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AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Standard Test Method for Determining J - R Curves¹

This standard is issued under the fixed designation E 1152; 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.

1. Scope

1.1 This test method² covers the determination of the J -integral versus crack growth resistance curves (J - R curve) for metallic materials.

1.2 The recommended specimens are the pin-loaded compact ($C(T)$) and the three-point bend ($SE(B)$) specimens. Both have in-plane dimensions of constant proportionality for all sizes. Specimen configurations other than those recommended in this test method may require different procedures and validity requirements.

1.3 This test method is intended to characterize the slow, stable crack growth resistance of bend-type specimens in such a manner that it is geometry insensitive within limits set forth in this test method.

1.4 The single specimen elastic compliance test method is detailed herein, but other techniques of measuring crack length are permissible if they equal or exceed the accuracy requirements of this test method.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *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:

- E 4 Practices for Force Verification of Testing Machines³
- E 8 Test Methods for Tension Testing of Metallic Materials³
- E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials³
- E 616 Terminology Relating to Fracture Testing³
- E 813 Test Method for J_{IC} , A Measure of Fracture Toughness³

3. Terminology

3.1 Terminology related to fracture testing contained in Terminology E 616 is applicable to this test method.

3.2 Definitions:

3.2.1 J -integral, $J(FL^{-1})$ —a mathematical expression, a line or surface integral that encloses the crack front from one crack surface to the other, used to characterize the local stress strain field around the crack front. See Terminology E 616 for further discussion.

3.2.2 R -curve—a plot of resistance to stable crack extension, Δa_p .

DISCUSSION—In this test method, the J - R curve is a plot of the far-field J -integral versus physical crack extension, Δa_p . It is recognized that the far-field value of J may not represent the stress-strain field local to a growing crack.

3.2.3 effective yield strength, $\sigma_Y(FL^{-2})$ —an assumed value of uniaxial yield strength that represents the influence of plastic yielding upon fracture test parameters.

DISCUSSION—In this test method, σ_Y is the average of the 0.2 % offset tensile yield strength, σ_{YS} , and the ultimate tensile strength, σ_{TS} . See Test Methods E 8.

3.2.4 specimen thickness, $B[L]$ —distance between the sides of the specimen.

3.2.5 net thickness, $B_N[L]$ —distance between the roots of the side grooves³ in side grooved specimens.

3.2.6 specimen width, $W[L]$ —distance from the reference plane to the back edge of the specimen.

3.2.7 $SE(B)$ specimen span, $S[L]$ —distance between specimen supports.

3.2.8 physical crack size, $a_p[L]$ —the distance from a reference plane to the observed crack front. The reference plane depends on the specimen form. Normally it is taken to be either a specimen boundary, or a plane containing either the load line or the centerline of a specimen or plate. The reference plane in compact specimens is the plane normal to the sides and containing the load line. In three-point bend specimens, it contains the notched edge of the specimen.

3.2.9 original crack size, $a_o[L]$ —the physical crack size at the start of testing.

3.2.10 original uncracked ligament, $b_o[L]$ —distance from the original crack front to the back edge of the specimen ($b_o = W - a_o$).

3.2.11 physical crack extension, $\Delta a_p[L]$ —an increase in physical crack size ($\Delta a_p = a_p - a_o$).

3.2.12 remaining ligament, $b[L]$ —distance from the physical crack front to the back edge of the specimen ($b = W - a_p$).

4. Summary of Test Method

4.1 This test method describes a single specimen technique of determining the J - R curve for a metallic material. The J - R curve consists of a plot of J versus crack extension, in the region of J -controlled growth, and is valid provided that the criteria of Sections 7, 8, and 9 are satisfied.

4.2 For the procedure described in this test method, crack

¹ This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E 08.08 on Elastic-Plastic Fracture Mechanics Technology.

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² Information on R -Curve round robin data is available from ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103. Request RR:E 24 – 1011.

³ Annual Book of ASTM Standards, Vol 03.01.

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length and crack extension are determined from elastic compliance measurements. These measurements are taken on a series of unloading/reloading segments spaced along the load-versus-displacement record.

5. Significance and Use

5.1 The J - R curve characterizes, within the limits set forth in this standard, the resistance of metallic materials to slow stable crack growth after initiation from a preexisting fatigue crack or other equally sharp flaw.

5.1.1 The J - R curve can be used as an index of material toughness for alloy design, material selection, and quality assurance.

5.1.2 The J - R curve from bend-type specimens defines the lower bound estimate of J -capacity as a function of crack extension, and has been observed to be conservative in comparison with those obtained with tensile loading specimen configurations.

5.1.3 The J - R curve can be used to assess the stability of cracks in structural details in the presence of ductile tearing, with awareness of the difference that may exist between laboratory test and field conditions.

5.2 The J - R curve is not intended to be used in the upper transition region for body-centered-cubic ferrous alloys where cleavage instability may follow ductile tearing.

6. Apparatus

6.1 Measurements of applied load and load-line displacement are needed to obtain the total energy absorbed by the

specimen. Load versus load-line displacements may be recorded digitally for processing by computer or autographically with an x - y plotter.

6.2 *Grips for C(T) Specimens*—A suggested clevis and pin arrangement for gripping compact specimens is shown in Fig. 1. It accommodates specimens have a thickness $B = 0.5 W$. The flat-bottom holes minimize friction caused by loading pin rotation. Clevises and pins should be fabricated from steels of sufficient strength to elastically resist indentation loads (greater than 40 Rockwell Hardness, C scale [HRC]).

6.3 *Bend Test Fixture*—A suggested fixture for $SE(B)$ specimen testing is shown in Fig. 2. It allows for roller pin rotation and minimizes friction effects during the test. Fixturing and rolls must be made of high hardness (greater than 40 HRC) steels.

6.4 Displacement Gage:

6.4.1 Displacement measurements are needed for two purposes: (1) to evaluate J from the area under the load-displacement record and, (2) for the elastic compliance method, to infer crack extension Δa_p from elastic compliance calculations.

6.4.2 In $C(T)$, displacement measurements on the load line are recommended. As a guide, select a displacement gage that has a working range of not more than twice the displacement expected during the test. When the expected displacement is less than 3.75 mm (0.15 in.), the gage recommended in Test Method E 399 may be used. When a greater working range is needed, an enlarged gage such as the one shown in Fig. 3 is recommended. Accuracy shall be within $\pm 1\%$ of the

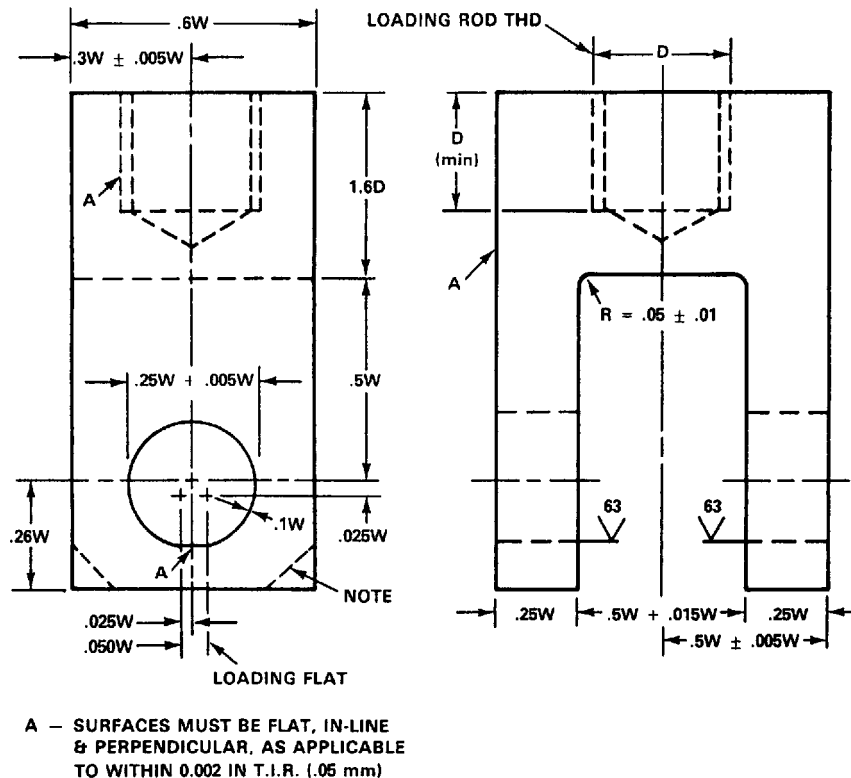
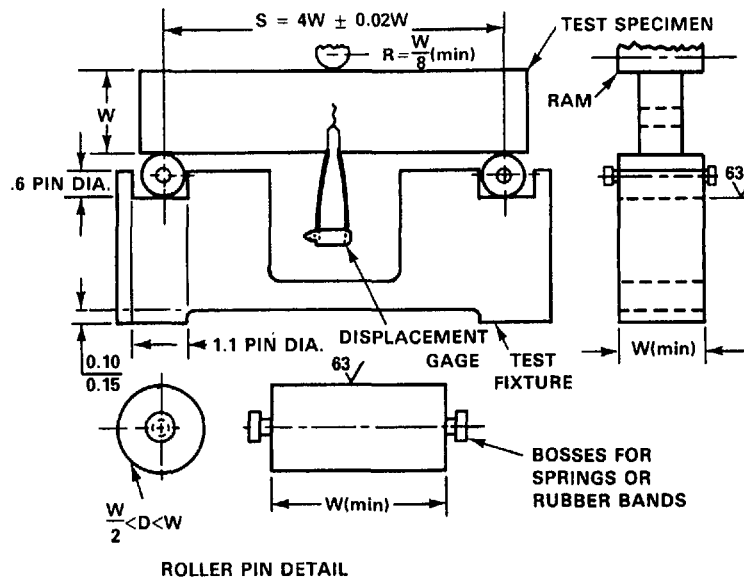


FIG. 1 Clevis for C(T) Specimen Testing



ROLLER PIN DETAIL

NOTE 1—Roller pins and specimen contact surface of loading ram must be parallel to each other within 0.002 M.

NOTE 2—0.10 in. = 2.54 mm 0.15 in. = 3.81 mm.

FIG. 2 Fixture for SE(B) Specimen Testing

full working range. In calibration, the maximum deviation of the individual data points from a fit to the data shall be less than $\pm 0.2\%$ of the calibrated range of the gage when using elastic compliance, and $\pm 1\%$ otherwise. For proper seating of gages, see 8.2.

6.4.3 The SE(B) specimen may require two displacement gages. A load-line displacement transducer is required for J computation and may also be used for elastic compliance calculations, provided that care is taken to account for elastic displacements of the load train. Often it is simpler to employ a second displacement gage, located at the crack mouth, for elastic compliance calculations. Whichever gage is used for the compliance calculations must meet the requirements of 6.4.2. In addition, the load-line gage shall display accuracy within $\pm 1\%$ and, if not used for compliance calculations, maximum deviation of the individual data points from a fit to the data shall be within $\pm 1\%$ of the range over which it is being calibrated. Direct methods for load line displacement measurement are described in Refs (1) through (4). If a remote transducer is used for load line displacement measurement, care must be taken to exclude the elastic displacement of the load train measurement and Brinelling displacements at the load points. A method to exclude these effects is described in 6.6.1.

6.4.4 For the elastic compliance method, suggested minimum digital signal resolution for displacement should be 1 part in 32 000 of the transducer signal range (V), or equivalent, and signal stability should be ± 4 parts in 32 000 of the transducer signal range (V) measured over a 10-min period. Recommended maximum signal noise should be less than ± 2 parts in 32 000 of the transducer signal range (V).

6.4.5 If an autographic method with expanded scales is used for elastic compliance measurements, displacement signal sensitivity which produces at least 50 mm (2 in.) pen travel on the displacement scale on each unload/reload sequence is recommended. Pen stability is required at the

above sensitivity at ± 3 mm (0.12 in.) for a 10-min period.

6.4.6 Gages other than those recommended in 6.4.2 and 6.4.3 are permissible if the required accuracy and deviation requirements can be met or exceeded.

6.5 Load Transducers:

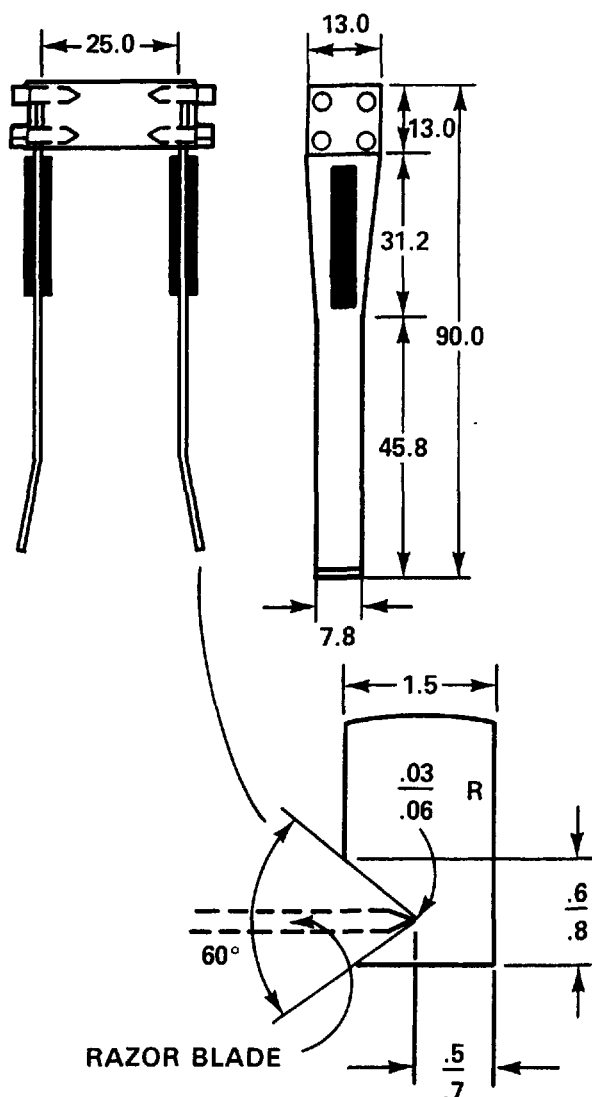
6.5.1 Testing is performed in a testing machine conforming to the requirements of Practices E 4. Applied load may be measured by any load transducer capable of being recorded continuously. Accuracy of load measurements shall be within $\pm 1\%$ of the working range. In calibration, the maximum deviation of individual data points from a fit to the data shall be less than $\pm 0.2\%$ of the calibrated range of the load transducer when using elastic compliance, and $\pm 1\%$ otherwise.

6.5.2 For the elastic compliance method, suggested minimum digital signal resolution on load should be 1 part in 4000 of the transducer signal range (V), or equivalent, and signal stability should be ± 4 parts in 4000 of the transducer signal range (V) measured over a 10-min period. Recommended maximum signal noise should be less than ± 2 parts in 4000 of the transducer signal range (V).

6.5.3 If an autographic method with expanded scales is used for elastic compliance measurements, the load signal sensitivity that produces at least 100 mm (4 in.) of pen travel on each unloading/reloading sequence is recommended. The required load signal stability at this sensitivity is ± 3 mm (0.12 in.) for a 10-min period.

6.6 Calibration accuracy of displacement transducers must be verified with due consideration for the temperature and environment of the test. Load calibrations must be documented periodically according to Practices E 4.

6.6.1 For SE(B) specimen testing using remote load-line displacement measurements, test machine/fixture compliance shall be measured before performing a series of tests or after any alteration in the test fixturing, specimen size, or material. For this determination, an unnotched specimen of



NOTE—ALL DIMENSIONS IN mm

FIG. 3 Clip-On Type Displacement Gage for 3.75 mm (0.15 in.) and More Working Range

the same material, geometry, and size as the specimen to be tested, heated (cooled) to the test temperature and equilibrated, should be elastically loaded to approximately 125 % of the actual maximum test load. Load and load-line displacement should be recorded only on the first loading, and compliance computed over that portion of the loading that corresponds to the range of loads encountered during the actual J - R curve test. Machine/fixture compliance is found by subtracting an unnotched specimen compliance, calculated using elastic beam formulae. The result then may be used in correcting load-line displacements during testing of cracked bars by subtracting the displacement caused by machine/fixture compliance from measured test displacements. Crack mouth opening displacements should not be corrected.

7. Specimen Configuration, Dimension, and Preparation

7.1 The recommended $C(T)$ specimen is similar to the configuration in Test Method E 399, but modified to permit

load-line displacement measurement. The ratio of half specimen height to specimen width $H/W = 0.6$ must be maintained. All in-plane dimensions are proportional to the specimen width W . The thickness is nominally $B = 0.5 W$, but any thickness may be used as long as the size criteria of Section 9 are met. When the component structure being evaluated has a thickness too small to meet the size requirement of Section 9, the J - R curve may be determined for that thickness so long as the planar size requirements are met. In that case the J - R curve may not be thickness independent but may give toughness that is appropriate for the component thickness being evaluated. The original crack size, a_o , shall be equal to or greater than $0.5 W$, but less than $0.75 W$. The pin spacing and the cutout section on the front edge provide room for attaching a clip gage on the load-line of the specimen. Figure 4 illustrates two specimen designs, both of which have been used successfully and satisfy the critical dimensional requirements of the basic compact specimen proportionately. Knife edges are recommended for friction-free seating of the gage. Care should be taken to maintain parallel alignment of the knife edges. Modifications of the compact specimen design are allowed providing equations for J , and compliance remain applicable.

7.2 The recommended $SE(B)$ specimen is shown in Fig. 5. Its span-to-width ratio is: $S/W = 4$. The thickness is nominally $B = 0.5 W$, but any thickness may be used as long as the size criteria of Section 9 are met. The original crack size, a_o , shall be equal to or greater than $0.5 W$, but less than $0.75 W$.

7.3 The crack slot for both specimens shall lie within the envelope shown in Fig. 6, which shall extend a distance $a_o - 0.1 W$ behind the crack tip.

7.4 For the data to be valid by this method, both the specimen thickness, B , the remaining ligament, b , and extent of crack growth must satisfy the validity requirements of 9.3. In addition, the crack front straightness criterion of 8.7.2 must be met. The initial selection of specimen dimensions can only be based on J values estimated from previous experience.

7.5 *Side Grooves*—Both types of specimens may need side grooves to ensure a straight crack front, as specified in 8.7.2. The total thickness reduction shall not exceed $0.25 B$. Side grooves with an included angle of 45° and a root radius 0.4 ± 0.2 mm (0.02 ± 0.01 in.) usually will produce results required by 8.7.2. To produce nearly straight fatigue crack fronts, specimens should be precracked before side grooving.

7.6 Fatigue Precracking:

7.6.1 All specimens shall be precracked in fatigue at load values based upon the load P_M , [F].

For $SE(B)$ specimens use:

$$P_M = 0.5 \frac{Bb_o^2\sigma_Y}{S} \quad (1)$$

For $C(T)$ specimens use:

$$P_M = 0.4 \frac{Bb_o^2\sigma_Y}{(2W + a)} \quad (2)$$

7.6.2 The length of the fatigue precrack extension from the machined notch shall not be less than 5 % of the total crack size, a_o , and not less than 1.3 mm (0.05 in.). For the final 50 % of fatigue precrack extension or 1.3 mm (0.05 in.), whichever is less, the maximum load shall be no larger than