot be met due to product dimensional constraints, the specimen shall be machined such that the *W* dimension is maximized to the nearest 12.7 mm (0.5 in.) at the specified test location while still meeting the requirements of 8.1.2 up to the specimen width required in the applicable material specification, or if no width is specified, up to an upper required limit of 127 mm (5.0 in.).

NOTE 4—It is not practical for *W* to vary continuously (that is, non-discretely) since many C(T) specimen dimensions are proportional to *W*. Each change in *W* requires a different machining or testing setup. Therefore, it is required that *W* be maximized to the nearest 12.7 mm (0.5 in.).

8.1.4 When the requirement ~~P~~of:$_{max}$
~~/~~P

[3] Kaufman, J. G., "Experience in Plane Strain Fracture Toughness per ASTM E399," *Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632*, ASTM, 1977, pp. 3-24.

$$\frac{P_{max}}{P_Q} \leq 1.10 \qquad (4)$$

Q ≤ 1.1 cannot be met due to product dimensional constraints, the specimen shall be machined such that the *B* dimension is maximized up to a required maximum thickness of 63.5 mm (2.5 in.) at the specified test location. The specimen ligament length should be maintained at:

$$(W - a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \qquad (5)$$

or as large as possible while still meeting the requirements of 8.1.2, up to the specimen width required in the applicable material specification, or if no width is specified, up to an upper required limit of 127 mm (5.0 in.).

NOTE 5—The upper limit on specimen thickness and width have been established because of practical limitations on how large a specimen can be routinely machined and tested for lot release purposes in a production environment using standard equipment. The producer may test thicker and/or wider specimens provided the testing capability and sufficient material are available, and the specimen proportions adhere to the requirements in 8.1.2.

8.1.5 When it is not possible to meet either the:

$$(W - a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \qquad (6)$$

or the:

$$\frac{P_{max}}{P_Q} \leq 1.1 \qquad (7)$$

$$\frac{P_{max}}{P_Q} \leq 1.10 \qquad (7)$$

requirements, then both the *W* and *B* dimensions shall be maximized in accordance with requirements in 8.1.2, 8.1.3, and 8.1.4.

NOTE 6—For aluminum products where the size requirement in either Eqs 4 or 5 cannot be consistently met because of high toughness, even when *B* and *W* are maximized, other measures of fracture toughness such as K_{R25} described in Practice B646 or the *K-R* curve as described in Test Method E561 should be considered for evaluating fracture toughness for lot release purposes.

~~NOTE 7—Test Method E399 permits the use of side-grooved specimens in certain specimen types. Side-grooved specimens may allow for valid K_{IC} values to be obtained for high toughness alloys or thin products that otherwise would have invalidities due to excessive plasticity. For lot acceptance testing, side-grooved specimens shall not be used unless specifically allowed by the product specification or by agreement between producer and user. Side-grooves increase the level of constraint with respect to the recommended specimen. The increased constraint promotes a more uniform stress state along the crack front and inhibits shear lip development. As a result, a K_{IC} value obtained from testing a side-grooved specimen is expected to be lower than a K_{IC} value obtained from testing the recommended specimen, particularly for thin products or tests exhibiting Type I behavior. For use of side-grooves in lot acceptance testing, minimum K_{IC} values specific to side-grooved specimens may need to be established.~~

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9. Fatigue Precracking

9.1 Fatigue precracking shall be performed and fatigue crack front measurements shall be made in accordance with Test Method E399.

10. Procedure

10.1 The test procedure, analysis of test record, and calculations shall be made in accordance with Test Method E399.

11. Interpretation of Results

11.1 A K_Q value that satisfies all of the validity requirements of Test Method E399 is a valid plane-strain fracture toughness K_{IC} in accordance with this practice. A K_Q value that does not meet all of the requirements of Test Method E399 is an invalid plane-strain fracture toughness, and is not a valid K_{IC} value in accordance with Test Method E399 or this practice, but is usable for lot release purposes if all of the appropriate requirements in this section are met.

11.2 A $K_Q$value that has invalidities in accordance with Test Method E399, but which meets the specimen width and thickness requirements in the individual material specification, is usable for lot release provided the secondary conditions in 11.5 and 11.6 are met.

11.3 In the absence of specific requirements in the individual material specification, a K_Q value having invalidities in accordance with Test Method E399 is usable for lot release provided that each invalidity meets all of the secondary conditions in 11.4, 11.5, and 11.6.

11.4 *Invalidities Related to Specimen Size and P_{max}/P_Q Requirements:*

11.4.1 In all cases, the specimen *W/B* ratio must meet the requirements in 8.1.2. Otherwise, a replacement test shall be performed using a specimen meeting those requirements.

11.4.2 If a K_Q value is invalid because the specimen does not meet the:

$$(W - a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \tag{8}$$

requirement but the test record meets the:

$$\frac{P_{max}}{P_Q} \leq 1.1 \tag{9}$$

$$\frac{P_{max}}{P_Q} \leq 1.10 \tag{9}$$

requirement, the K_Q value may be usable for lot release if the specimen width *W* is maximized according to 8.1.3.

11.4.3 If a K_Q value is invalid because the test record does not meet the:

$$\frac{P_{max}}{P_Q} \leq 1.1 \tag{10}$$

$$\frac{P_{max}}{P_Q} \leq 1.10 \tag{10}$$

requirement but the specimen size does meet the:

$$(W - a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \tag{11}$$

requirement, the K_Q value may be usable for lot release if the thickness is maximized according to 8.1.4.

11.4.4 If a K_Q value is invalid because it fails to meet both the:

$$\frac{P_{max}}{P_Q} \leq 1.1 \tag{12}$$

$$\frac{P_{max}}{P_Q} \leq 1.10 \tag{12}$$

requirement and the:

$$(W - a) \geq 2.5 \cdot \left(\frac{K_Q}{\sigma_{YS}}\right)^2 \tag{13}$$

requirement, the K_Q value may be usable for lot release if the width *W* and the thickness *B* are maximized according to 8.1.5.

NOTE 8—Under the conditions in 11.4.2, 11.4.3, and 11.4.4, the K_Q value may not represent or approximate K_{Ic}, but it does represent a measure of the material's resistance to fracture. K_Q values obtained under these conditions may also depend significantly on the specimen geometry and dimensions. Therefore, both the specified value and the qualification testing should be based on a specimen of the same geometry and dimensions.

11.5 *Invalidities Related to Fatigue Precracking:*

11.5.1 If the maximum stress intensity in the final stage of precracking (K_{fmax}) exceeds the limit of 60% of K_Q allowed in Test Method E399, but still satisfies the requirement that: