1.Scope 1.1 This test method covers the determination of fracture toughness (KIc) of metallic materials under predominantly linear-elastic, plane-strain conditions using fatigue precracked specimens having a thickness of 1.6 mm (0.063 in.) or greater2 subjected to slowly, or in special (elective) cases rapidly, increasing crack-displacement force.The stress intensity factor, KIc, is measured using the operational procedure (and satisfying all of the validity requirements) specified in Test Method E399, that provides for the measurement of crack-extension resistance at the onset (2% or less) of crack extension and provides operational definitions of crack-tip sharpness, onset of crack extension, and crack-tip plane strain.Significance and Use 5.1 The property KIc determined by this test method characterizes the resistance of a material to fracture in a neutral environment in the presence of a sharp crack under essentially linear-elastic stress and severe tensile constraint, such that (1) the state of stress near the crack front approaches tritensile plane strain, and (2) the crack-tip plastic zone is small compared to the crack size, specimen thickness, and ligament ahead of the crack.Terminology 3.1 Definitions:Terminology E1823 is applicable to this test method: 3.1.1 stress-intensity factor, K, KI, KII, KIII [FL-3/2]-- magnitude of the ideal-crack-tip stress field (a stress-field singularity), for a particular mode of crack displacement, in a homogeneous, linear-elastic body.7.1.3 Alternatively, the ratio of yield strength to elastic modulus may be used for selecting a specimen size that will be adequate for all but the toughest materials When it has been established that 2.5(KIc/?YS)2 is substantially less than the minimum recommended ligament size given in the preceding table, then a correspondingly smaller specimen can be used.5.1.2 Lower values of KIc can be obtained for materials that fail by cleavage fracture; for example, ferritic steels in the ductile-to-brittle transition region or below, where the crack front length affects the measurement in a stochastic manner independent of crack front constraint.5.2 This test method can serve the following purposes: 5.2.1 In research and development, to establish in quantitative terms significant to service performance, the effects of metallurgical variables such as composition or heat treatment, or of fabricating operations such as welding or forming, on the fracture toughness of new or existing materials.NOTE 6--For plane-sided specimens the value of BN is equal to the thickness B. 8.2.2 Specimen width, W, shall be measured, in conformance with the procedure of the annex appropriate to the specimen configuration, to the nearest 0.03 mm (0.001 in.) or 0.1 %, whichever is larger, at not less than three positions near the notch location, and the average value recorded.The specification of K Ic values in relation to a particular application should signify that a fracture control study has been conducted for the component in relation to the expected loading and environment, and in relation to the sensitivity and reliability of the crack detection procedures that are to be applied prior to service and subsequently during the anticipated life.6.4.3 It is not the intent of this test method to exclude the use of other types of gages or gage-fixing devices provided the gage used meets the requirements listed above and provided the gage length does not exceed those limits given in the Annex appropriate to the specimen being tested.Measurements essential to the calculation of K Ic are specimen thickness, B (and in the case of side-grooved alternative specimens, BN), crack size, a, and width, W. 8.2.1 Specimen thickness, B (and in the case of sidegrooved alternative specimens, BN), shall be measured before testing to the nearest 0.03 mm (0.001 in.) or to 0.1 %, whichever is larger.The second part consists of Annexes that give specific information on displacement gage and loading fixture design, special requirements for individual specimen configurations, and detailed procedures for fatigue precracking.NOTE 3--Alternative W/B ratios different from the recommended ratio in 7.2.1.1 but still meeting the requirements in 7.2.1 are sometimes useful, especially for quality control or lot releases purposes, because they allow a continuous range of product thicknesses to be tested using a discrete number of specimen widths while still maintaining specimens of full product thickness.Calculation and Interpretation of Results 9.1 Interpretation of Test Record and Calculation of KIc--In order to substantiate the validity of a KIc determination, it is first necessary to calculate a conditional result, KQ, which involves a construction on the test record, and then to determine whether this result is consistent with the size and yield strength of the specimen according to 7.1.Therefore it is advisable to minimize this nonlinearity by preliminarily loading the specimen to a maximum force corresponding to a stress-intensity factor level not exceeding that used in the final stage of fatigue cracking, then unloading.3.1.2 plane-strain fracture toughness, KIc [FL-3/2]--the crack-extension resistance under conditions of crack-tip plane strain in Mode I for slow rates of loading under predominantly linear-elastic conditions and negligible plastic-zone adjustment.L = axial direction R = radial direction C = circumferential or tangential direction 3.1.4.6 In the case of complex structural shapes, where the grain flow is not uniform, specimen location and crack plane orientation shall reference host product form geometry and be noted on component drawings.Summary of Test Method 4.1 This test method covers the determination of the planestrain fracture toughness (KIc) of metallic materials by increasing-force tests of fatigue precracked specimens.However, because specimen width influences the amount of crack extension corresponding to the 95 % slope, KIc obtained with alternative W/B ratios may not agree with those obtained using the recommended W/B ratio, particularly in products exhibiting a Type I force-CMOD record (5).The value of K Ic from a side-grooved specimen may better represent the fracture toughness of the material in structural situations where plasticity is more highly constrained by the crack front geometry such as may be the case for a surface or corner crack, or by structural details such as keyways, radii, notches, etc.Side-grooving increases the likelihood of meeting the Pmax/PQ requirement, enabling a valid KIc to be obtained in products for which it would not be possible using the recommended specimen.3.1.4.5 For cylindrical sections, where grain flow can be in the longitudinal, radial or circumferential direction, specimen location and crack plane orientation shall reference original cylindrical section geometry such that the L direction is always the axial direction for the L-R-C system, as indicated in Fig.Guide B909 includes additional guidelines for recognizing when residual stresses may be significantly biasing test results, methods for minimizing the effects of residual stress during testing, and guidelines for correction and interpretation of data.Specimen Size, Configurations, and Preparation 7.1 Specimen Size: 7.1.1 In order for a result to be considered valid according to this test method (see also 3.1.2.1), the specimen ligament size (W - a) must be not less than 2.5(KIc/?YS)2, where ?YS is the 0.2 % offset yield strength of the material in the environment and orientation, and at the temperature and loading rate of the test (1, 3, 4).8.3 Loading Rate--For conventional (quasi-static) tests, the specimen shall be loaded such that the rate of increase of stress-intensity factor is between 0.55 and 2.75 MPa?m/s (30 and 150 ksi?in./min) during the initial elastic displacement.The force at a 5 % secant offset from the initial slope (corresponding to about 2.0 % apparent crack extension) is established by a specified deviation from the linear portion of the record (1).The validity of the KIc value determined by this test method depends upon the establishment of a sharp-crack condition at the tip of the fatigue crack in a specimen having a size adequate to ensure predominantly linear-elastic, plane-strain conditions.Indications of residual stress include distortion during specimen machining, results that are specimen configuration dependent, and irregular fatigue precrack growth (either excessive crack front curvature or out-of-plane growth).6.4 Displacement Gage--The displacement gage electrical output represents relative displacement (V) of two precisely located gage positions spanning the crack starter notch mouth.Also, because a shorter ligament length may hinder resistance curve development, an alternative specimen with W/B2 (allowed only for bend specimens) may pass the P max/PQ requirement, while a specimen with the recommended W/B ratio would fail.The value of KIc from the recommended specimen may better represent the fracture toughness of the material in structural situations where surface plasticity and shear lip development is not constrained such as a through crack in a region of uniform thickness.Side grooving after precracking beneficially removes a portion of the non-linear crack front at the ends of the crack front, thus increasing the likelihood of meeting crack front straightness requirements.For the chevron notch starter configuration, the fatigue crack shall emerge from the chevron on both surfaces; furthermore, neither surface crack size measurement shall differ from the average crack size by more than 15 %, and their difference shall not exceed 10 % of the average crack size.10.2.4 Fatigue precracking conditions, specifically the maximum stress-intensity factor, Kmax, stress-intensity factor range, ?KI, and number of cycles for the final 2.5 % of the overall crack size, a (size of notch plus fatigue crack extension).A hyphenated code defined in Terminology E1823 is used wherein the letter(s) preceding the hyphen represents the direction normal to the crack plane and the letter(s) following the hyphen represents the anticipated direction of crack extension (see Fig.In most cases the L direction corresponds to the direction of maximum grain flow, but some products such as pancake, disk, or ring forgings can have the R or C directions correspond to the direction of maximum grain flow, depending on the manufacturing method.To establish the suitable crack-tip condition, the stressintensity factor level at which specimen fatigue precracking is conducted is limited to a relatively low value.Guide B909 provides supplementary guidelines for plane strain fracture toughness testing of aluminum alloy products for which complete stress relief is not practicable.5.2.3 For specifications of acceptance and manufacturing quality control, but only when there is a sound basis for specifying minimum KIc values, and then only if the dimensions of the product are sufficient to provide specimens of the size required for valid KIc determination.The test machine shall have provisions for autographic recording of the force applied to the specimen; or, alternatively, a computer data acquisition system that may be used to record force and CMOD for subsequent analysis. For the straight-through notch starter configuration, no part of the crack front shall be closer to the machined starter notch than 0.025W or 1.3 mm (0.050 in.), whichever is larger; furthermore, neither surface crack size measurement shall differ from the average crack size by more than 15 % and their difference shall not exceed 10 % of the average crack size.Hence, the magnitude of their influence on KQ and KIc in the test specimen may be quite different from that in the original or finish machined product (see also 5.1.6.) 9.1.2 When a computer data acquisition system is used, the data reduction program shall determine the same forces (PQ and P max) as above.NOTE 1--

Plane-strain fracture toughness tests of thinner materials that are sufficiently brittle (see 7.1) can be made using other types of specimens (1).3 There is no standard test method for such thin materials.3.1.4.1 Wrought Products--the fracture toughness of wrought material depends on, among other factors, the orientation and propagation direction of the crack in relation to the material's anisotropy, which depends, in turn, on the principal directions of mechanical working and grain flow.3.1.4.8 Discussion--when products are to be compared on the basis of fracture toughness, it is essential that specimen location and orientation with respect to product characteristic directions be comparable and that the results not be generalized beyond these limits.The value of K Ic is calculated from this force using equations that have been established by elastic stress analysis of the specimen configurations specified in this test method.Likewise this test method does not apply to high toughness or high tearing-resistance materials whose failure is accompanied by appreciable amounts of plasticity.The effect can be especially significant for specimens removed from as-heat treated or otherwise nonstress relieved stock, from weldments, from complex wrought parts, or from parts with intentionally induced residual stresses.However, for material that cannot be machined in the final condition, the final treatment may be carried out after machining provided that the required dimensions and tolerances on specimen size, shape, and overall finish are met (see specimen drawings of Figs.To facilitate fatigue precracking at low stress intensity levels, the suggested root radius for a straight-through slot terminating in a V-notch is 0.08 mm (0.003 in.) or less.7.3.2.2 The size of the fatigue crack on each face of the specimen shall not be less than the larger of 0.025W or 1.3 mm (0.050 in.) for the straight-through crack starter configuration, not less than the larger of 0.5D or 1.3 mm (0.050 in.) for the slot ending in a hole (of diameter DW/10), and need only emerge from the chevron starter configuration. 8.2.4 The plane of the fatigue precrack and subsequent 2 % crack extension (in the central flat fracture area; that is, excluding surface shear lips) shall be parallel to the plane of the starter notch to 610?.Thus, in calculating the secant line OP5, the rotation point of the slope adjustment should be at the intersection of the line OA with the displacement-axis.7, Types II and III), then this maximum force is P Q. NOTE 7--Slight initial nonlinearity of the test record is frequently observed, and is to be ignored.The applied loading is superimposed on the residual stresses, resulting in a total crack tip stress-intensity different from that based solely on the externally applied forces.If P max/PQ does exceed 1.10, then the test is not a valid K Ic test and the user is referred to Test Method E1820 on elastic-plastic fracture toughness.Notwithstanding these variations, however, KIc is believed to represent a lower limiting value of fracture toughness (for 2 % apparent crack extension) in the environment and at the speed and temperature of the test.5.1.4 Cyclic forces can cause crack extension at KI values less than K Ic. Crack extension under cyclic or sustained forces (as by stress corrosion cracking or creep crack growth) can be influenced by temperature and environment.5.2.2 In service evaluation, to establish the suitability of a material for a specific application for which the stress conditions are prescribed and for which maximum flaw sizes can be established with confidence.6.2 Fatigue Precracking Machine--When possible, the calibration of the fatigue machine and force-indicating device shall be verified statically in accordance with Practices E4.6.4.1 The specimen shall be provided with a pair of accurately machined knife edges to support the gage arms and serve as displacement reference points.The required linearity shall correspond to a maximum deviation of 0.003 mm (0.0001 in.) of the individual displacement readings from a least-squares-best-fit straight line through the data.If the form of the material available is such that it is not possible to obtain a test specimen with ligament size equal to or greater than 2.5(KIc/?YS)2, then it is not possible to make a valid KIc measurement according to this test method.7.2.2.1 Alternative Side-Grooved Specimens--For the compact C(T) and the bend SE(B) specimen configurations sidegrooving is allowed as an alternative to plain-sided specimens.As a result, the KIc value from a side-grooved specimen is expected to be lower than the K Ic obtained from the recommended specimen, particularly for thin products or products exhibiting Type I behavior.The increased constraint also can lead to increased likelihood of material delamination, for instance, in the plane of the specimen, which could lead to test results different from those obtained from plane-sided specimens.However, the results of several studies (6) indicate that KIc from side-grooved specimens is zero to 10 % less than that of plain-sided specimens, the difference increasing with increasing material toughness.8.2.3 Specimen crack size, a, shall be measured after fracture to the nearest 0.5 % at mid-thickness and the two quarter-thickness points (based on B for plain-sided specimens and B N for side-grooved specimens).If this ratio does not exceed 1.10, proceed to calculate KQ as described in the Annex appropriate to the specimen configuration.10.2 The following information shall be additionally reported for each specimen tested: 10.2.1 Characterization of the material (alloy code or chemistry and metallurgical condition) and product form (sheet, plate, bar, forging, casting, and so forth) tested.3.1.3 crack mouth opening displacement (CMOD), Vm [L]-- crack opening displacement resulting from the total deformation (elastic plus plastic), measured under force at the location on a crack surface that has the largest displacement per unit force.1(a), the T-L specimen fracture plane normal is in the width direction of a plate and the expected direction of crack propagation is coincident with the direction of maximum grain flow (or longitudinal) direction of the plate.The designation L-TS, for example, indicates the crack plane to be perpendicular to the principal deformation (L) direction, and the expected fracture direction to be intermediate between T and S. The designation TS-L means that the crack plane is perpendicular to a direction intermediate between T and S, and the expected fracture direction is in the L direction.5.1.3 The value of K Ic obtained by this test method may be used to estimate the relation between failure stress and crack size for a material in service wherein the conditions of high constraint described above would be expected.6.3 Loading Fixtures--Fixtures suitable for loading the specified specimen configurations are shown in the Annexes.The verification procedure shall be performed three times, removing and reinstalling the gage in the calibration fixture after each run.The gage shall be verified during the time the gage is in use at time intervals defined by established quality assurance practices.The specimen must also be of sufficient thickness, B, to satisfy the specimen proportions in 7.2.1 or 7.2.1.1 and meet the P max/PQ requirement in 9.1.3.7.1.2 The initial selection of specimen size for a valid KIc measurement is often based on an estimated value of K Ic for the material.7.2.1 Specimen Proportions--Crack size, a, is nominally between 0.45 and 0.55 times the width, W. Bend specimens can have a width to thickness, W/B, ratio of 1 bridge arrangement is also shown in Fig.A suggested design for attachable knife edges is shown in Fig.For the design shown, the major diameter of the screw is used in setting this gage length.Likewise, the crack size, a, should be nominally equal to one-half the width, W (that is a/W = 1/2).6 is a schematic showing an example cross section of an alternative side grooved specimen.For the chevron form of notch, the suggested root radius is 0.25 mm (0.010 in.) or less.For the slot ending in a drilled hole, it is necessary to provide a sharp stress raiser at the end of the hole.However, it is important to establish the initial slope of the record with high precision. This code shall be followed with the loading code (T for tension, B for bending) and the code for crack plane orientation (see 3.1.4).The latter two codes shall appear in separate parentheses.The first of the two letters in the last bracket (S) indicates the normal to the crack plane to be normal to the direction of principal deformation.The second of these letters (T) indicates the intended direction of crack extension to be parallel with the direction of least deformation.For side-grooved specimens, B, BN and (B. BN)1/2.10.2.7 Relative humidity as determined by Test Method E337.1.2 This test method is divided into two parts.Orientation of the crack plane shall be identified wherever possible.1(b), which give examples for rolled plate.1(b), crack plane orientation is identified by a three-letter code.1(c), regardless of the maximum grain flow.As such, the direction of maximum grain flow shall be reported when the direction is known.Force is applied either in tension or three-point bending.2 and described in Annex A1.2 and 3, or they may be separate pieces affixed to the specimen.This design features a knife edge spacing of 5 mm (0.2 in.).Tension specimen configurations can be 2