INTERNATIONAL

Designation: B 646 – 034

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

This standard is issued under the fixed designation B 646; 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 Department of Defense.

INTRODUCTION

Fracture toughness is a key property for a number of aluminum alloys utilized in aerospace and process industries, but at the current stage of development of fracture test techniques no standard methods exist to cover a number of the product lines or dimensional ranges involved. Plane-strain fracture toughness, K_{Ic}, is a keystone of the industry, but for the very tough alloys of principal interest, valid measurements can be made only for relatively thick sections. Thus it is necessary to provide this standard practice for uniform quality control test procedures for the industry, pointing out which current standards are utilized in specific cases, and providing guidelines where no standards exist.

1. Scope*

1.1 Fracture toughness is a key property for a number of aluminum alloys utilized in aerospace and process industries. Fracture toughness testing is often required for supplier qualification, quality control, and material release purposes. The purpose of this practice is to provide uniform test procedures for the industry, pointing out which current standards are utilized in specific cases, and providing guidelines where no standards exist. This practice provides guidance for testing (*1*) *(a)* thin products, of thicknesses equivalent to sheet that is, (≤0.249 in. (6.30 mm)), (*2*) (≤6.32 mm), *(b)* intermediate thicknesses of plate, forgings, and extrusions, too thin for valid plane-strain fracture toughness testing but too thick for treatment as sheet, that is for example, over 0.249 in. (6.302 mm) and up to 1 to 2 in. (25 to 50 mm), dependent upon toughness level, and (*3*) *(c)* relatively thick products where Test Method E 399 is applicable. For changes to this specification since the last issue, refer to the Summary of Changes section at the end of the standard. applicable.

1.2 This practice addresses the problem both direct measurements of fracture toughness and screening tests, the latter recognizing the complexity and expense of making formal fracture toughness measurements on great quantities of production lots, and provides alternatives in the form of simpler, less expensive tests that may be carried out either in a research or production test laboratory. lots.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values in SI units given in parenthesis are provided for information purposes 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.*

[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.
Current edition approved Sept. 10, 2003. March 1, 2004. Published September 2003. March 2004. Originally approved in 1978. Last previous edition approved in 1997 2003 as B 646 – 9703.

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

B 557 Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products

B 645 Practice for Plane-Strain Fracture Toughness Testing of Aluminum Alloys

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials

E 338 Test Method of Sharp-Notch Tension Testing of High-Strength Sheet Materials

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials

E 561 Practice for R-Curve Determination

E 602 Test Method for Sharp-Notch Tension Testing with Cylindrical Specimens

E 1304 Test Method for Plane-Strain (Chevron Notch) Fracture Toughness of Metallic Materials

E 1823 Terminology Relating to Fatigue and Fracture Testing

2.2 *Other Document:*

Aluminum Association Bulletin T5, "Fracture Toughness Testing of Aluminum Alloys"

3. Terminology

3.1 The terminology and definitions in the referenced documents are applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 For purposes of this practice, the following descriptions of terms are applicable in conjunction with Practice Test Method E 561 and use of the compact specimen:

3.2.2 K_{R25}—A — a value of K_R on the R-curve based on a 25 % secant intercept of the force-crack opening displacement test record from a C(T) specimen and the effective crack length, a_e, at that point that otherwise satisfies the remaining-ligament criterion of Practice Test Method E 561.

3.2.3 K_{Rmax}—A — a value of K_R on the R-curve based on the maximum force value of the force-crack opening displacement test record from a C(T) specimen and the effective crack length, a_e, at that point that otherwise satisfies the remaining-ligament criterion of Practice Test Method E 561. The K_{Rmax} value is used when the 25 % secant intercept occurs at a point after the maximum force is reached.

3.2.4 FK_c— for the purposes of this practice, K_c is the following descriptions critical stress intensity factor based on the maximum force value of terms are applicable in conjunction with the chevron notch (short-rod force-crack opening displacement test record from an M(T) specimen and short-bar) the effective crack length, a_e, at that point that otherwise satisfies the remaining-ligament criterion of Test Method E 1304. E 561.

3.2.5 K_{app} (also commonly designated K_{co})—the apparent plane stress fracture toughness based on the original crack length, a_o, and the maximum force value of the force-crack opening displacement test record from an M(T) specimen that otherwise satisfies the remaining-ligament criterion of Test Method E 561.

4. Summary of Practice

4.1 This practice provides guidelines for the selection of tests for to evaluate the evaluation of the fracture toughness properties of aluminum alloys, particularly for quality assurance and material release purposes, including:

4.1.1 Center-slotted panel testing of sheet products in accordance with Practice E 561, M(T) purposes. It also provides supplemental information regarding specimen procedures.

4.1.2 Screening tests size selection, analysis, and interpretation of sheet results for the following products and test methods:

4.2 *Fracture Toughness Testing of Thin Products*:

4.2.1 R-Curve testing of middle-crack tension, M(T), specimens in accordance with Test Method E 338.

4.1.3 Plane-strain fracture toughness tests E 561.

4.2.2 K_c and K_{app} (K_{co}) testing of M(T) specimens in general accordance with Test Method E 399.

4.1.4 Intermediate thickness fracture toughness tests E 561.

4.3 *Fracture Toughness Testing of Intermediate Thickness Products*:

4.3.1 Testing of compact-tension, C(T), specimens in accordance with Practice B 645 and Test Method E 399.

4.1.5 Intermediate thickness fracture toughness tests E 399 supplemented with Practice B 645.

4.3.2 Tests on C(T) specimens in accordance with Practice Test Method E 561 using the C(T) (compact specimen) and a 25 % secant-intercept value concept, designated as toughness parameter, $KR_{R_{25}}$, as a single value or discrete point evaluation.

4.4 *Fracture Toughness Testing of the crack-growth resistance curve (R-curve).*

4.1.6 Screening Thick Products:

4.4.1 Plane-strain fracture testing in accordance with Test Method E 399 supplemented with Practice B 645.

4.5 *Screening Tests*:

4.5.1 Screening tests of thin products using sharply-edge-notched, sheet-type specimens in accordance with Test Method E 338.

---

[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*, Vol 02.02. volume information, refer to the standard's Document Summary page on the ASTM website.

4.5.2 Screening tests of both intermediate and relatively thick~~ materials~~ products using the chevron notch (short-rod or short-bar) in accordance with Test Method E 1304.

4.~~1~~5.~~7~~3 Screening tests for a range of thicknesses from about 0.1~~-~~ in. (2.54 mm) upward using the sharp-notch Charpy test as covered in Test Methods E 23.

4.~~1~~5.~~8~~4 Screening tests of thick~~ m~~ products using sharply-notched cylindrical specimens in accordance with Test Method E 602.

5. Significance and Use

5.1 This practice is provided to develop and maintain uniformity in practices for the evaluation of the toughness of aluminum alloys, particularly with regard to supplier qualification, quality assurance, and material release to specifications.

5.2 It is emphasized that the use of these procedures will not alter the validity of data determined with specific test methods, but provides guidance in the interpretation of test results (valid or invalid) and guidance in the selection of a reasonable test procedure in those instances where no standard exists today.

6. Selection of Fracture Toughness Test~~ Procedures~~

~~6.1 The following~~ Methods for Specific Products

6.1 Direct measures of fracture toughness are preferred over screening test methods and are highly recommended for~~ individual products~~ supplier qualification and~~ situations:~~

~~6.1.1 For sheet products with nominal thickness, 0.249 in. (6.30 mm), use~~ periodic quality control testing. The following measures of~~ a middle cracked tension (M(T)) specimen is~~ fracture toughness and test methods are recommended for~~ measurement of~~ these products:

6.2 *Thin Products*—For sheet and other products having a thickness less than 0.250 in. (6.35 mm):

6.2.1 The critical stress intensity factor (K_c)~~ w~~ or the apparent fracture toughness (K_{app}) from a middle-cracked tension, M(T), specimen and tested in general accordance with~~ Practice E 561,~~ Test Method E 561 as~~ described~~ supplemented by this practice in ~~7.2.~~

~~6.1.2 For products~~ 8.1.

6.2.2 The R-curve measured from a middle-cracked tension, M(T), specimen tested in~~ sheet thicknesses, the use of tension tests of sharply edge-notched specimens in~~ accordance with Test Method~~ E 338, and the corresponding correlations of such data with the critical stress-intensity factors from tests of center-slotted panels in accordance with Practice E 561,~~ E 561 as~~ modified~~ supplemented by this~~ practice, are recommended for screening and quality control purposes as described~~ practice in~~ 7.3. The sharp notch Charpy screening test in accordance with Test Methods E 23 may also be applied for correlative purposes.~~

~~6.1.3 For relatively~~ 8.2.

6.3 *Thick Products*—For products sufficiently thick~~ high-strength products, plane-strain~~ to obtain a valid plane strain fracture toughness~~ t~~ measurement, K_{Ic}, from C(T) specimens measured in accordance with Test Method E 399~~ as~~ supplemented by Practice B 645~~ are recommended. For further guidelines, refer to Practice B 645; no further description is covered herein.~~

~~6.1.4 For screening tests of relatively thick high-strength products, tension tests of sharply notched cylindrical specimens~~ and ~~the associated correlations with plane-strain fracture toughness as determined~~ by this practice in~~ accordance with Test Method E 399 are recommended, as described in 8.2.3. Additional alternative screening tests that are recommended for relatively thick~~ 8.3.

6.4 *Intermediate Thickness Products*— For products~~ are the chevron notch (short-rod and short-bar) test described in Test Method E 1304 and 8.2.1, and the sharp notch Charpy screening test in accordance with Test Methods E 23 and 8.2.4.~~

~~6.1.5 For intermediate thicknesses of high-strength products,~~ having a thickness ≥0.250 in. (≥6.35 mm), but too thin for valid plane-strain fracture toughness~~ testing but too thick for large panel testing~~ testing:

6.4.1 K_Q from compact-tension, C(T), specimens tested in accordance with Test Method E 399 supplemented with Practice ~~E 561,~~ B 645 and this practice in 8.3; or

6.4.2 KR_{25} from a~~ modification of compact~~ compact-tension, C(T) specimen~~ testing~~ tested in accordance with Test Method ~~E 399~~ E 561 as~~ described~~ supplemented by this practice in~~ Practice B 645 and Section 9 is recommended. For such~~ 8.4.

6.5 *Thin Specimens from Thicker Products*—The methods of 6.2 may also be utilized on thin specimens machined from intermediate thickness~~ products, three additional alternative tests exist. They are as follows: a direct measure~~ or thick products for the purpose of evaluating their fracture toughness~~ using Practice E 561 and the $K_{R_{25}}$ concept as described in 9.2.1.1, the same screening tests suggested~~ under plane stress conditions. These methods may be particularly desirable for~~ thick~~ products~~ involving the chevron notch (short-rod~~ which will be subsequently thinned by machining or~~ short-bar) test as described in Test Method E 1304 and 8.2.1 and~~ other means. Typically, the~~ sharp notch Charpy test in accordance with Test Methods E 23 and 8.2.4.~~

~~6.2 It~~ specimen is~~ pointed out~~ machined from the product to a thickness representative of that in the final application.

6.6 *Low Strength Alloy Products*—There are no current standard recommendations for toughness testing of relatively low-strength aluminum alloys which display large-scale yielding even in the presence of extremely large cracks in very thick sections. Such cases must be dealt with individually on a research basis using tests selected from program needs and anticipated design criteria. A typical case for general guidance is given in the literature.[3]

7. Fracture ToughnessSelection of Screening Test Methods for Specinfic Products

7.1 Screening tests are permitted for high volume, material release testing provided they are allowed by the material specification or by agreement between the purchaser and supplier. The following screening test methods are recommended for these products:

7.12 If*Thin Products*—For sheet and other products having a thickness less than 0.250 in. (6.35 mm):

7.2.1 Tension tests of sharply-edge-notched, sheet-type specimens in accordance with Test Method E 338 as supplemented by this practice in 9.1 and precise measure 9.2, and the corresponding correlations of such data with the critical stress-intensity factors (K_c) determined in accordance with this practice are recommended.

7.2.2 The sharp-notch Charpy screening test in accordance with Test Methods E 23 as supplemented by this practice in 9.1 and 9.3 may also be applied for correlative purposes for products 0.10 in. (2.54 mm) and thicker.

7.3 *Thick Products*—For products sufficiently thick to obtain a valid plane strain fracture toughness measurement:

7.3.1 Tension tests of sheet or of sections of an extruded, welded, or forged shape equal to or less than 0.249 in. (6.30 mm) sharply-notched, cylindrical specimens in thickness is required, accordance with Test Method E 602 as supplemented by this practice in 9.1 and 9.4 and the crack-resistance curve should be measured associated correlation with plane-strain fracture toughness, K_{Ic}, as determined in accordance with Test Method E 399 and Practice E B 5645 are recommended. In addition, the following recommended alternative screening tests may be applied:

7.3.2 The chevron notch (short-rod and short-bar) test described in Test Method E 1304 as supplemented by this practice in 9.1 and 9.5.

7.3.3 The sharp-notch Charpy screening test in accordance with Test Methods E 23 as supplemented by this practice in 9.1 and 9.3.

7.4 –*Intermediate Thickness Products*— For q products having a thickness ≥0.250 in. (≥6.35 mm), but too thin for valid plane-strain fracture toughness testing there is insufficient data to justify strong recommendations for screening test procedures. Presumably, correlation with fracture toughness indices could be made with the results of tests using either chevron-notch (short-rod or short-bar) specimens, sharp-edge-notched, sheet-type specimens, sharply-notched, cylindrical specimens or sharp-notch Charpy spelcimens.

8. Fracture Toughness Testing Methods and Interpuretation

8.1 *K_c and K_{app} (K_{co}) Testing* —Fracture toughnes,s testing to obtain either the critical (or maximum) stress intensity factor for monotonically loaded (K_c) or the apparent fracture toughness (K_{app}) shall be performed on M(T) panels tested specimens in general accordance with Practice Test Method E 561 and the following supplemental requirements. K_{co} is recommended as another commonly used designation for the index of apparent fracture toughness. This value is designated toughness, so all requirements for K_{app} testing are also applicable to K_{co}.

NOTE 1—K_c, K_{app} , and the R-curve may all be obtained from the same test record and specimen. K_c or K_{app} are often preferred for quality assurance or material release purposes because they provide a single value measure of this practice.

7.2.1 The material fracture toughness that can be compared against a minimum specification value. For higher strength, lower toughness alloys where the maximum force is preceded by one or more unstable extensions of the crack, K_{app} is recommended for material release purposes.

8.1.1 The M(T) specimen width, *W*, and original crack length, a_o, shall be in accordance with the material specification and the specimen thickness shall be the full thickness of the product for thin products ≤0.250 in. (≤6.35 mm) in thickness and 0.250 in. (6.35 mm) for thicker products, unless otherwise stated in the material specification. Specimens not of full product thickness shall be excised from the mid-plane of the product unless otherwise stated in the material specification. Recommended widths are *W* = 16 in. (406 mm) for medium strength, higher toughness products and *W* = 6.3 in. (160 mm) for high strength, lower toughness products. For very high toughness sheet alloys, *W* = 30 in. (760 mm) are also sometimes used for supplier qualification. The recommended original crack size is one quarter of the width, *W*; that is $2a_o/W = 0.25$. In all cases the original crack size, a_o, should be within the range of 0.25 to 0.40 *W*, inclusive, allowed in Test Method E 561. If no dimensional requirements are given in the material specification, the nominal specimen size shall be 16 in. (405 mm) wide, with 15 in. (380 mm) being an acceptable minimum width. T and the initial crack length, $2a_o$ a_o shall be equal to one quarter of the width, *W*; that is, $2ao_o/W = 0.25$. *For all specimen widths and original crack sizes, the tolerance of +0.0125 W − 0W. The center-slot length for the original crack size shall be machined and precracked in accordance with E 561. Fatigue precracking may be omitted only if it can be shown that doing so does not increase the measured value +0.0125W − 0W or +0.1/−0 in. (+2.5/−0 mm), whichever is greater.*

NOTE 2—The values of K_c and K_{app} are dependent upon the interaction of the crack driving force, which is a function of specimen width, *W*, and the crack resistance curve (R-curve). Thus, they are specimen width (as well as thickness) dependent and their values will typically decrease with decreasing

Annual Book

[3] Kaufman, J. G., and Kelsey, R. A., "Fracture Toughness and Fatigue Properties of 5083-0 Plate and 5183 Welds for Liquefied Natural Gas Applications," *Properties of Materials for Liquefied Natural Gas Tankage*, *ASTM Standards, Vol 03.01.* STP 579, ASTM, 1975, pp. 138–158.

specimen width, all other factors being equal. They also depend to a lesser extent on the original crack length, a_o. Therefore, both the specified value and qualification or lot release testing should be based on specimens having the same width and original crack length.

8.1.2 The M(T) specimen shall be machined and precracked in accordance with Test Method E 561. The value of K_{fmax} in the fatigue precracking shall not exceed 15 ksi√in. (16.5 MPa√m). Fatigue precracking may be omitted only if it can be shown that doing so does not increase the measured value of K_c or K_{app}.

7.2.2 Specimen widths less than 15 in. (381 mm) may be used for quality assurance or lot release testing, but it must be recognized that the maximum or critical stress intensity factor is dependent upon the interaction of the crack-driving force, a function of specimen width, and the crack-resistance curve, so the value is specimen width (as well as thickness) dependent. The value will decrease with decreasing specimen width, all other factors being identical.

7.2.3 Except

8.1.3 Except when specifically stated, test to measure K_c with such specimens stated in the material specification, testing shall be made performed with face stiffeners on the specimen to prevent buckling above or below the center slot.

78.21.4 The *K_c value shall be calculated at the maximum force by the use of the secant or polynomial equation for M(T) panels specimen given in Practice Test Method E 561. The half crack length used in the K-expression shall be the effective half crack length, a_e, at the maximum force point calculated using the compliance expression for M(T) panels in Practice E 1561. Test Method E 561. If, as sometimes happens, there is considerable crack extension at maximum force, the point at which the force first reaches the maximum shall be used in the crack length calculations.*

8.1.5 The K_{app} value shall be calculated at the maximum force by the use of the secant equation for the M(T) specimen given in Test Method E 561. The half crack length used in the *K*-expression shall be the original crack length, a_o.

8.1.6 The net section validity of K_c or K_{app} shall be determined at the maximum force in accordance with Test Method E 561.

8.1.7 Values of K_c or K_{app} calculated under conditions in which the net section stress exceeds 100 % of the tensile yield strength of the material are not suitable for design purposes and do not express the full toughness capability of the material, but they are useful for quality control or lot release; and such value of K_c or K_{app} that equals or exceeds a specified minimum value shall constitute evidence that the material passes the stated specification if the latter is based upon tests of the same or larger width of specimen.

8.2 *R-Curve Testing*—Fracture toughness testing to obtain the R-curve shall be performed on M(T) specimens in accordance with Test Method E 561 and the following supplemental requirements.

NOTE 1—K_c is sometimes confused with 3—The R-curve provides a complete measure of a material's resistance to slow-stable crack extension and consists of multiple data points (typically ten or more). When the R-curve is used for material release purposes, the apparent fracture toughness, which release criterion is usually designated typically based on minimum specified values of K_R at two or more values of effective crack extension, Δa_e. Use of the R-curve for quality control purposes is suitable only for higher toughness alloys that exhibit stable crack extension and smoothly rising R-curves. For higher strength, lower toughness alloys where the maximum force is preceded by one or more unstable extensions of the crack, use of K_{app} is recommended.

8.2.1 The specimen size, location, and testing requirements for K_{coc}. The apparent fracture toughness differs from *Kc* in that the initial half crack length, a_o, is used in the *K*-expression instead of the effective crack length.

7.2.5 Values of K_c calculated under conditions in which the net section stress exceeds 100 % of the tensile yield strength of the material are not suitable for design purposes and do not express the full toughness capability of the material, but they are useful for quality control or lot release; and such value of K_c that equals or exceeds a specified minimum value shall constitute evidence that the material passes the stated specification if the latter is based upon tests of the same or a larger width of specimen.

7.3 In cases where the use of screening tests is desired, the double-edge notched sheet-type specimen in Fig.3 of Test Method E 338 is recommended, and those methods should be used in making the tests. The ratio of sharp-notch strength to tensile yield strength or the Charpy energy has been shown to correlate reasonably with K_c from 16 in. (405 mm) wide center-slotted panels and, if a suitable correlation has been established for the alloy/temper/product in question, the ratio may be used as a lot release criterion. Additional background and guidance on such use is presented in Section 10.

8. Fracture Toughness of Thick Sections

8.1 For thick sections of high-strength alloys, plane-strain fracture toughness, K_{Icapp} , as determined by Test Method E 399, is the standard, as supplemented by Practice B 645.

8.2 Where screening tests are desired, any one of the following three different type tests may be used; the chevron notch (short-rod or short-bar) specimen tested testing in accordance with Test Method E 1304. The sharp cylindrically notched tension specimen tested in accordance with Test Method E 602 8.1.1, 8.1.2, and the sharp notch Charpy test with root radius <0.001-in. (0.0254 mm) tested in accordance with Test Methods E 23.

8.2.1 Chevron notch (short-rod or short-bar) specimens.

8.2.2 Standard chevron notch (short-rod or short-bar) specimens 1.00-in. (25.4-mm) in diameter or 1.00 in. (25.4-mm) wide are recommended.

8.2.2.1 Use of the Chevron notch (short-rod or short-bar) specimen test method is strongly recommended 8.1.3 shall also be used for screening purposes. This test R-curve testing. For R-curve testing, fatigue precracking is highly recommended. It may be omitted only if it can be shown that doing so does not increase the measured values of K_{IcR} ant the specified values of Δa_e.

NOTE 4—The R-curve is a replacement or an alternative to Test Method E 399. Two relatively attractive features function of the chevron notch (short-rod or short-bar) method are that fatigue precracking is not required material and small overall test volume.

8.2.2.2 The stress intensity value, its thickness but is relatively independent of other geometric factors. However, the amount of valid R-curve obtained (the maximum valid Δa_e) increases with specimen width, *W*.

8.2.2 For the R-curve, it is recommended that at least 20 pairs of (K_{IvMR}, Δa_e) pairs be determined from the test record of force versus crack opening displacement in accordance with Test Method E 1304, has been shown to correlate reasonably well with plane-strain fracture toughness and if E 561. At a suitable correlation has been established for the alloy/temper/product in question, the value may minimum, (K_R, Δa_e) pairs shall be used as a lot release criterion. Additional background and guidance on such use is presented in Section 10 and in the literature.

8.2.3 Sharp cylindrically notched tension specimen.

8.2.3.1 While both standard specimens, ½ in. (12.5 mm) and 1 in. (27 mm) in diameters, are used for quality control testing, the 1 1⁄16-in. (27-mm) specimen is generally calculated using secant offsets having slope decrements of no more cost effective particularly for very tough alloys and tempers, because than 5 % of the greater sensitivity to differences in fracture toughness at high toughness levels.

8.2.3.2 The ratio initial linear slope of sharp-notch strength the test record. The values of K_R corresponding to tensile yield strength has been shown to correlate reasonably well with plane-strain fracture toughness, and if a suitable correlation has been established each secant offset shall be determined using the secant equation for the alloy/temper/product M(T) specimen in question, the ratio may be Test Method E 561. The effective half crack length, a_e, used as a lot release criterion. Additional background and guidance on such use is presented in Section 10 and the literature.

8.2.4 *Sharp Notch Charpy Specimens* :

8.2.4.1 Charpy impact tests have long been employed as a measure calculation of toughness of metals K_R and have been used to predict the plane strain fracture toughness. Various types of notches have been used including a precrack, but a sharp notch is considerably more cost effective.

9. Fracture Toughness of Intermediate Sections

9.1 For alloy, temper and product combinations greater than 0.249 in. (6.30 mm) in thickness but thinner than that sufficient to satisfy the thickness criterion Δa_e for plane-strain conditions, each secant offset, shall be determined using the fracture toughness compliance expression for M(T) panels in Test Method E 561.

8.2.3 The net section validity shall be determined for each pair of K_R and Δa_e in accordance with Test Method E 399 as supplemented by Practices B 645 or E 561, utilizing E 561. Those pairs meeting the validity requirement comprise the valid portion of the R-curve. K R_{25_R} *concept with* values in the compact specimen.

9.1.1 Test Method E 399 as supplemented by Practice B 645.

9.1.1.1 The lot shall invalid region where net section yielding has occurred may be c higher than valid points that would have been obtained with a larger specimen. However, provided tohe same spetcimen or smallexr specimen size was used to establish the requirements of the specification if all minimums, K_R values in the validity requirements of invalid region that equal or exceeds a specified minimum shall constitute evidence that the test listed in 9.1 and 9.1.1 are met except for thickness and material passes the values of stated specification.

8.2.4 Since minimum *K* Q_R *exceed the values specified for material release purposes are typically specified at certain values of* Δa_e*, which do not necessarily coincide with those from the R-curve analysis, linear interpolation between adjacent (*K_R*,* Δa_e*) pairs is acceptable as long as there is at least one (*K_{IcR}*,* Δa_e*) point between each specified value of* Δa_e.

9.2 Practice E 561 utilizing the $K_{R_{25}}$ concept with the compact specimen.

9.2.1 This practice employs the compact specimen and Practice E 561. The recommended specimen geometry for the compact specimen is dependent on the strength, toughness, and thickness of the material. An evaluation of the material being tested for lot release should be made

8.3 *Plane Strain Fracture Toughness Testing*—Plain strain fracture toughness testing to determine the optimum specimen geometry that will yield a valid result in general accordance with Practice E 561. Once the specimen geometry is established, all future tests must be made utilizing the same specimen geometry.

9.2.2 In the event that a valid $K_{R_{25}}$ value (one satisfying the general requirements stated in Practice E 561) is not obtained and specimen buckling is not involved, the $K_{R_{25}}$ value obtained may still be useful as a qualitative result for general correlation purposes. Also, if the reason for invalidity is the critical remaining ligament criterion and the $K_{R_{25}}$ value exceeds the applicable specification values based upon tests of specimens of the same geometry for material of the same thickness, the result shall be considered as evidence that the lot meets the requirements of the specification.

9.3 For this class of materials, there are insufficient data to justify strong recommendations for screening test procedures. Presumably correlation with K_{Ic} test data could be made with the results of tests using either chevron-notch (short rod or short bar) specimens, or sharp-edge notched sheet-type specimens, circumferentially notched cylindrical specimens, or sharp notch Charpy specimens.

10. Screening Tests

10.1 Because tension tests of M(T) panels and obtain K_{IcIc} tests are complex and expensive and require judgment in interpretation of results, they are not preferred for high-volume, plant quality control testing.

10.2 The more recently developed $K_{R_{25}}$ test method concept for testing intermediate thickness material and the chevron notch (short-rod or short-bar) screening test methods are less complex, much less expensive, and may be better suited for high volume testing for quality control or lot release purposes, or both. These two approaches also provide results that can be used in a strictly qualitative manner as an ordinary screening test, and also hold the promise for direct quantitative measurement of fracture toughness if all appropriate criteria of Test Method E 399 and Practice E 561 are satisfied.

10.3 Notch tension and sharp notch Charpy impact tests provide a relatively simple, inexpensive procedure and freedom from judgmental interpretation, and thus are used whenever possible for day-to-day in-plant production lot surveillance.[7]

10.3.1 The notch yield ratio, NYR, (ratio of sharp-notch strength to tensile yield strength) and sharp notch Charpy impact energies are generally a good indicator of relative fracture toughness, and may be used in correlation with K_c or KIc_Q *to develop lot for material release criteria.*

10.3.2 Notched tension and sharp notch Charpy impact purposes shall be performed on C(T) specimens u in accordance with Test Method E 399 and Practice B 645. For any test result failing to meet the validity requirements for K_{Ic} in Method E 399, the q resulting K_Q value is usable for loty e release, provided the requirements in Practice B 645 are met. A K_Q meeting these requirements, which meets or exceeds the specified minimum value of fracture toughness should K_{Ic}, shall be ceontsidered as evidence that the same level through lot meets the thickness requirements of the section as would the center-cracked tension panel or plane-strain fracture material specification.

8.4 K_{R25} *Testing* —Fracture toughness testing to obtain the K_{R25} value shall be performed on C(T) specimens in accordance with Test Method E 561 and the following supplemental requirements.

8.4.1 An evaluation of the material should be made to determine the optimum C(T) specimen for which they are being substituted.

10.3.3 Ideally, tensile geometry that will yield strengths used for validating a valid K_{R25}*Ic result in accordance with Test Method E 561. The optimum geometry (that is, width and original crack length) will depend on the strength, toughness, and thickness of the material. The minimum recommended C(T) specimen width is W measurements = 3 in. (76.2 mm) with a width of W = 4 (102 mm) or calculating notch-yield ratio values should larger, preferred. Once the optimum specimen geometry is established, the testing to establish the specification minimums and all future material release tests shall be determined from specimens whose center lines are at made utilizing the same level in specimen geometry. The specimen thickness shall be the plate full product thickness as unless otherwise stated in the material specification.*

8.4.2 The C(T) speciment shall be machined and precracked in accordance with Test Method E 561. The value of K_{fmax} in the fracture toughness specimen. In general, this will fatigue precracking shall not coincide with exceed 15 ksi$\sqrt{}$in. (16.5 MPa$\sqrt{}$m).

8.4.3 The K_{R25} value shall be calculated from the forcequ corresponding to the 25 % secant offset and the effective crack lemngth, a_e, at that point using the polynomial expression for tension the C(T) specimen location in Tests Methods B 557. To avoid confusion resulting from two sets Test Method E 561. The 25 % secant offset is a line through the origin (as determined by the *x*-intercept of tensile properties, the y initial linear slope of the test record) with a slope 75 % of the initial slope. The 25 % secant force is the force at the intersection of the force-crack opening displacement trace and the 25 % secant offset. The effective crack length at that point is determined from the slope of the 25 % secant offset using the method in u Test Method E 561.

8.4.4 If K_{R25} corresponds to show conformance with tensile requirements (Test Methods B 557) should a point on the test record at a crack opening displacement beyond the maximum force value, K_{Rmax}, shall be used in the fracture toughness calculations.

10.4 Screening tests for lot release based on the correlation between chevron notch (short-rod or short-bar) values, notch-yield ratios or sharp notch Charpy values and equivalent values place of K_{R25} for comparison with the specification minimum. The K_{Rmax}c value shall be calculated from the maximum force and the effective crack length at that point using the polynomial expression for the C(T) specimen in Test Method E 561.

8.4.5 The net section validity of the K_{R25} or K_{Rmax}Ic value shall be determined in accordance with Test Method E 561. Provided there is no evidence of specimen buckling, an invalid K_{R25} or K_{Rmax} value which meets or exceeds the applicable specification value for K_{R25}, based upon tests of specimens of the same geometry, shall be considered as evidence that the lot meets the requirements of the specification.

8.5 *Yield Strength for Validity Determination*—Preferably, the tensile yield strength for calculating certain validity requirements in the above fracture toughness tests should be taken from the same test location as the fracture toughness specimen. However, when this location does not coincide with the requirements for the tension test location in Test Methods B 557, or the material specification is different than Test Methods B 557, the yield strength from the specimen used to show conformance with the tensile requirements may be used in the calculations.

9. Screening Test Methods and Interpretation

9.1 *General Requirements*:

9.1.1 Screening tests for lot release based on the correlation between a screening test result and a fracture toughness index always have a region of uncertainty, as illustrated in Fig. 1. Screening test values in this region are not suitable for use as acceptance/rejection criteria. In this case, testing with the primary specimens (in accordance with Practices E 399 or E 561) fracture toughness test method is required for lot release purposes.

10.5 In

9.1.2 Data for determining the case of correlation between an indicator test and the compact specimen referred to in 6.1.5, the

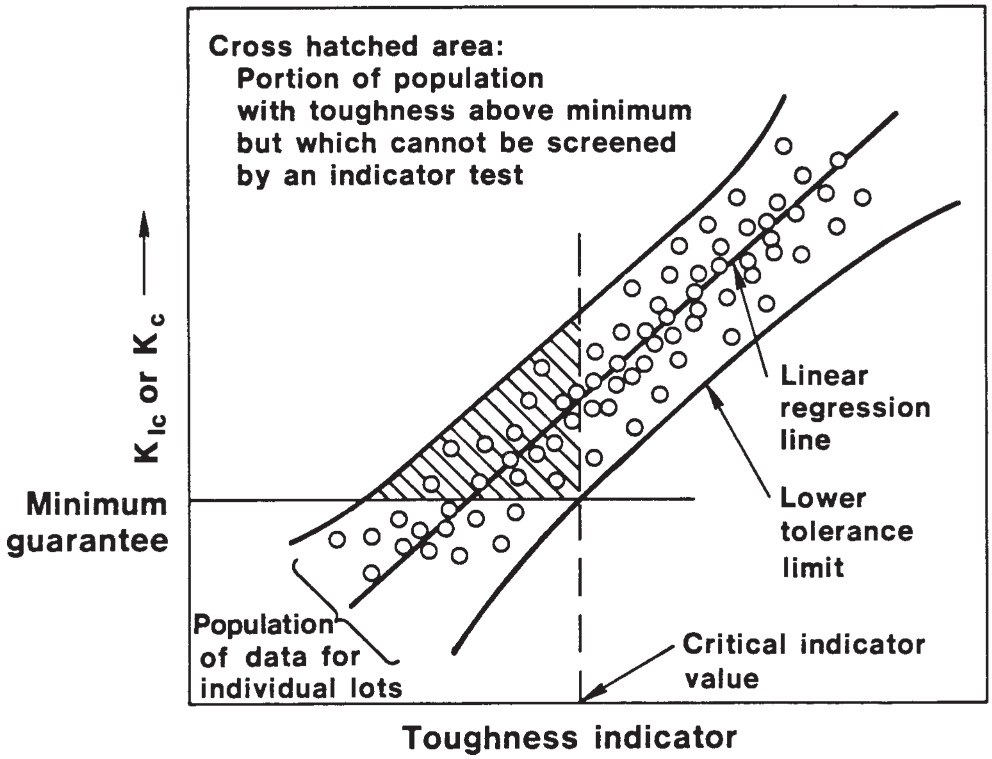

FIG. 1 Typical Toughness versus Toughness Indicator Relationship

method involves selecting discrete points primary toughness test should be collected on the force versus crack opening curve a periodic basis and using the proper compliance equation data should be analyzed regularly to determine an effective crack length. It has been found ensure that the correlation and tolerance limits do not change. If a 25 % secant change is detected, new correlation and tolerance limits should be determined.

9.1.3 Screening test specimens shall be centered at the same test location in the product as that required for the primary fracture toughness test specimen. Preferably, the tensile yield strength for calculating the notch yield ratio, NYR (ratio of sharp notch strength to tensile yield strength) in accordance with 9.2 or maximum force secant (whichever gives 9.4 or the validity of the chevron-notch test in 9.5, should be taken from the same test location. However, when this location does not coincide with the requirements for the tension test location in Test Methods B 557, or the material specification ifs different thang Test Methods B 557, the yield stre)ngth from the specimen used to show conformance with the tensile requirements may be used in the calculatiovns.

9.2 *Tension Testing of Sharply-Notched, Sheet-Type Specimens*—The notch yield ratio, NYR, from a discriminatory value (sharply-notched, sheet-type specimen has been shown to correlate reasonably well with $K_{R_{25}c}$ from 16 in. (406 mm) wide M(T) specimens. If a suitable correlation has been established for an alloy/product/temper between NYR and or $K_{R_{max}c}$) or other fracture indices, NYR may be used as a lot release criterion for that alloy/product/temper.

9.2.1 Testing of sharply-notched, sheet-type specimens shall be performed in accordance with Test Method E 338. The double-edge notched, sheet-type specimen in Fig. 3 of Test Method E 338 is recommended. The specimen shall have the same nominal thickness as the primary fracture toughness.

10.5.1 To reduce toughness specimen.

9.3 *Sharp-Notch Charpy Testing*—Charpy impact tests have long been employed as a measure of the toughness of metals and have been used to predict the plane strain frablcture toughness, K_{Ic}. The Charpy energy has also been shown to ciorrelated reasonable well with K_c from 16 in. (406 mm) wide M(T) specimens. If a suitable correlation has been established for an alloy/product/temper between the Charpy energy and K_{Ic} or method appliedK_c or other fracture indices, Charpy energy may be used as a screening test, the following guidelines should lot release criterion for that alloy/product/temper.

9.3.1 Charpy impact testing shall be observed: choose performed in accordance with Test Method E 23. Various types of notches have been used, including a convenient compact specimen size that precrack, but a sharp notch is near the required ligament length for most effective. The sharp notch shall have a valid test without root radius of <0.001 in. (<0.0254 mm).

9.3.2 Charpy impact testing is limited to product thickness >0.10 in. (>2.54 mm). The Charpy specimen shall have the necessity for absolutely meeting it and same nominal thickness as the crack length should be held essentially constant.

10.6 In conducting sharp notch primary fracture toughness specimen up to a thickness of 0.394 in. (10 mm). If the thickness of the primary fracture toughness specimen is >0.394 in. (10 mm), the Charpy impact tests, specimen shall have a nominal thickness of 0.394 in. (10 mm).

9.3.3 A low capacity impact machine of approximately 25 ft.-lbf (33.9 N·m) is recommended with sufficient sensitivity to measure preferably to the nearest 0.01 ft.-lbf (0.014 N·m). Machining and maintaining the sharp notch may be most conveniently accomplished on a fly cutter with a single point carbide tool ground to a sharp point.

9.4 *Tension Testing of Sharply-Notched, Cylindrical Specimens*—The notch yield ratio, NYR, from a sharply-notched, cylindrical specimen has been shown to correlate reasonably well with plane strain fracture toughness, K_{Ic}. If a suitable correlation has been established for an alloy/product/temper between NYR and K_{Ic}, NYR may be used as a lot release criterion for that alloy/product/temper. Additional background and guidance on such use is presented in the literature.[4]

9.4.1 Testing of sharply-notched, cylindrical specimens shall be performed in accordance with Test Method E 602.

9.4.2 Both the standard ½-in. (12.5-mm) and 1¹⁄₁₆-in. (27-mm) are permitted. However, whenever product dimensions allow for use of the larger standard specimen, it is recommended, particularly for very tough alloys and tempers, because of its greater sensitivity to fracture toughness at high levels.

9.5 *Chevron Notch (Short Rod or Short Bar) Testing* —The plane-strain (chevron-notch) toughness K_{IvM}, has been shown to correlate reasonably well with the plane strain fracture toughness, K_{Ic}, and if a suitable correlation has been established for an alloy/product/temper between K_{IvM} and K_{Ic}, then K_{IvM} may be used as a lot release criterion for that alloy/product/temper. Additional background and guidance on such use is presented in the literature.[5]

9.5.1 Testing and analysis of short-rod or short-bar specimens to obtain K_{IvM} shall be performed in accordance with Test Method E 1304. The standard chevron notch specimens (short-rod or short-bar specimens 1.00-in. (25.4-mm) in diameter or 1.00-in. (25.4-mm) in width are recommended.

9.5.2 The plane-strain (chevron-notch) toughness, K_{IvM}, may also be used as a direct quantitative measure of fracture toughness[6] when permitted by the material specification or by agreement between the purchaser and supplier. If used for direct measurement of fracture toughness rather than for correlation purposes, fracture toughness minimums for K_{IvM} should be established using the specimens and procedures of Test Method E 1304 as they may differ significantly from minimums for K_{Ic} established using Test Method E 399.

NOTE 5—Test Method E 1304 can be employed as an alternative to Test Method E 399. Two relatively attractive features of the chevron notch test method are fatigue precracking is not required and the small specimen volume.

10. Report

10.1 The test record shall include all information required by the applicable test method(s).

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

10.3 *Rounding*—For the purpose of determining conformance with a specified limit in a material or product specification, the value of the fracture toughness or screening test indices obtained from the applicable 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.

10.4 *Replacement Tests*—The test result from a fracture toughness or screening test specimen may be discarded and a replacement test performed when: *(1)* the specimen was machined incorrectly, *(2)* the test procedure was incorrect, or *(3)* the test machine malfunctioned.

10.5 *Retests of Fracture Toughness Tests*—Retests for direct measures of fracture toughness in Section 8 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 for reasons other than those in 10.4 after rounding in accordance with 10.3, the lot represented by that test result shall be subject to rejection, except as provided below:

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

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

10.5.3 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.

10.6 *Retests of Screening Tests*—Retests of screening tests in Section 9 are not permitted. If a screening tests result falls below

---

[4] Available from The Aluminum Association, 750 3rd Ave., New York, NY 10017.

[4] Jones, M. H., et al., "Sharply Notched Cylindrical Tension Specimen for Screening Plane-Strain Fracture Toughness," *Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632,* ASTM, 1977, pp. 115–152.

[5] Kaufman,

[5] Bray, J. G., and Kelsey, R. A., "Fracture Toughness and Fatigue Properties W., "Use of 5083-0 Plate and 5183 Welds Chevron Notch Short Bar Test to Guarantee Fracture Toughness for Liquefied Natural Gas Applications," Lot-Release in Aluminum Alloys," *Properties of Materials for Liquefied Natural Gas Tankage, Chevron-Notch Fracture Test Experience: Metals and Non-Metals, ASTM STP 579, 1172,* ASTM, 197592, *pp. 138–158. 131–143.*

[6] Bray, J. W., "Use

[6] Rolfe, S. T. and Novak, S. R. "Review of Chevron Notch Short Bar Test to Guarantee Developments in Plane Strain Fracture Toughness for Lot-Release in Aluminum Alloys," Testing," *Chevron-Notch Fracture Test Experience: Metals and Non-Metals, ASTMASTM STP 1172, ASTM, 1992, 463, ASTM, Sept. 1970, pp. 131–143. 124–159.*

the critical indicator value as illustrated in Fig. 1, testing with the primary fracture toughness test method is required for material release purposes.

11. Keywords

11.1 aluminum alloys; fracture toughness; plane strain; plane stress; quality assurance; screening tests

SUMMARY OF CHANGES

Committee B07 has identified the location of selected changes to this standard since the last revision (B 646 – 9703).

(1) Changed "load" to "force" where applicable. Separated recommendations and requirements for test method selection (Sections 6 and 7) from recommendations and requirements for testing and interpretation (Sections 8 and 9).
(2) Corrected the reference to the terminology standard from E 616 to E 1823 Added information on K_{app} testing (3.2.5, 8.1, and subparas.).
(3) Editorial corrections made throughout. Added additional M(T) specimen sizes (8.1.1).
(4) Re-worded 6.1.1. Added information on use of R-curve test for quality control purposes (8.2 and subparas.).
(5) Changed 7.2 to clarify Added maximum allowable K_{cfmax} for fatigue precracking (8.1.2 and 8.4.2).
(6) Re-worded 7.2.1 to emphasize E 561 notch geometry and precracking. Added minimum recommended width for KR_{25} testing (8.4.1).
(7) Re-worded 9.2.1. Added Section 10 on reporting, replacement testing and retesting.