

SHORT-BAR FRACTURE TOUGHNESS OF METALLIC MATERIALS
Determination of

1. SCOPE:

1.1 This method covers the determination of the fracture toughness of metallic materials (K_{SR} or K_{SB}) by testing slotted short-rod or short-bar specimens.

1.2 The short-rod has a circular cross section of diameter "B", and length 1.500B. Preferred specimen sizes are B = 25.4 mm (1.000 in.), 19.05 mm (0.750 in.), or 12.7 mm (0.500 in.).

1.3 The short-bar specimen has a rectangular cross section. Its dimensions are breadth "B" by thickness 0.870B by length 1.500B. Preferred "B" dimensions are the same as for the short-rod specimen.

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications (AMS) shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

2.1.1 Aerospace Material Specifications:

AMS 2350 - Standards and Test Methods

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E399 - Plane-Strain Fracture Toughness of Metallic Materials

ASTM E616 - Terminology Relating to Fracture Testing

3. SUMMARY OF METHOD: The method involves the application of an opening load to the mouth of the short-rod or short-bar specimen which contains a chevron-shaped slot. Load versus displacement across the slot at the specimen mouth is recorded autographically. As the load is increased, a crack initiates at the point of the chevron slot and slowly advances longitudinally, tending to split the specimen in half. The load goes through a smooth maximum when the width of the crack front is about one-third of the specimen diameter (short-rod) or breadth (short-bar); thereafter, the load decreases with further crack growth. Two unloading-reloading cycles are performed during the test to measure the effects of any macroscopic residual stresses or of excessive plasticity in the specimen. The fracture toughness is calculated from the maximum load in the test and residual stress and plasticity parameters which are evaluated from the unloading-reloading cycles on the test record.

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4. **SIGNIFICANCE:** The value K_{SR} or K_{SB} determined by this method is believed to characterize the resistance of an aluminum alloy to fracture in a neutral environment in the presence of a sharp crack under severe triaxial constraint, such that the state of stress near the crack front approaches plane strain, and the crack-tip plastic region is small compared with the crack size and the specimen dimensions in the constraint direction. A K_{SR} or K_{SB} value is believed to represent a lower limiting value of fracture toughness and, hence, correlates with K_{IC} determined by the ASTM E399 standard method.

- 4.1 Background information concerning the basis for development of this test method in terms of linear elastic fracture mechanics may be found in References (1), (2), (3), and (4).

5. DEFINITIONS:

- 5.1 **Stress-Intensity Factor:** K_1 (dimensional units $FL^{-3/2}$) is the magnitude of the ideal-crack-tip stress field for mode I in a linear-elastic body.

- 5.1.1 Values of K for mode I are given by:

$$K_1 = \lim_{r \rightarrow 0} [\sigma_y \sqrt{2\pi r}]$$

where "r" equals a distance directly forward from the crack tip to a location where the significant stress σ_y is calculated; σ_y is the principal stress normal to the crack plane.

- 5.2 **Fracture Toughness of Metallic Materials, K_{SR}** (dimensional units $FL^{-3/2}$): The material-toughness property measured in terms of the stress-intensity factor K_1 by the operational procedure specified in this test method.

6. SPECIMEN CONFIGURATION, DIMENSIONS, AND PREPARATION:

- 6.1 Both the round short-rod specimen and the rectangular-shaped short-bar specimen are equally acceptable and have been found to have the same calibration.⁵ The short-rod dimensions are given in Fig. 1, the short-bar in Fig. 2.
- 6.2 **Grip Slot:** Depending on the apparatus used to test the specimen, a grip slot may be required in the specimen front face, as shown in Fig. 3. The surfaces in the grip slot should have a smooth machined finish so that the contact with each grip will be along an essentially continuous line along the entire grip slot, rather than at a few isolated points or along a short segment within the grip slot.
- 6.3 **Crack-Guiding Slots:** These may be ground using a diamond abrasive wheel of approximately $124 \text{ mm} \pm 3$ ($4.9 \text{ in.} \pm 0.1$) diameter with a thickness of $0.36 \text{ mm} \pm 0.01$ ($0.014 \text{ in.} \pm 0.0005$). The resulting slots in the specimen are slightly thicker than the diamond wheel ($0.38 \text{ mm} \pm 0.02$) ($0.015 \text{ in.} \pm 0.001$). A concentration of 50 and a grit size of 150 are suggested.

7. APPARATUS:

- 7.1 The procedure involves testing of chevron-slotted specimens and recording the load versus specimen-mouth-opening displacement during the test.

7.2 Grips and Fixtures for Tensile Test Machine Loading: Grip slots are required in the specimen face, as shown in Fig. 3. Fig. 4 shows the grip design. Grips should have a hardness of 45 HRC or higher and should be capable of providing loads to at least 1560 N (350 lb). The grips are attached to the arms of a tensile test machine by the pin and clevis arrangement shown in Fig. 5. The grip lips are inserted into the grip slot in the specimen, and the specimen is loaded as the test machine arms apply a tensile load to the grips. A transducer for measuring the specimen mouth opening displacement during the test and means for automatically recording the load-displacement test record, such as an X-Y recorder, are also required when using the tensile test machine apparatus. A suggested design for the specimen-mouth-opening displacement gage appears in Fig. 6. The gage should have a displacement resolution of $0.25 \mu\text{m}$ ($10 \times 10^{-6} \text{ in.}$) or better. However, it is not necessary to calibrate the displacement axis of the test record because only displacement ratios are used in the data analysis.

7.3 This test can also be performed on a proprietary machine* that loads the grip slot by grips attached to motor driven lever arms. The grips contain a floating displacement gage and the lever arms incorporate a load cell. Both transducers are connected to an in-built micro-computer that calculates, stores, and displays the applied stress intensity (K). The outputs are also plotted on an X-Y recorder as in 7.2 above.

8. PROCEDURE:

8.1 Number of Tests: It is recommended that at least three replicate tests be made.

8.2 Specimen Measurement: All specimen dimensions shall be measured and recorded. If the dimensions are within the tolerances shown in Fig. 1 and 2, no correction to the data need be made for out-of-tolerance dimensions. If a_0 , W, or θ are out of tolerance by up to three times the tolerances shown in Figs. 1 and 2, valid tests may still be made by the application of appropriate factors (Reference 7) to account for the deviation from standard dimensions. If the slot centering is outside the indicated tolerance, the crack is less likely to follow the chevron slots. However, the test may still be considered successful if the crack follows the slots sufficiently well, as discussed in 9.2 below.

8.3 Specimen Testing Procedure:

8.3.1 Load Transducer Calibration: Calibrate the output of the load cell in the test machine to ensure that the load cell output, as recorded on the load versus displacement recorder, is accurately translatable into the actual force applied to the specimen.

8.3.2 Install the specimen on the test machine. If using the tensile test machine (See 7.2), operate the test machine in the "displacement control" mode. Bring the grips sufficiently close together such that they simultaneously fit into the grip slot in the specimen face. Then very carefully increase the spacing between the grips until an opening load of 10 to 30 N (2.2 - 6.7 lb) is applied to the specimen. Check the alignment of the specimen with respect to the grips, and the alignment of the grips with respect to each other. The grips should be centered in the specimen grip slot to within 0.25 mm (0.010 in.). The vertical offset between the grips should not exceed 0.13 mm (0.005 in.). Using a magnifying glass, observe the grips in the grip slot from each side of the specimen to ensure that the specimen is properly installed. The grips should extend as far as possible into the grip slot. Correct any deviations from the desired specimen alignment.

*A source of such a machine is TerraTek, Inc., Salt Lake City, Utah, available under the trade name Fractometer II. TerraTek holds patents on this machine.

- 8.3.3 Install the mouth-opening displacement gage on the specimen. The gage must sense mouth opening no farther than 1 mm (0.040 in.) from the front face of the specimen. If the gage design of Fig. 6 is used, the contact force between the gage arms and the specimen can be adjusted with a rubber elastic band so the gage will support itself, as indicated in Fig. 5. However, the contact force must not be more than 2 N (1/2 lb), as it increases the measured load to fracture the specimen.
- 8.3.4 Adjust the displacement (x-axis) sensitivity of the load-displacement recorder to produce a convenient-size data trace. A 70-deg angle between the x-axis and the initial elastic loading trace of the test is suggested. A quantitative calibration of the displacement axis is not necessary.
- 8.3.5 With the load-displacement recorder operating, test the specimen by causing the specimen mouth to open at a rate of 0.0025 to 0.0125 mm/sec (0.0001 to 0.0005 in. per sec). The specimen is unloaded by reversing the motion of the grips twice during the test. The first unloading is begun when the slope of the unloading line on load-displacement will be approximately 60% of the initial elastic loading slope. (For estimating the point at which the unloadings should be initiated, it can be assumed that the unloading paths will be linear and will point toward the origin of the load-displacement record). The second unloading is begun when the unloading slope will be approximately 35% of the initial elastic loading slope. Each unloading should be continued until the load on the specimen has decreased to less than 10% of the load at the initiation of the unloading. The specimen should be immediately reloaded and the test continued after each unloading. The test record generated by the above procedure should be similar to that of Fig. 7.
- 8.3.6 Crack Pop-In: During the initial part of the test when the load is rising most rapidly, if a sudden load drop occurs simultaneously with an audible "pop" or "tick" sound from the specimen, a crack pop-in has occurred at the point of the chevron slot. If the pop-in is large, such that the first unloading slope which can be drawn is less than one-half of the initial elastic loading slope, the test is invalid.

9. CALCULATION AND INTERPRETATION OF RESULTS:

- 9.1 Remove the specimen from the apparatus. If the two halves are still joined, break them apart with a wedge. Examine the fracture surfaces for any imperfections which may have influenced the measured peak load. Any imperfection (such as a void, a surface irregularity, or a piece of foreign matter) which is visible to the naked eye may influence the measurement if the imperfection is located between 0.6B and 1.12B from the mouth of the specimen. Imperfections outside this region do not affect the peak load unless they are very large. Discard the data whenever the peak load may have been affected by an imperfection in the fracture plane.
- 9.2 The crack should follow the crack plane. If it deviates more than 5% from the intended crack plane, the results may be considered invalid.
 - 9.2.1 Imperfect crack-follow often results from poor centering of the chevron slot in the specimen or from strong residual stresses in the test specimen.
- 9.3 Out-of-Tolerance Dimension Corrections: If the specimen dimensions are all within the tolerances specified in Figs. 1 and 2, assign $C_c = 1$, where C_c is the specimen configuration correction factor. However, if a , W , and θ are out-of-tolerance by as much as three times the tolerances shown in Figs. 1 and 2, corrections can be made as indicated in Reference 7.

- 9.4 Analyze the test record to obtain "p", the plasticity and residual stress parameter. The basis for the use of "p" to compensate for the effects of any macroscopic longitudinal residual stresses in the specimen is given in References 3 and 8.
- 9.4.1 Locate the "high" and "low" points on each unloading-reloading cycle. A high point is the point at which the mouth opening displacement started decreasing to unload the specimen, and the corresponding low point is on the reloading part of the unloading-reloading cycle at one-half the load of the high point. The high and low points are labeled "H" and "L", respectively, in Fig. 7.
- 9.4.2 Draw the ideal elastic release path approximations through the high and low points of each unloading-reloading cycle (slanted dashed lines of Fig. 7).
- 9.4.3 Draw the horizontal "average load" line between the two ideal elastic release lines (Fig. 7). The average load line is drawn at the level of the average load on the data trace between the two unloading-reloading cycles. It must be drawn horizontal, but the choice of the average load can vary by $\pm 5\%$ from the correct value without materially affecting the results.
- 9.4.4 Measure ΔX (the distance between the ideal elastic release lines at the average load line) and ΔX_0 (the distance between the ideal elastic release lines at the zero load line). Calculate $p = \Delta X_0 / \Delta X$. If the release lines cross before reaching the zero load axis, ΔX_0 , and therefore p, are considered to be negative. The analysis is nevertheless valid. However, the test is considered invalid unless $-0.15 < p < +0.15$, inasmuch as the theory assumes relatively small values of p.
- 9.5 From the test record, measure the maximum load in the experiment, F_c .
- 9.6 Calculate K_{SR} or K_{SB} from the equation:

$$K_{SR} \text{ or } K_{SB} = AF_c C_c (1+p) / B^{3/2},$$

A is the dimensionless specimen configuration calibration constant defined in Reference 1 and evaluated in Reference 6. It is not a function of machine stiffness, material properties, or absolute specimen size, as long as the scaled specimen configuration, including the location of the applied load on the specimen, remains constant. The calibrated value of A is uncertain by about 5%.

- 9.6.1 The specimen's B dimension (short-rod diameter or short-bar breadth) should satisfy

$$B > \left(\frac{K_{SR}}{\sigma_{ys}} \right)^2$$

where σ_{ys} is the material's tensile yield strength.

10. REPORT:

- 10.1 The report shall include the following for each specimen tested:

- 10.1.1 Specimen identification,
- 10.1.2 Environment of test, if other than normal atmosphere and room temperature,
- 10.1.3 Diameter, B (short-rod) or Breadth, B (short-bar),