Designation: B 645 – 9802

Standard Practice for Plane–Strain Fracture Toughness Testing of Aluminum Alloys[1]

This standard is issued under the fixed designation B 645; 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.

INTRODUCTION

Plane-strain fracture toughness testing of aluminum alloys is performed essentially in accordance with Test Method E 399. However, there is a need, in the application of Test Method E 399 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 E 399 is the basic ~~standard~~ 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 inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

1.4 *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:*

[1] This practice is under the jurisdiction of ASTM ~~B-7~~ Committee B07 on Light Metals and Alloys~~,~~ and is the direct responsibility of Subcommittee B07.05 on Testing. Current edition approved ~~Nov.~~ Apr. 10, ~~1998.~~ 2002. Published ~~March 1999.~~ June 2002. Originally published as B 645–78. Last previous edition B 645–9~~5~~8.

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

B 646 Practice for Fracture Toughness Testing of Aluminum Alloys[2]
E 399 Test Method 29 Practice for Plane-Strain Fracture Toughness of Metallic Materials Using Significant Digits in Test Data to Determine Conformance with Specifications[3]
E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[4]
E 1823 Terminology Relating to Fatigue and Fracture Testing[4]

3. Terminology

3.1 *General*—Terms, definitions, symbols, and orientation designations in Test Method E 399 and Terminology E 1823 are applicable herein.

3.2 The following additional definitions are applicable:

3.2.1 *invalid plane-strain fracture toughness*—test result, ~~Kq,~~ K_Q, that does not meet one or more of the validity requirements in Test Method E 399 and, where so characterized, is of no value in judging the true plain-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 *meaningful plane-strain fracture toughness*—test result, designated ~~Kq,~~ K_Q, that does not meet one or more of the validity requirements in Test Method E 399, but for which there is experimental or analytical evidence that the departure from validity is small enough that the value of ~~Kq~~ K_Q is expected to be within 5 or 10 % of the value of K_{Ic} that would have been obtained had all the validity criteria been met.

3.2.3 *valid plane-strain, fracture toughness*—test result meeting all the validity requirements in Test Method E 399, that is, a value of K_{Ic}.

4. Summary of Practice

4.1 This practice supplements Test Method E 399 and Practice B 646 in three main areas:

4.1.1 Specimen sampling,

4.1.2 Specimen size selection, and

4.1.3 Interpretation of results which fail the validity requirements in Test Method E 399 in one of the following areas in order to determine if the invalid results are acceptable for lot release:

4.1.3.1 P_{max}/P~~q~~$_Q$ 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 E 399. 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 E 399.

5.2 It must be understood that the interpretations and guidelines in this practice do not alter the validity requirements of Test Method E 399 or promote the designation of data that are invalid according to Test Method E 399 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, by replacement testing, to obtain valid plane-strain fracture toughness according to Test Method E 399, that is the preferred approach.

6. Apparatus

6.1 All apparatus shall be in conformance with Test Method E 399.

7. Sampling

7.1 Sampling requirements shall be as stated in the individual material specifications. 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 so 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.

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[2] *Annual Book of ASTM Standards*, Vol 02.02.

[3] *Annual Book of ASTM Standards*, Vol ~~03.01.~~ 14.02.

[4] ~~Kaufman, J. G., "Experience in Plane Strain Fracture Toughness per~~

[4] *Annual Book of ASTM ~~E 399," Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632,ASTM, 1977, pp. 3-24.~~ Standards, Vol 03.01.*

8. Test Specimen Configuration and Dimensions

8.1 The specimen types, general configuration and size requirements in Test Method E 399 are applicable herein with the following supplemental recommendations and requirements:

8.1.1 For aluminum products, it is recommended that the thickness, *B*, and crack length, *a*, equal or exceed 5 ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$ rather than the required minimum of 2.5 $(K_Q/\sigma_{YS})^2$ in Test Method E 399.

NOTE 2—Experimental studies[5] have shown that more uniform values of ~~Kq~~ K_Q are obtained for high toughness aluminum alloys when $B,a \geq 5$ ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$.

8.1.2 When it is not possible to obtain a specimen thickness $B \geq 5$ ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$, it is recommended that the thickness be the maximum possible considering the basic product dimensions, and that crack length, *a*, be maintained at ~~≥ 5 (Kq/σys)~~ ≥ 5 $(K_Q/\sigma_{YS})^2$ or as large as possible while still meeting the requirements of 8.1.4.

NOTE 3—Specimens having $B \geq 2.5$ $(K_Q/\sigma_{YS})^2$ and crack length, $a \geq 5$ $(K_Q/\sigma_{YS})^2$ may allow for a meaningful ~~Kq~~ K_Q to be obtained as described in 11.3.1 even though the P_{max}/P_Q requirement in Test Method E 399 is not met.

8.1.3 When the minimum size requirements of *B*, $a \geq 2.5$ ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$ in Test Method E 399 cannot be met due to product dimensional constraints, the specimen shall be machined such that ~~t~~:

8.1.3.1 The *B* dimension is maximized ~~(for~~ at the specified test location, for test orientations where it is the constrained dimension~~)~~, up to the specimen thickness required in the applicable material specification, or if no thickness is specified, up to an upper required limit of 2.5 in. (63.5 ~~mm) for thick products (a~~ mm). A thickness greater than 2.5 in. (63.5 mm) may be used at the discretion of the producer but is not required~~,~~ (see Note ~~5), or W~~ 5).

8.1.3.2 The *W* dimension is maximized ~~(for~~ to the nearest 0.5 in. (12.7 mm) at the specified test location for test orientations where it is the constrained ~~dimension) while still meeting the requirements of 8.1.4.~~ dimension (see Note 6).

NOTE 4—A specimen which fails to satisfy the minimum size requirements in Test Method E 399 but meets the requirements in 8.1.3, is not valid per Test Method E 399 or this practice, or meaningful as defined in this practice, but may be acceptable for lot release purposes.

NOTE 5—An upper limit of 2.5 in. (63.5 mm) has been placed on specimen thickness for thick products in recognition that there are practical limitations on how large a specimen can be routinely machined and tested for lot release purposes in a production environment using standard test equipment. The producer may test thicker specimens provided the testing capability and sufficient material are available.

NOTE 6—Unlike *B*, it is not practical for *W* to vary continuously (that is, non-discretely) since many C(T) specimen dimensions are proportional to it. Each change in *W* requires a different machining or testing setup. Therefore, it is required that *W* be maximized to the nearest 0.5 in. (12.7 mm).

NOTE 7—For aluminum products where the size requirements $B,a \geq 2.5$ ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$ cannot be consistently met even when *B* is maximized or at the upper thickness limit of 2.5 in. (63.5 mm) and *W* is maximized, because of high toughness, other measures of fracture toughness such as $K_{R_{25}}$ as described in Practice B 646 or the R-curve as described in Practice E 561 should be considered for evaluating fracture toughness for lot release purposes.

8.1.4 In all cases, specimen *B/W* ratios shall be greater than or equal to 0.25 and less than or equal to 0.5 based on nominal specimen dimensions. Other dimensional proportions in Test Method E 399 shall also be maintained.

NOTE ~~7~~8—Specimens meeting this requirement correspond to the standard ($B/W = 0.5$) or alternative specimen geometries ($0.25 \leq B/W < 0.5$) in Test Method E 399.

9. Fatigue Precracking

9.1 Fatigue precracking shall be performed and fatigue crack front measurements shall be made in accordance with Test Method E 399.

10. Procedure

10.1 The test procedure, analysis of test record, and calculations shall be made in accordance with Test Method E 399.

11. Interpretation of Results

11.1 A test result which satisfies the validity requirements of Test Method E 399 is valid per this practice.

11.2 For results which are invalid per Test Method E 399, the following additional interpretations may be made for quality assurance and material release purposes.

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

11.3.1 If $B \geq 2.5$ $(K_Q/\sigma_{YS})^2$ and $a \geq 5$ ~~(Kq/σys)~~ $(K_Q/\sigma_{YS})^2$, and P_{max}/P_Q does not exceed the following levels for the *B/W* range specified, a test result may be characterized as meaningful and the material considered to meet an applicable specification if ~~Kq~~ K_Q equals or exceeds the specified value of K_{Ic}.

~~*B/W* Range~~ *B/W* Range	~~Maximum Value, P_{max}/Pq~~ Maximum Value, P_{max}/P_Q
$0.30 \leq B/W \leq 0.40$	1.15

[5] Kaufman, J. G., "Experience in Plane Strain Fracture Toughness per ASTM E 399," *Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632,* ASTM, 1977, pp. 3-24.

$0.25 \leq B/W < 0.30$	1.20

11.3.2 If the minimum size requirements of ~~$B,a \geq 2.5\ (Kq/\sigma ys)^2$ or~~ $B,a \geq 2.5\ (K_Q/\sigma_{YS})^2$ or the P_{max}/Pq_Q requirement in Test Method E 399 are not met and the result is not meaningful per 11.3.1, it shall be acceptable to use ~~Kq~~ K_Q for lot release provided the requirements in 8.1.3 and 8.1.4 are met. Otherwise, a replacement test shall be performed using a specimen meeting these requirements.

NOTE ~~8~~9—Under the conditions in 11.3.2, the ~~Kq~~ K_Q value may not represent or approximate K_{Ic}. It does however, represent a measure of the materials' resistance to fracture. ~~Kq~~ 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.

11.4 *Invalidities Related to Fatigue Precracking*:

11.4.1 With regard to maximum stress intensity during the final stage of precracking, if the maximum stress intensity exceeds the maximum of 60 % of ~~Kq~~ K_Q allowed in Test Method E 399, but still satisfies the requirement that $K_{max}/E \leq 0.002$ in.$^{1/2}$ (0.00032 m$^{1/2}$) and is no more than 80 % of ~~Kq, K_Q,~~ a test result may be characterized as meaningful and the material considered to meet an applicable specification if ~~Kq~~ K_Q equals or exceeds the specified value of K_{Ic}. Otherwise, a replacement test shall be performed.

11.4.2 With regard to fatigue crack length, if that length is outside the range allowed in Test Method E 399 (0.45W to 0.55W) but is within the range 0.4W to 0.6W, a test result may be characterized as meaningful and the material considered to meet an applicable specification if ~~Kq~~ K_Q equals or exceeds the specified value of K_{Ic}. Otherwise, a replacement test shall be performed.

11.4.3 Annex A1 provides a flowchart that may help the individual user understand the additional interpretation of invalid test results given in this practice to determine if they are meaningful or acceptable for lot release.

12. Report

12.1 The record shall include all information required by Test Method E 399 and individual reasons for invalid results being considered meaningful or acceptable for lot release per this practice.

12.2 The complete record is not normally required for material certification and lot release purposes. Such records are usually retained by the producer for future audit by the purchaser.

12.3 For the purpose of determining conformance with a specified limit in a material or product specification, the value of K_{Ic} (or K_Q when meaningful or usable for lot release) obtained in the test shall be rounded "to the nearest unit" in the last right hand significant digit used in expressing the limiting value in accordance with the rounding method of Practice E 29. For a limit specified as a whole number, all digits shall be considered significant including zeros.

12.4 *Replacement Tests*—A test specimen may be discarded and a replacement test performed as instructed in 11.3.2, 11.4.1, and 11.4.2, or when *(1)* the specimen was machined incorrectly, *(2)* the test procedure was incorrect, or *(3)* the test machine malfunctioned.

12.5 *Retests*—Retests shall be performed and interpreted in accordance with the applicable material specification or as otherwise agreed upon between the purchaser and supplier. If there is no specific provision for retests, and one or more test results fail to conform with the requirements of the material specification after rounding in accordance with 12.3, for reasons other than those in 12.4, the lot represented by that test result shall be subject to rejection except as provided below:

12.5.1 For each specimen that failed, retest at least two additional specimens at the specified test location from an area in the original sample adjacent the failing specimen, or

12.5.2 For each specimen that failed, retest an additional specimen at the specified location from at least two other samples.

12.5.3 If any retest fails, the lot shall be subject to rejection, except that the lot may be resubmitted for testing provided the producer has reworked the lot, as necessary, to correct the deficiencies.

13. Keywords

13.1 aluminum alloys; fracture toughness; plane strain; quality assurance

ANNEX

(Mandatory Information)

A1. FLOWCHART FOR ADDITIONAL INTERPRETATION OF TEST RESULTS INVALID PER TEST METHOD E 399

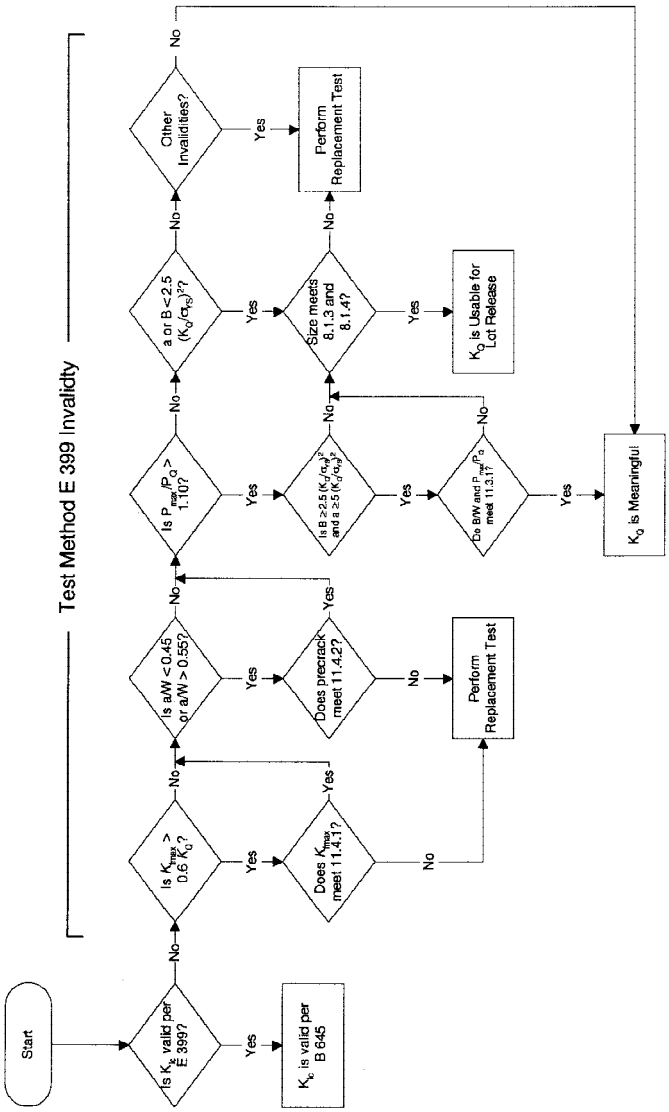

FIG. A1.1 Flowchart

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SUMMARY OF CHANGES

Committee B07 has identified the location of selected changes to this standard since the last revision (B 645 – 98) that may impact the use of this standard.

(1) 8.1.3.1 and 8.1.3.2 were revised.
(2) A new Note 6 was added to 8.1.3.2.
(3) 12.3, 12.4, and 12.5 and subsections were added.
(4) The flowchart in Annex A1 was revised.