Lecture 12

Ductile Fracture Testing

Ductile fracture toughness

1 Ductile fracture is a mechanism of failure in a material which occurs by the initiation, growth and coalescence of voids

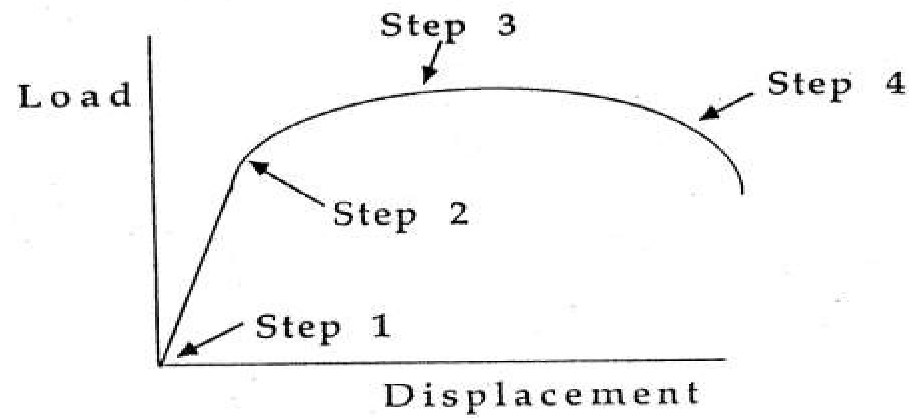
2 Ductile fracture is a process rather than an event; therefore it is better characterized by a curve than a single point

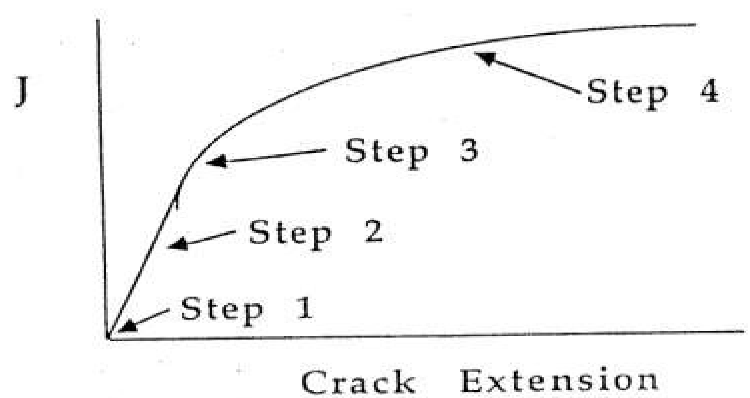
3 The curve is a plot of a fracture parameter versus crack extension, called the crack growth resistance curve or R curve

4 J or CTOD, δ, are the fracture parameters used

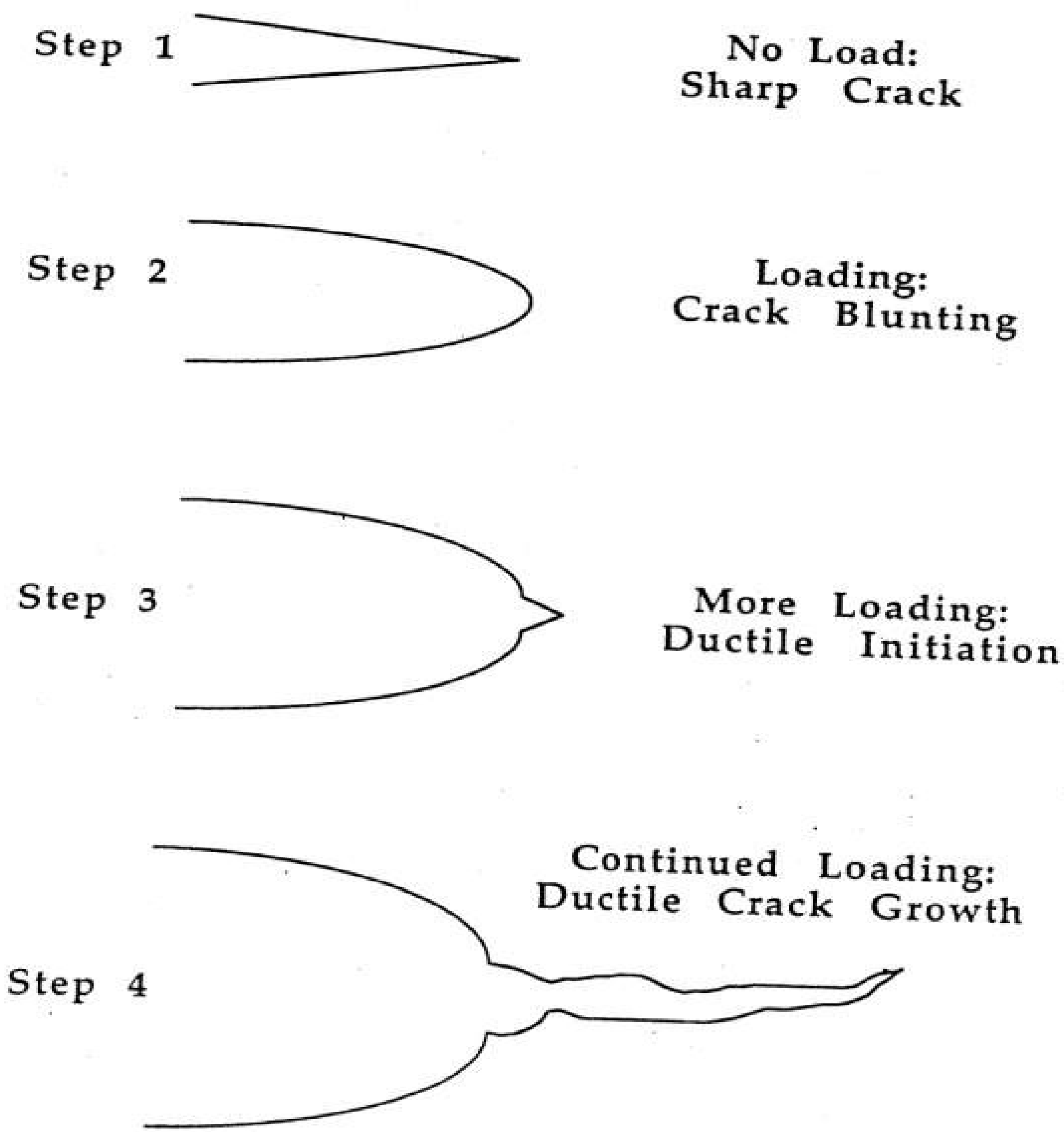
Ductile Fracture Process

Load vs Displacement and J vs Δa





Ductile Fracture Process



Concept of crack initiation in ductile fracture

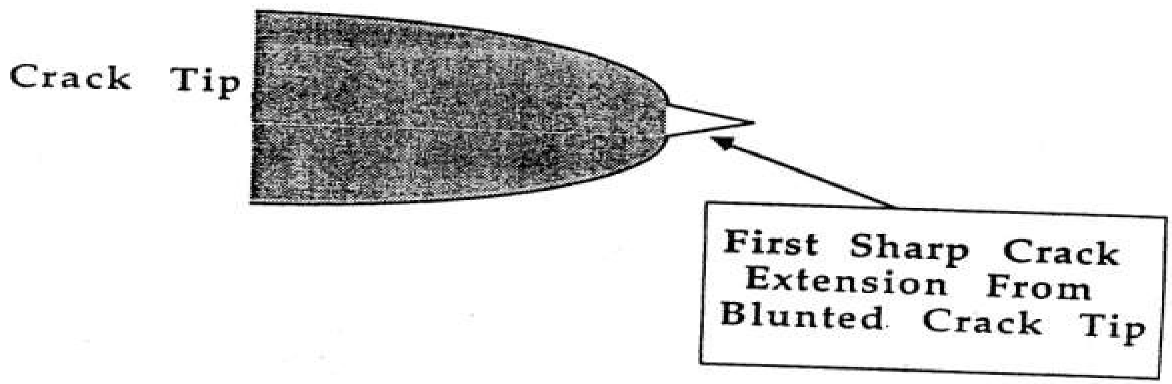
1. J_{Ic} is the value of fracture toughness near the initiation of slow, stable crack growth for metallic materials

2. The concept of the first point of initiation versus an engineering estimate, analogy to the tensile test, σ_{ys}

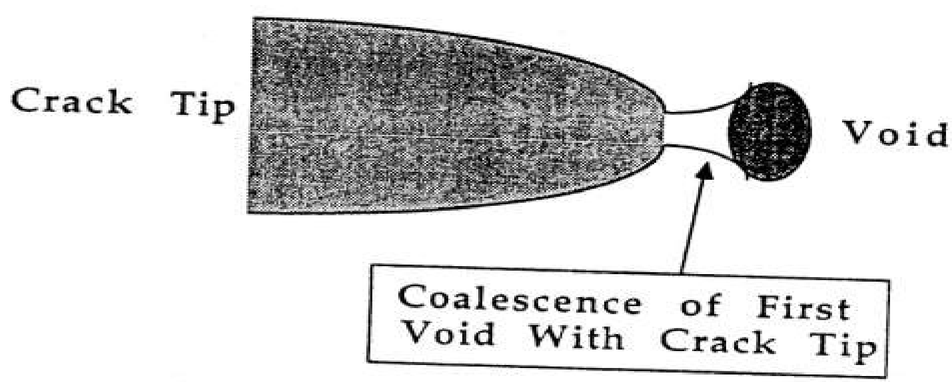
3. J is determined from a J-R curve using a set of construction and analysis rules

Concept of ductile fracture initiation

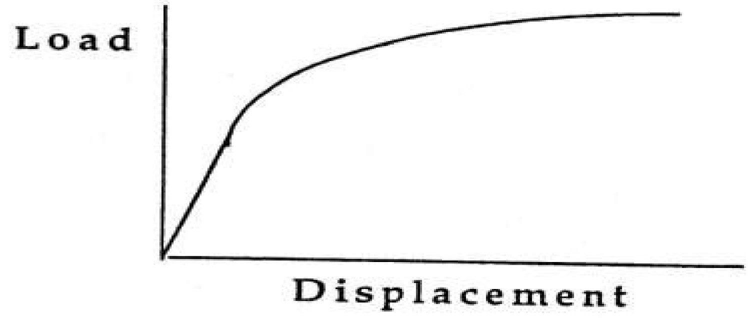
Macro-mechanics View



Micro-mechanics View

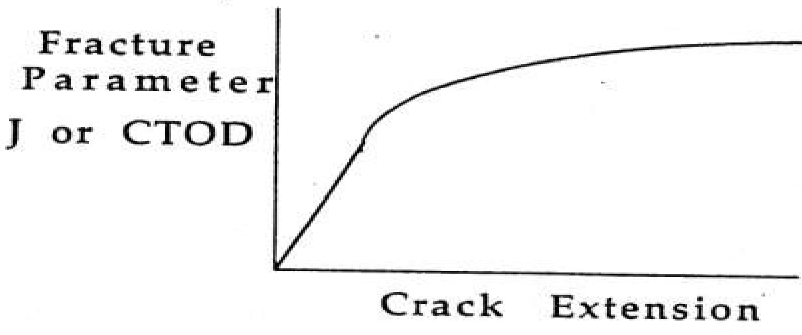


Goal of ductile fracture toughness test



1. Test fracture toughness specimen to get load versus displacement data

2. Analyze data to get plot of fracture parameter versus crack extension



Basic need for a ductile fracture toughness test

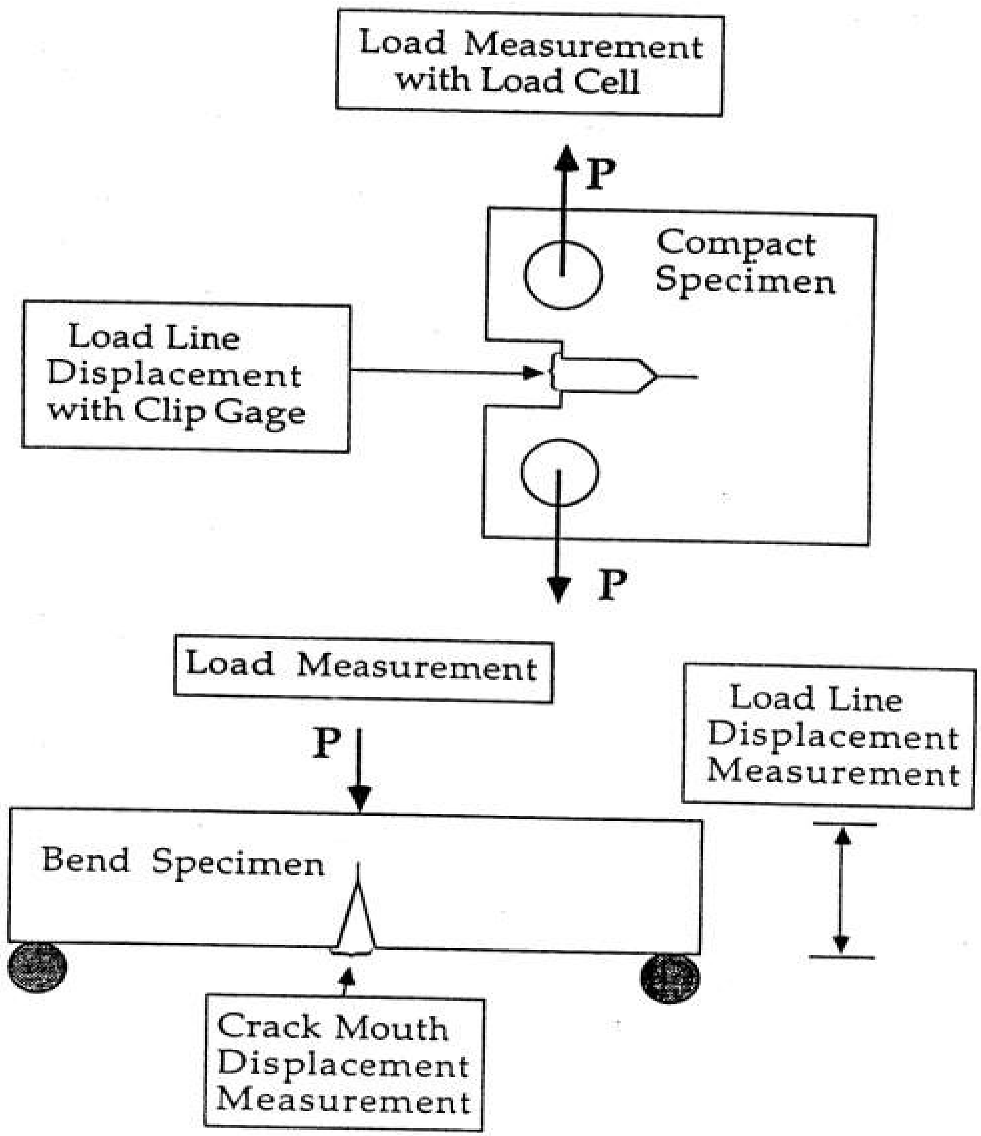
1. Load versus displacement data with a measurement of crack extension

2. Formulas to calculate the fracture parameters; J or CTOD

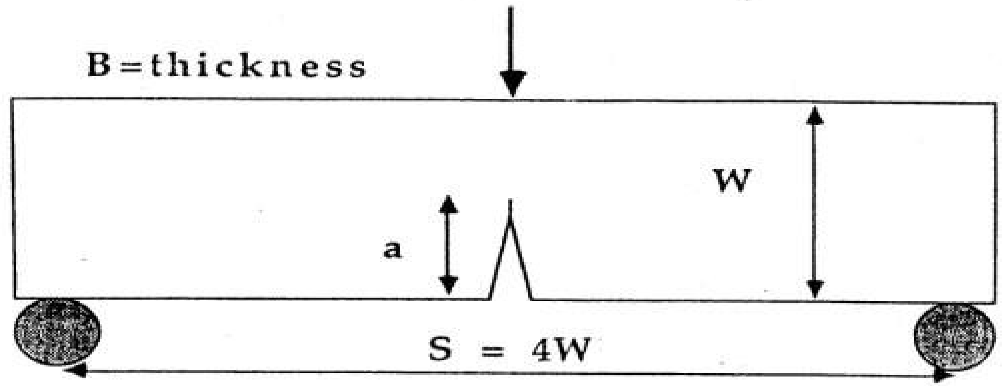
3. Special plotting of construction if an initiation point is desired

4. Qualification or validity requirements

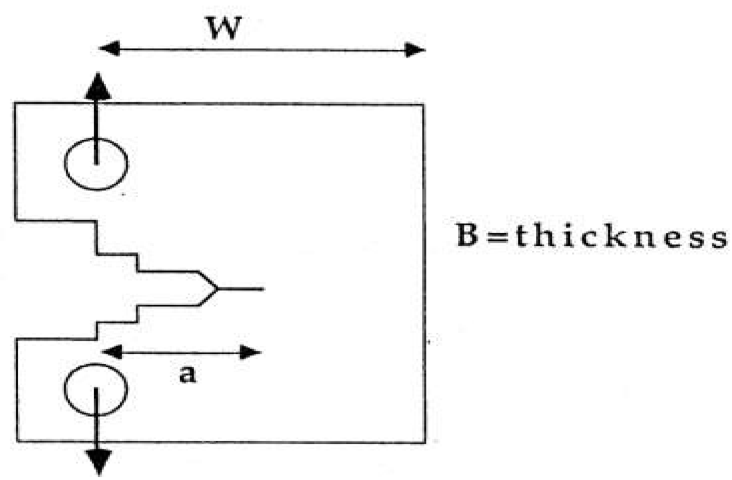
Fracture Toughness Test Parameters



Fracture toughness test specimens



Single Edge Notched Bend Specimen
with Three Point Loading

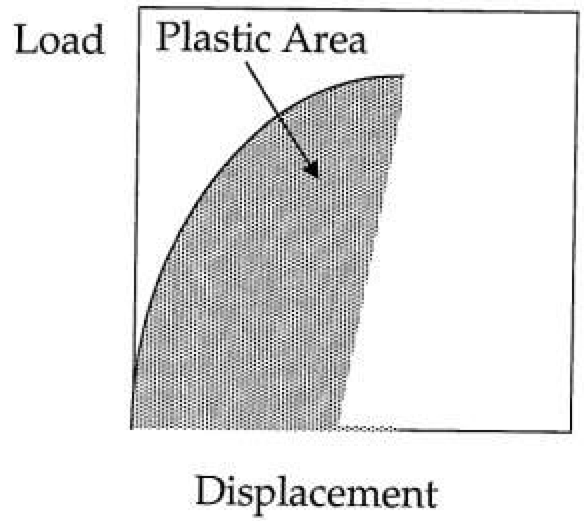


Compact Specimen
with Pin and Clevis Loading

J Formulas for J_{Ic} test

1. $J = J_{el} + J_{pl}$

$$J = \frac{K^2(1-\nu^2)}{E} + \frac{\eta_{pl} Area}{Bb}$$



$$\eta_{pl} = 2.0 \qquad \textit{bend specimen}$$

$$\eta_{pl} = 2.0 + 0.522\frac{b}{W} \quad \textit{compact specimen}$$

E 813 J_{Ic} multiple specimen test

1. Specimen type CT or Bend

2. Precrack

3. Load several specimen to a range of displacements

4. Calculate $J = J_{el} + J_{pl}$

   $J_{el} = K^2(1 - \nu^2)/E$

   $$J_{pl} = \frac{\eta_{pl}}{B\ b} \int_0^{v_{pl}} P\, dv_{pl}$$

where

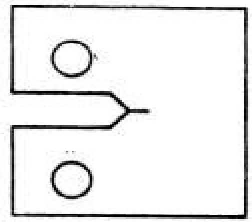
$\eta_{pl} = 2,$ bend

$\eta_{pl} = 2 + 0.522\, b/W,$ CT

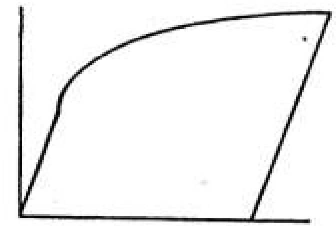
5. Hint tint and measure Δa with 9 point average

6. Plot and construct to measure J_{Ic}

Multiple Specimen J_{Ic} Test



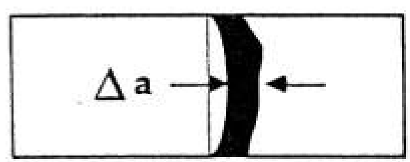
1. Start with Precracked Test Specimen



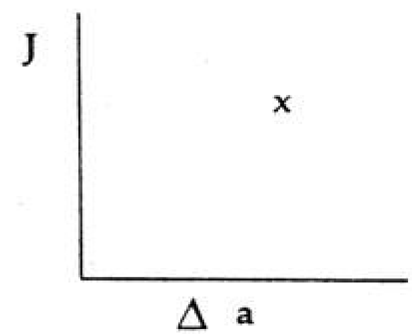
2. Generated Load vs Displacement Plot

3. Heat tint to mark crack and break open

4. Calculate J from load and displacement

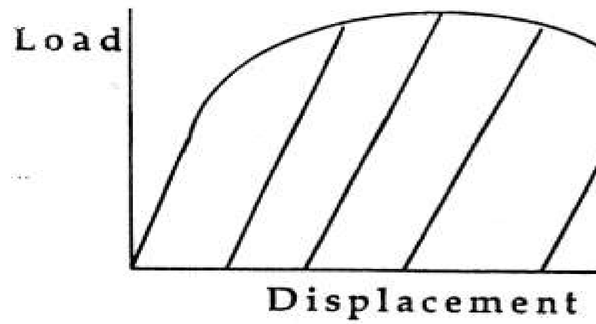


5. Measure Crack Extension Nine Point Average

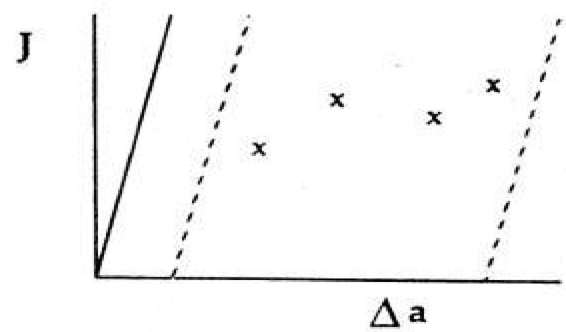


6. Plot Single Point on J vs Δ a Curve

Multiple Specimen J_{Ic} test (cont)



7. Test four or more specimens and analyze like the first one



8. Plot all J vs Δ a Points

and do J_{Ic} Construction

J_{Ic} construction

1. Consider only points falling between exclusion lines, need four or more points

   i) Blunting line is construction line,

   $J = 2\ \sigma_Y \Delta a$

   ii) Exclusion lines offset 0.15 and 1.5 mm (0.006 and 0.06 in) , same slope as construction lines

2. Top limit is $J_{max} = (b, B)\sigma_Y/15$

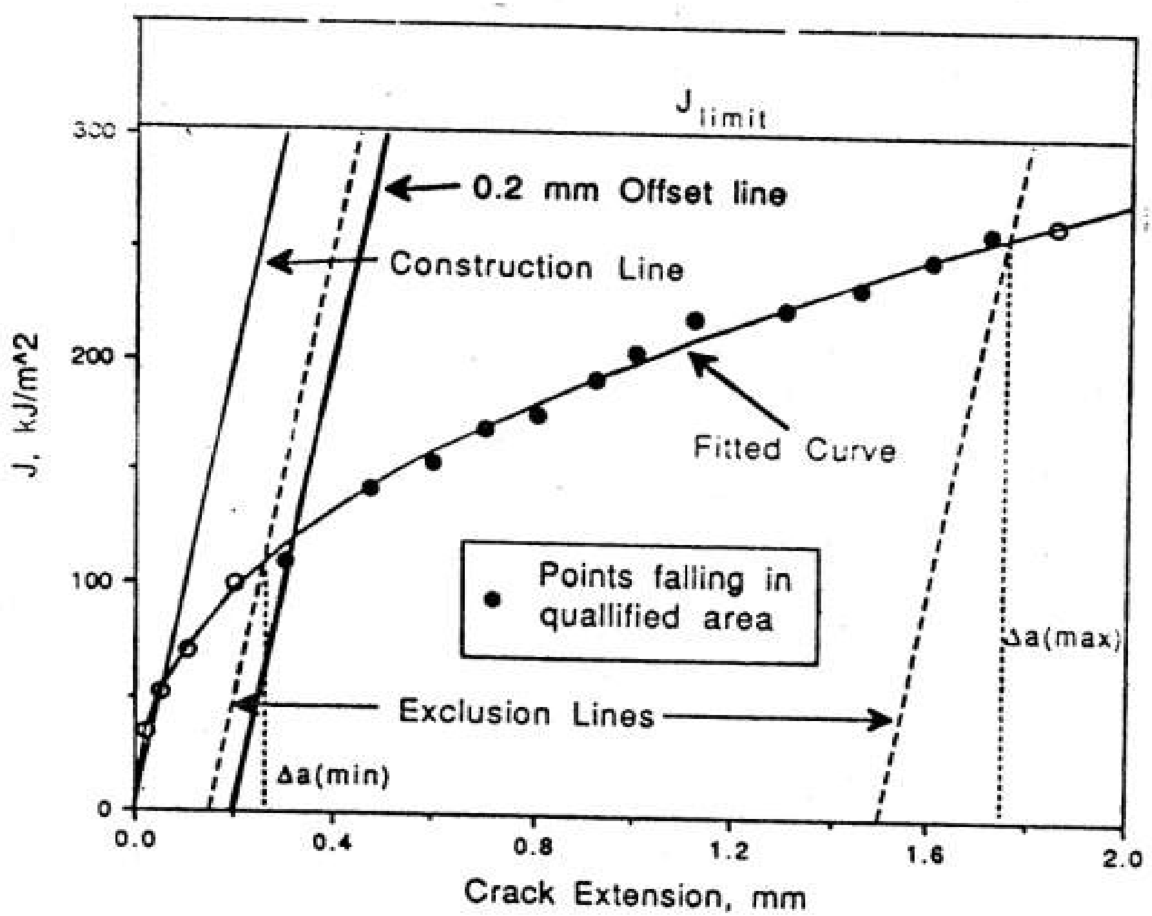
3. Fit points with a power law

   $J = C_1\ (\Delta a\ )^{C_2}$

   can use,
   $\ln J = \ln C_1 + C_2 \ln(\ \Delta a)$
   with a least square fit

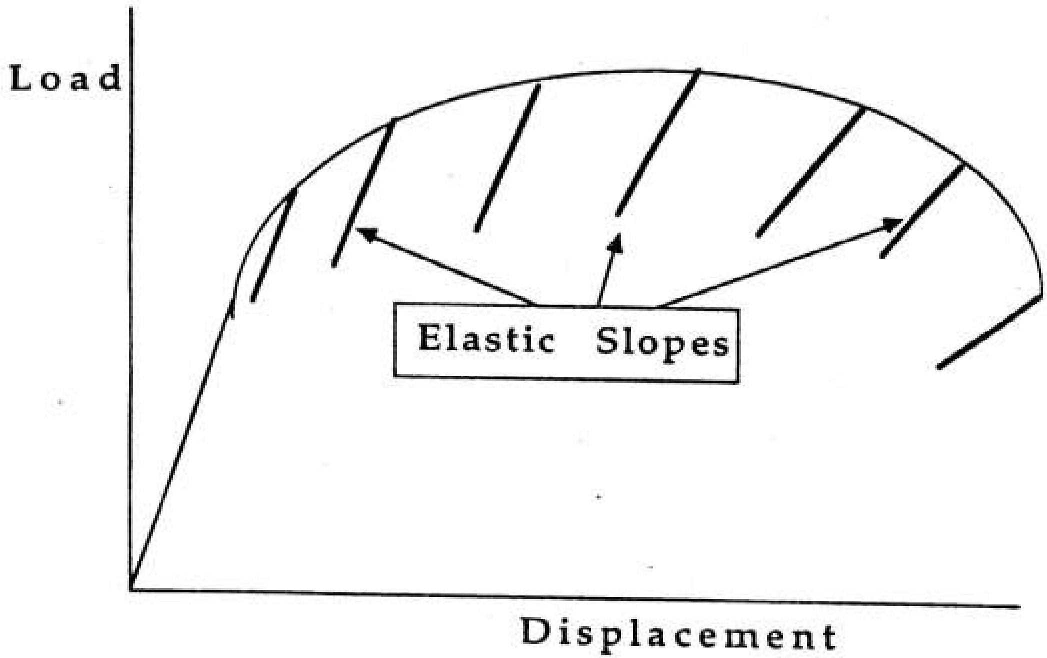
4. J_Q is at the intercept of the fitted line and a 0.2 mm (.008 in) offset to the blunting line

5. J_Q is J_{Ic} if $B, b \geq 25\ J_Q/\sigma_Y$



J_{Ic} Construction plot

Elastic Unloading Compliance



1. Elastic Slope is a measure of crack length
2. At each unload J and Δa can be determined
3. J versus Δa points are plotted and analyzed for J_{Ic} like the multiple specimen test

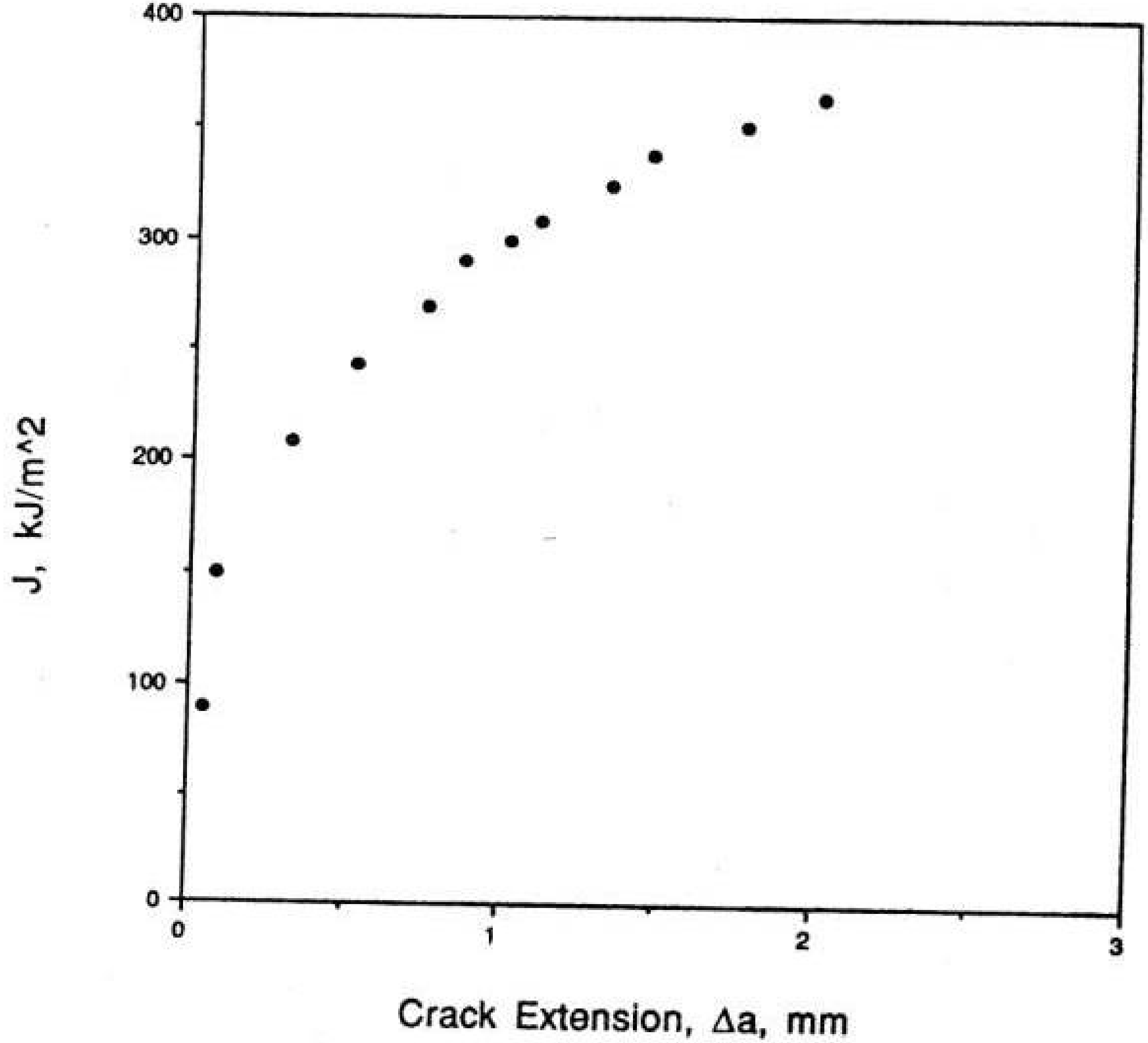


Fig. 4b - Typical J-R Curve

Standard Test Method for Measurement of Fracture Toughness[1]

This standard is issued under the fixed designation E 1820; 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 method covers procedures and guidelines for the determination of fracture toughness of metallic materials using the following parameters: *K*, *J*, and CTOD (δ). Toughness can be measured in the *R*-curve format or as a point value. The fracture toughness determined in accordance with this test method is for the opening mode (Mode I) of loading.

1.2 The recommended specimens are single-edge bend, [SE(B)], compact, [C(T)], and disk-shaped compact, [DC(T)]. All specimens contain notches that are sharpened with fatigue cracks.

1.2.1 Specimen dimensional (size) requirements vary according to the fracture toughness analysis applied. The guidelines are established through consideration of material toughness, material flow strength, and the individual qualification requirements of the toughness value per values sought.

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

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—Other standard methods for the determination of fracture toughness using the parameters *K*, *J*, and *CTOD* are contained in Test Methods E 399, E 813, E 1152, E 1290, and E 1737. This test method was developed to provide a common method for determining all applicable toughness parameters from a single test.

2. Referenced Documents

2.1 *ASTM Standards:*

E 4 Practices for Force Verification of Testing Machines[2]

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[2]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[2]

E 813 Test Method for J_{Ic}, A Measure of Fracture Toughness[2]

E 1152 Test Method for Determining *J-R* Curves[2]

E 1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement[2]

E 1737 Test Method for J-Integral Characterization of Fracture Toughness[2]

E 1823 Terminology Relating to Fatigue and Fracture Testing[2]

3. Terminology

3.1 Terminology E 1823 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *compliance* $[LF^{-1}]$, *n*— the ratio of displacement increment to load increment.

3.2.2 *crack displacement [L]*, *n*—the separation vector between two points (on the surfaces of a deformed crack) that were coincident on the surfaces of an ideal crack in the undeformed condition.

3.2.2.1 *Discussion—In this practice, displacement*, v, is the total displacement measured by clip gages or other devices spanning the crack faces.

3.2.3 *crack extension*, Δa *[L]*, *n*—an increase in crack size.

3.2.4 *crack-extension force*, G $[FL^{-1}$ *or* $FLL^{-2}]$, *n*—the elastic energy per unit of new separation area that is made available at the front of an ideal crack in an elastic solid during a virtual increment of forward crack extension.

3.2.5 *crack size, a [L]*, *n*—a lineal measure of a principal planar dimension of a crack. This measure is commonly used in the calculation of quantities descriptive of the stress and displacement fields, and is often also termed crack length or depth.

3.2.5.1 *Discussion*—In practice, the value of a is obtained from procedures for measurement of physical crack size, a_p, original crack size, a_o, and effective crack size, a_e, as appropriate to the situation being considered.

3.2.6 *crack-tip opening displacement (CTOD)*, δ *[L]*, *n*—the crack displacement due to elastic and plastic deformation at variously defined locations near the original (prior to an application of load) crack tip.

3.2.6.1 *Discussion—In this test method*, CTOD is the displacement of the crack surfaces normal to the original (unloaded) crack plane at the tip of the fatigue precrack, a_o. In this test method, CTOD is calculated at the original crack length,

[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.08 on Elastic-Plastic Fracture Mechanics Technology.

Current edition approved January 10, 1999. Published July 1999. Originally published as E 1820 - 96. Last previous edition E 1820 - 98.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

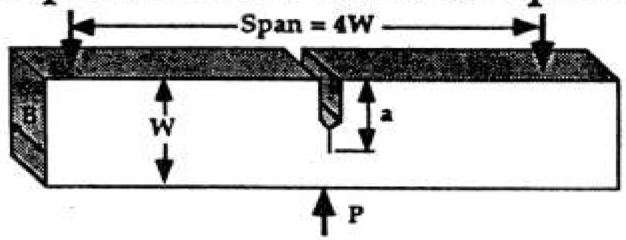
Latest Combined Standard

- **ASTM E1820 - 08a Standard Test Method for Measurement of Fracture Toughness**

CTOD TESTING (ASTM E 1290-89)

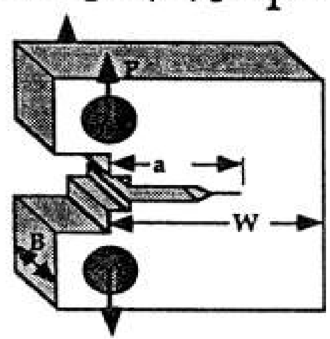
A. Specimen Configurations and Dimensions

Three-point bend [SE(B)] specimen:



$0.45 \leq a_o/W \leq 0.55$
$W/B = 1$ or 2

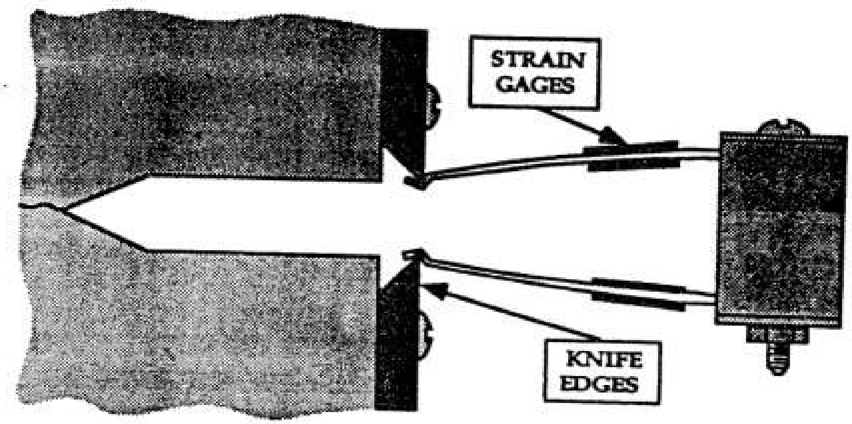
Compact [C(T)] specimen:



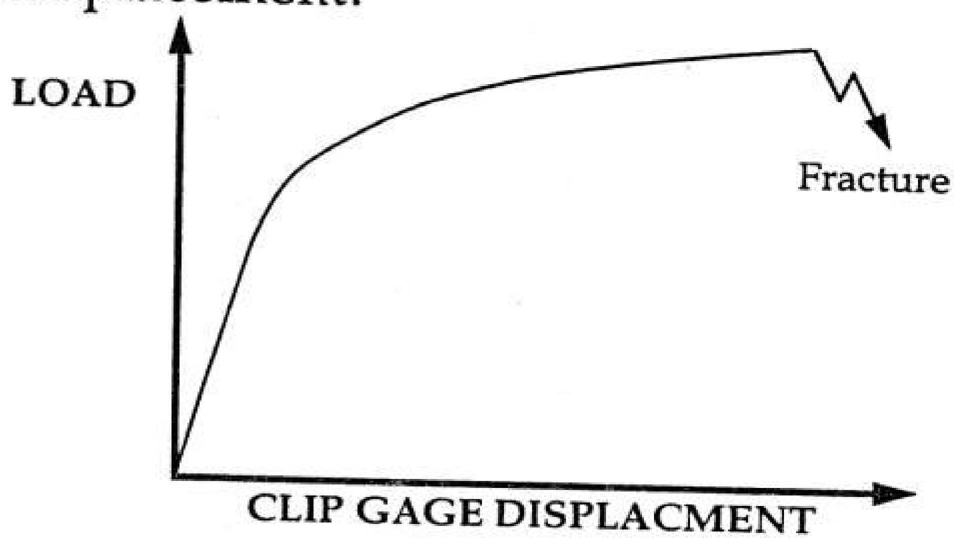
$0.45 \leq a_o/W \leq 0.55$
$2 \leq W/B \leq 4$

B. Instrumentation

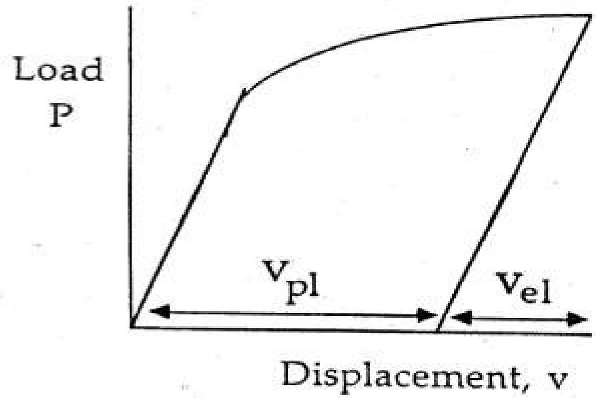
Clip gage displacement measured at the mouth of the crack:

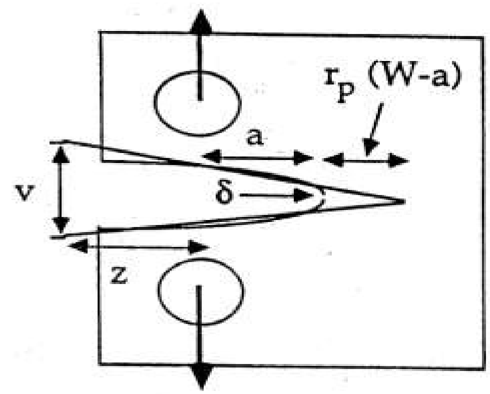


Load is plotted versus clip gage displacement:



CTOD Equations





$$\delta = \delta_{el} + \delta_{pl}$$

$$= \frac{K^2(1-\nu^2)}{2\,\sigma_{ys}E} + \frac{r_p(W-a)v_{pl}}{r_p(W-a) + a + z}$$

$$r_p = 0.4(1 + \alpha)$$

For a bend specimen:

$$\alpha = 0.10$$

$$r_p = 0.44$$

For a compact specimen:

$$\alpha = 2\left[\left(\frac{a_o}{b_o}\right)^2 + \frac{a_o}{b_o} + 0.5\right]^{1/2} - 2\left[\frac{a_o}{b_o} + 0.5\right]$$

where $b_o = W - a_o$

$$r_p \approx 0.47 \text{ for } 0.45 \leq a_o/W \leq 0.50$$

and

$$r_p \approx 0.46 \text{ for } 0.50 < a_o/W \leq 0.55$$

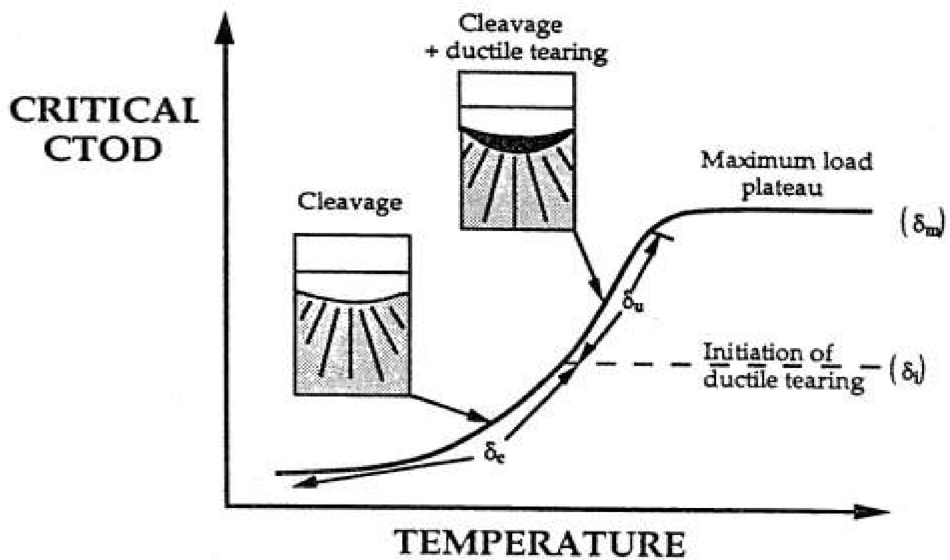
D. Notation for Critical CTOD Values

δ_c - Critical CTOD at the onset of unstable fracture without prior stable crack growth.

δ_u - Critical CTOD at the onset of unstable fracture which has been preceded by stable crack growth.

δ_i - CTOD at the initiation of stable crack growth.

δ_m - CTOD at the maximum load plateau.



Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement[1]

This standard is issued under the fixed designation E 1290; 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 method covers the determination of critical crack-tip opening displacement (CTOD) values at one or more of several crack extension events. These CTOD values can be used as measures of fracture toughness for metallic materials, and are especially appropriate to materials that exhibit a change from ductile to brittle behavior with decreasing temperature. This test method applies specifically to notched specimens sharpened by fatigue cracking. The recommended specimens are three-point bend [SE(B)] or compact [C(T)] specimens. The loading rate is slow and influences of environment (other than temperature) are not covered. The specimens are tested under crosshead or clip gage displacement controlled loading.

1.1.1 The recommended specimen thickness, B, is that of the material in thicknesses intended for an application. Superficial surface machining may be used when desired.

1.1.2 For the recommended three-point bend specimens [SE(B)], width, W, is either equal to, or twice, the specimen thickness, B, depending upon the application of the test. (See 4.3 for applications of the recommended specimens.) For SE(B) specimens the recommended initial normalized crack size is $0.45 \leq a_o/W \leq 0.55$. The span-to-width ratio (S/W) is specified as 4.

1.1.3 For the recommended compact specimen [C(T)] the initial normalized crack size is $0.45 \leq a_o/W \leq 0.55$. The half-height-to-width ratio (H/W) equals 0.6 and the width to thickness ratio is within the range $2 \leq W/B \leq 4$.

1.2 *This standard does not purport to address all of the safety problems, 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 Machines[2]

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[2]

E 616 Terminology Relating to Fracture Testing[2]

E 813 Test Method for J_{Ic}, A Measure of Fracture Toughness[2]

E 1152 Test Method for Determining J-R Curves[2]

3. Terminology

3.1 Terminology E 616 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *crack tip opening displacement, (CTOD),* $\delta[L]$—the crack displacement due to elastic and plastic deformation at variously defined locations near the original (prior to an application of load) crack tip.

Discussion—In this test method, CTOD is the displacement of the crack surfaces normal to the original (unloaded) crack plane at the tip of the fatigue precrack, a_o.

In CTOD testing, δ_c [L] is the value of CTOD at the onset of unstable brittle crack extension (see 3.2.13) or pop-in (see 3.2.7) when $\Delta a_p < 0.2$ mm (0.008 in.). The load P_c and the clip gage displacement v_c, for δ_c are indicated in Fig. 1.

In CTOD testing, δ_u [L] is the value of CTOD at the onset of unstable brittle crack extension (see 3.2.13) or pop-in (see 3.2.7) when the event is preceded by $\Delta a_p > 0.2$ mm (0.008 in.). The load P_u and the clip gage displacement v_u, for δ_u are indicated in Fig. 1.

In CTOD testing, δ_m [L] is the value of CTOD at the first attainment of a maximum load plateau for fully plastic behavior. The load P_m and the clip gage displacement v_m, for δ_m are indicated in Fig. 1.

3.2.2 *effective yield strength,* σ_Y $[FL^{-2}]$—an assumed value of uniaxial yield strength that represents the influence of plastic yielding upon fracture test parameters.

Discussion—The calculation of σ_Y is the average of the 0.2 % offset yield strength (σ_{YS}), and the ultimate tensile strength (σ_{TS}), that is $(\sigma_{YS} + \sigma_{TS})/2$. Both σ_{YS} and σ_{TS} are determined in accordance with Test Methods E 8.

3.2.3 *original crack size,* a_o $[L]$—see Terminology E 616.

3.2.4 *original uncracked ligament,* b_o $[L]$—the distance from the original crack front to the back surface of the specimen at the start of testing, $b_o = W - a_o$.

3.2.5 *physical crack extension,* Δa_p $[L]$—an increase in physical crack size, $\Delta a_p = a_p - a_o$.

3.2.6 *physical crack size,* a_p $[L]$—see Terminology E 616.

Discussion—In CTOD testing, $a_p = a_o + \Delta a_p$.

3.2.7 *pop-in*—a discontinuity in the load versus clip gage displacement record. The record of a pop-in shows a sudden increase in displacement and, generally, a decrease in load. Subsequently, the displacement and load increase to above their respective values at pop-in.

3.2.8 *slow stable crack extension* $[L]$—a displacement controlled crack extension beyond the stretch zone width (see 3.2.12). The extension stops when the applied displacement is held constant.

3.2.9 *specimen span,* S $[L]$—the distance between spec-

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[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.08 on Elastic-Plastic Fracture Mechanics Technology.

Current edition approved March 15, 1993. Published May 1993. Originally published as E 1290 – 89. Last previous edition E 1290 – 89[ε1].

[2] *Annual Book of ASTM Standards*, Vol 03.01.

Latest CTOD Standard

- **ASTM E1290 - 08 Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement**

Choices in fracture characterization

1 Deformation behavior
- Linear-elastic versus elastic plastic
- Determines fracture parameter

2 Fracture behavior
- Ductile versus brittle
- Determines type of fracture

3 Constraint
- Plane strain versus plane stress
- Determines fracture toughness values

Matrix of Deformation versus Fracture Behavior

	Fracture Behavior	
Deformation Behavior	Brittle	Ductile
Linear Elastic	K_{Ic},	K_{Ic}, K-R curve
Elastic-Plastic	J_c, δ_c	J_{Ic}, J-R curve δ_m

Common Test Methods

A. ASTM has 5 major test methods

E 399 - K_{Ic}
E 561 - K - R curve
E 813 - J_{Ic}
E 1152 - J - R curve
E 1290 - CTOD
Other special interest ones, not mentioned here

B. Problem with 5 Similar Specimens and Goals

Different details that make them exclusive

Examples: K_{Ic} test
J_{Ic} test

C. Common Test Method Test Philosophy

1. Run single specimen type, single procedure

2. Let material choose type of result

3. Allow measurement of toughness in terms of K, J or d, whichever is appropriate

D. Test Details

1. Specimens: C(T), SEN(B), DC(T)

2. Fracture type: Fracture instability or stable tearing

3. Approach:

   a) Run test to get P, v, a pairs

   (Compliance or electrical potential)

   b) Continue test until there is a fracture instability or enough Δa to analyze

   c) Evaluate all possible fracture parameters

4. Examples

   a) Instability before Δa, J_c or δ_c

   b) Instability after Δa, J_u of δ_u

   c) No instability J or d vs Δa R curve, can evaluate J_{Ic} or δ_{Ic}

5. Validity now called qualified or size insensitive

Designation: E 1820 – 99

Standard Test Method for Measurement of Fracture Toughness[1]

This standard is issued under the fixed designation E 1820; 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 method covers procedures and guidelines for the determination of fracture toughness of metallic materials using the following parameters: K, J, and CTOD (δ). Toughness can be measured in the R-curve format or as a point value. The fracture toughness determined in accordance with this test method is for the opening mode (Mode I) of loading.

1.2 The recommended specimens are single-edge bend, [SE(B)], compact, [C(T)], and disk-shaped compact, [DC(T)]. All specimens contain notches that are sharpened with fatigue cracks.

1.2.1 Specimen dimensional (size) requirements vary according to the fracture toughness analysis applied. The guidelines are established through consideration of material toughness, material flow strength, and the individual qualification requirements of the toughness value per values sought.

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

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—Other standard methods for the determination of fracture toughness using the parameters K, J, and *CTOD* are contained in Test Methods E 399, E 813, E 1152, E 1290, and E 1737. This test method was developed to provide a common method for determining all applicable toughness parameters from a single test.

2. Referenced Documents

2.1 *ASTM Standards:*

E 4 Practices for Force Verification of Testing Machines[2]

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[2]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[2]

E 813 Test Method for J_{Ic}, A Measure of Fracture Toughness[2]

E 1152 Test Method for Determining J-R Curves[2]

E 1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement[2]

E 1737 Test Method for J-Integral Characterization of Fracture Toughness[2]

E 1823 Terminology Relating to Fatigue and Fracture Testing[2]

3. Terminology

3.1 Terminology E 1823 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *compliance* $[LF^{-1}]$, *n*— the ratio of displacement increment to load increment.

3.2.2 *crack displacement* $[L]$, *n*—the separation vector between two points (on the surfaces of a deformed crack) that were coincident on the surfaces of an ideal crack in the undeformed condition.

3.2.2.1 *Discussion—In this practice, displacement*, v, is the total displacement measured by clip gages or other devices spanning the crack faces.

3.2.3 *crack extension*, Δa $[L]$, *n*—an increase in crack size.

3.2.4 *crack-extension force*, G $[FL^{-1}$ *or* $FLL^{-2}]$, *n*—the elastic energy per unit of new separation area that is made available at the front of an ideal crack in an elastic solid during a virtual increment of forward crack extension.

3.2.5 *crack size*, a $[L]$, *n*—a lineal measure of a principal planar dimension of a crack. This measure is commonly used in the calculation of quantities descriptive of the stress and displacement fields, and is often also termed crack length or depth.

3.2.5.1 *Discussion*—In practice, the value of a is obtained from procedures for measurement of physical crack size, a_p, original crack size, a_o, and effective crack size, a_e, as appropriate to the situation being considered.

3.2.6 *crack-tip opening displacement (CTOD)*, δ $[L]$, *n*—the crack displacement due to elastic and plastic deformation at variously defined locations near the original (prior to an application of load) crack tip.

3.2.6.1 *Discussion—In this test method*, CTOD is the displacement of the crack surfaces normal to the original (unloaded) crack plane at the tip of the fatigue precrack, a_o. In this test method, CTOD is calculated at the original crack length.

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[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.08 on Elastic-Plastic Fracture Mechanics Technology.

Current edition approved January 10, 1999. Published July 1999. Originally published as E 1820 - 96. Last previous edition E 1820 - 98.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

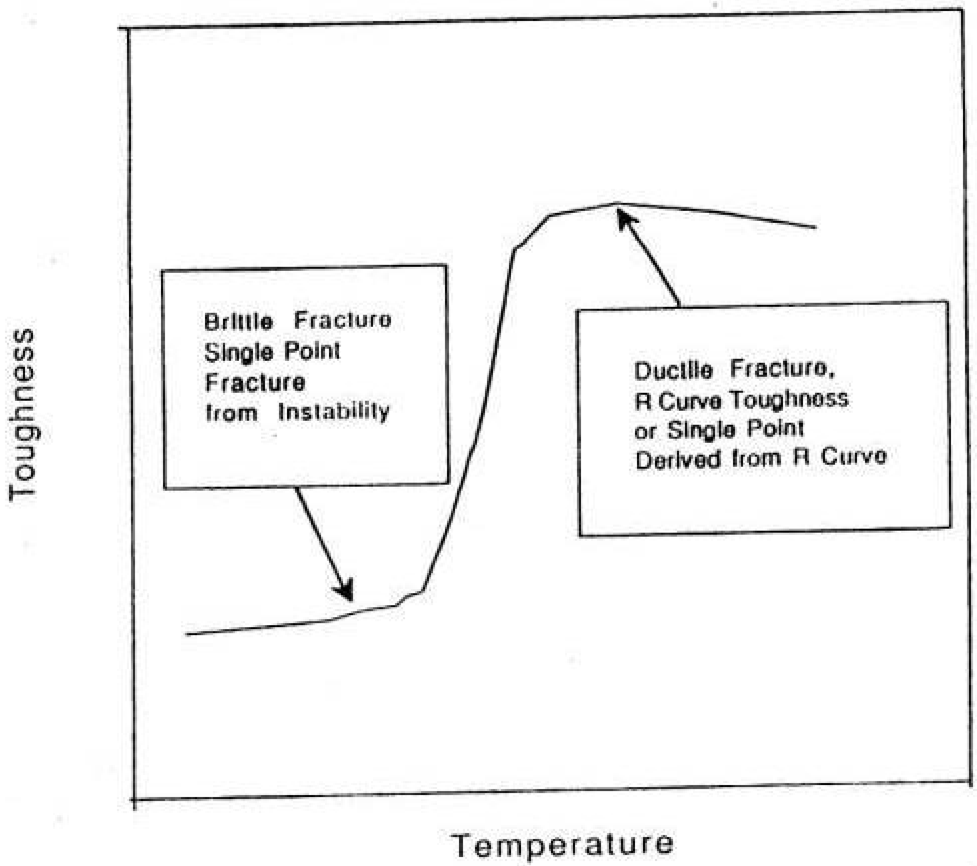
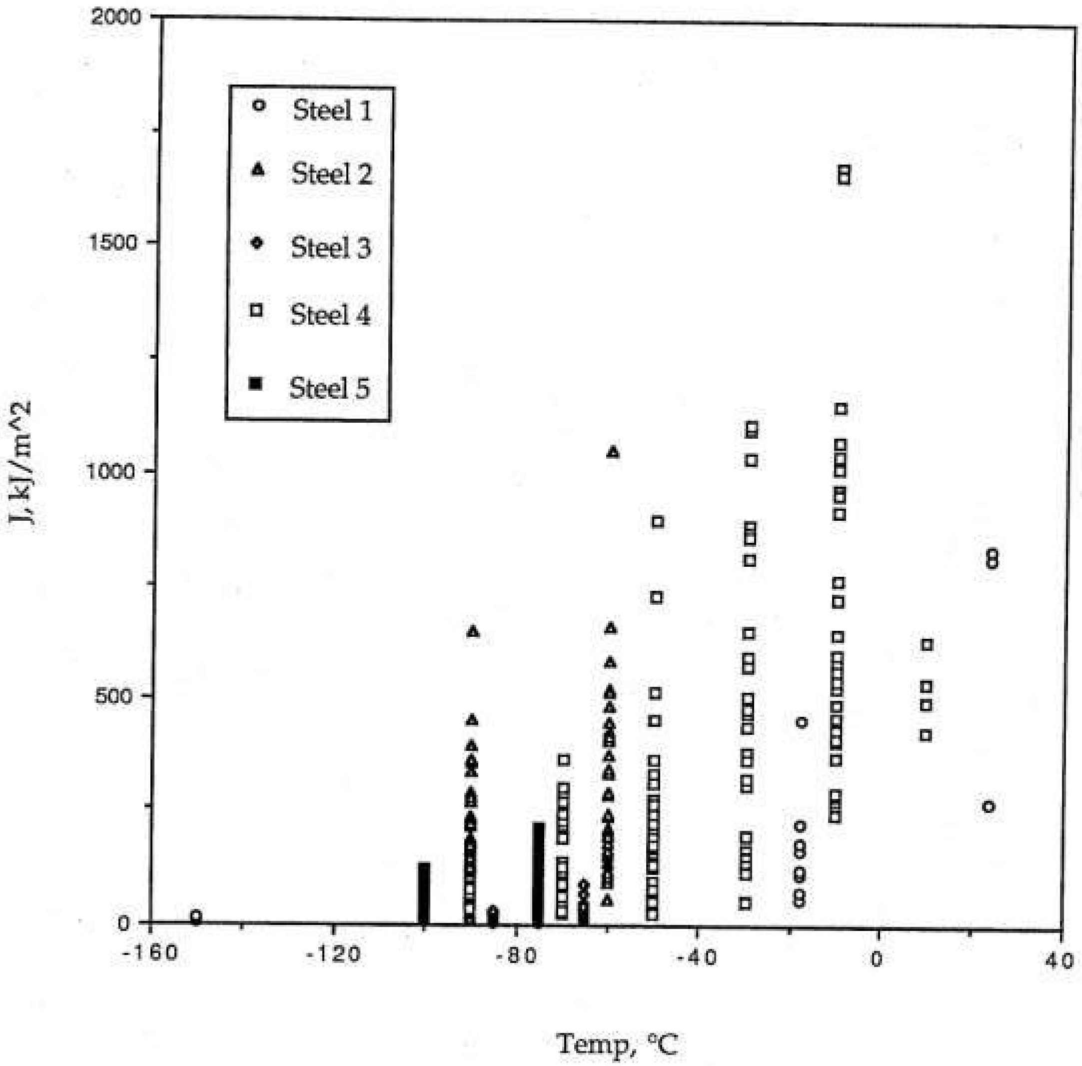
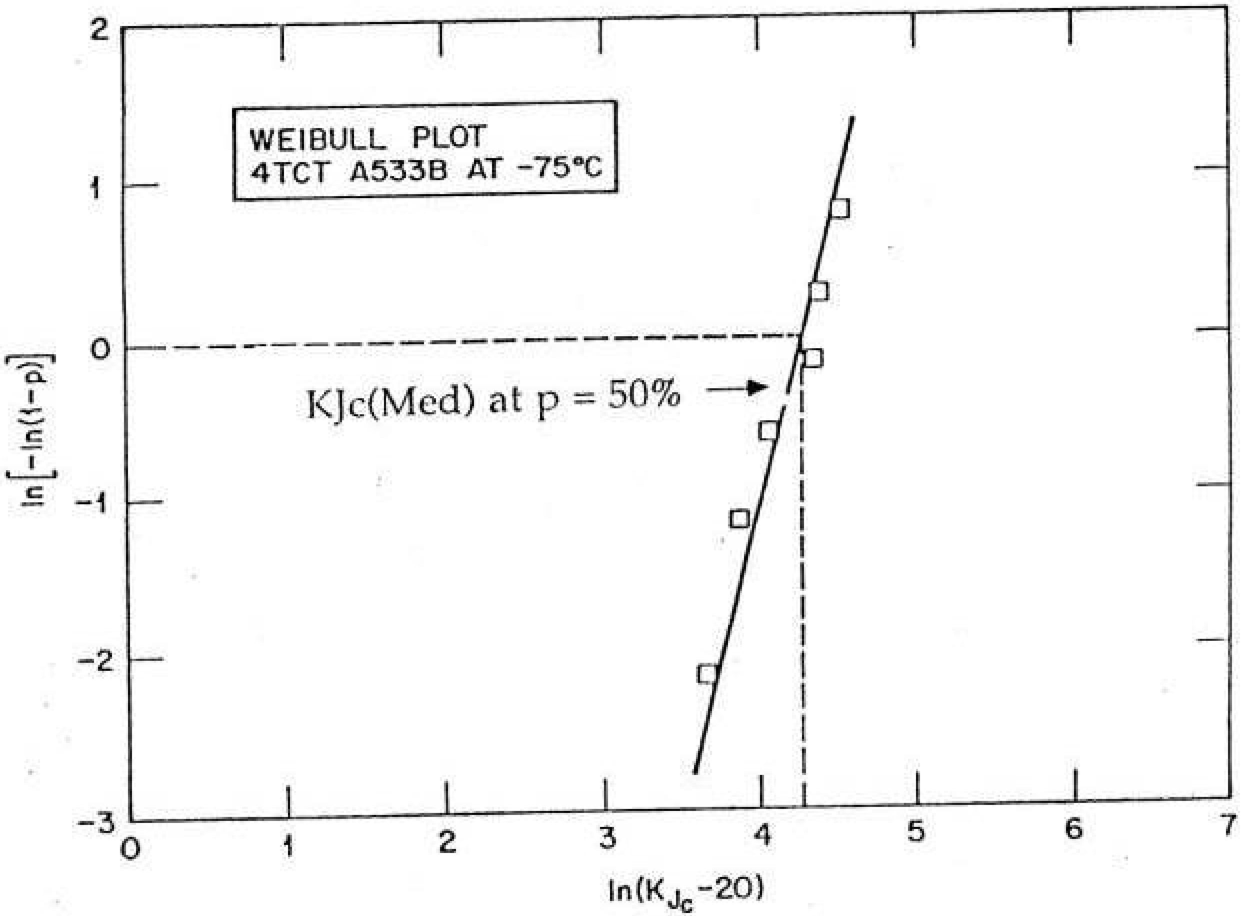


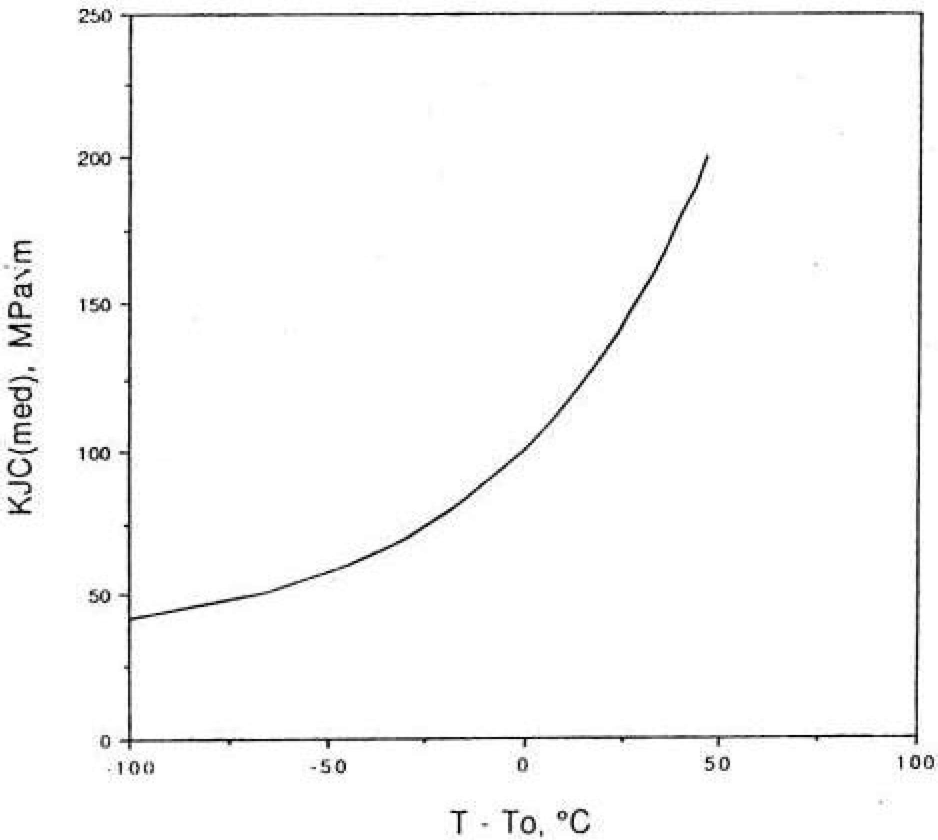
Fig. 1 - Schematic Showing Region of Ductile Fracture



Transition Toughness Results for five steels



Evaluation of KJc(Med) from Weibull Plot



Master Curve of KJC(med) Values in the Transition

Transition toughness with Master Curve

1. Determine K_{Jc} from J_c

$$K_{Jc} = \sqrt{J_c E}$$

2. Adjust to unit size

$$K_{Jco} = K_{KJcx}\left(\frac{B_x}{B_o}\right)^{\frac{1}{4}}$$

4. Characterize scatter with Weibull statistics

$$1 - P_f = \exp\left[-\left(\frac{K_{Jc} - 20}{K_o - 20}\right)\right]^4$$

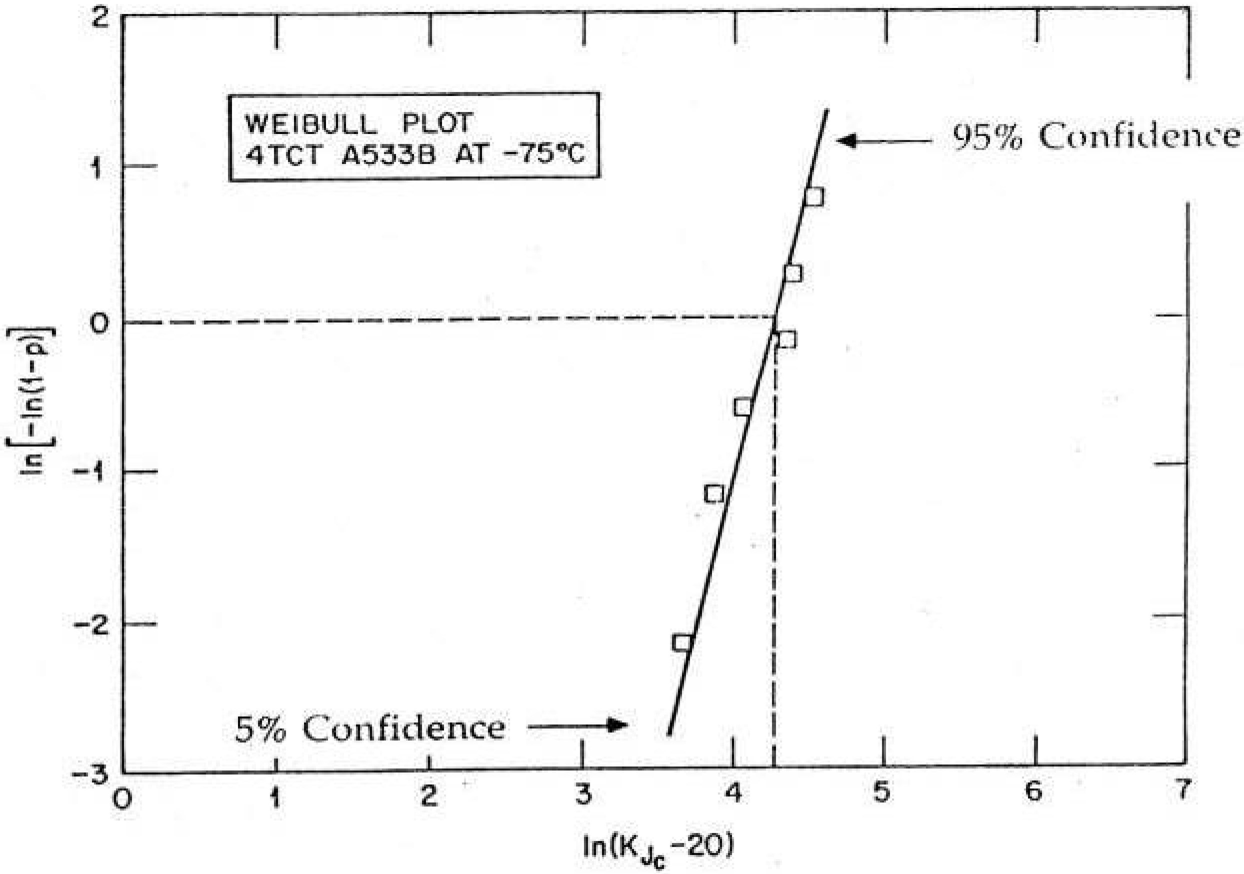
4. Determine the median value, $K_{Jc(med)}$ at $P_f = 50$ %

5. Plot the master curve of

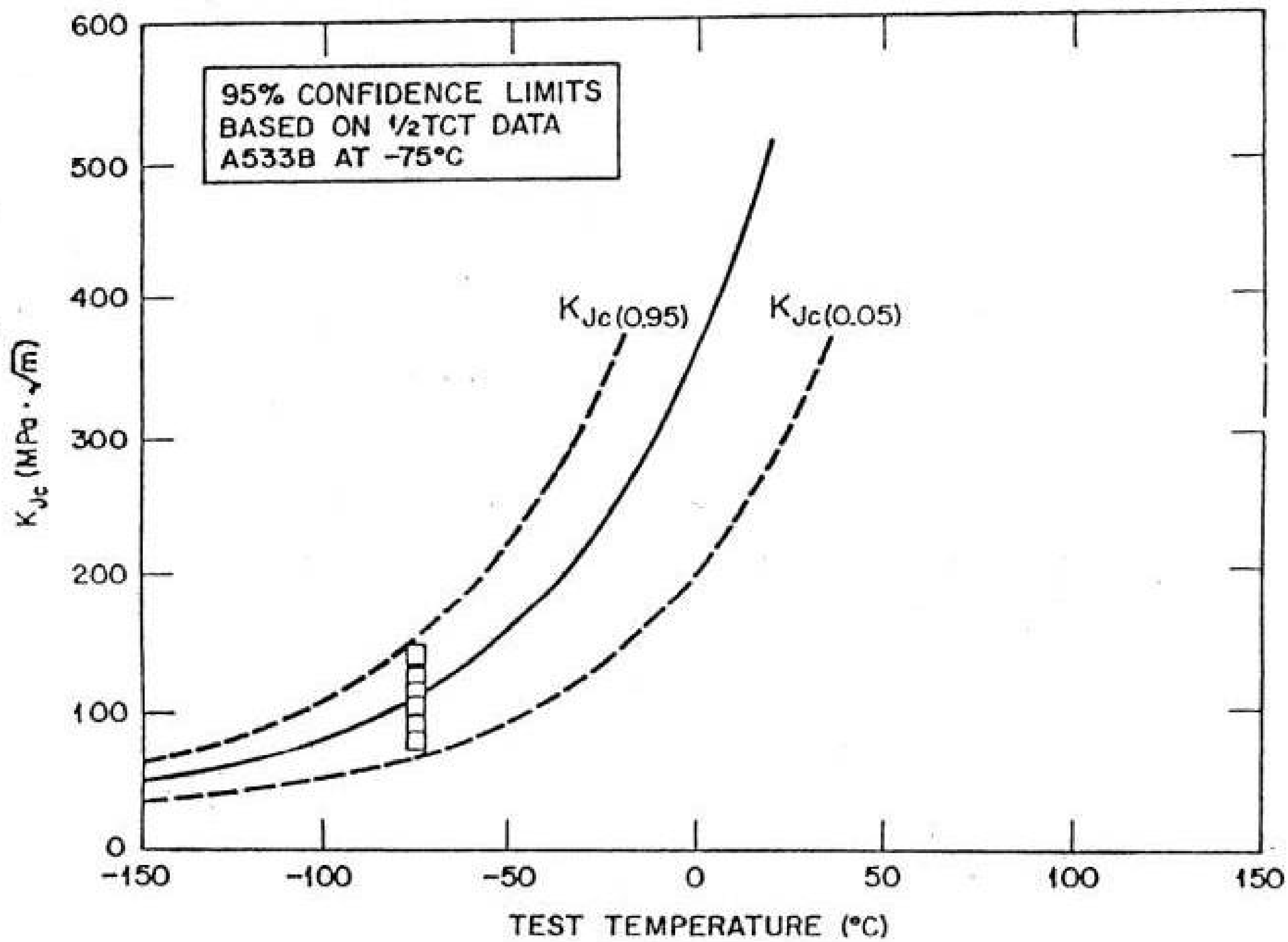
$$K_{Jc(med)} = 30 + 70\exp\left[0.019(T - T_o)\right] \quad (\text{K in MPa}\sqrt{\text{m}})$$

6. Calculate T_o

$$T_o = \left(\frac{1}{0.019}\right)\ln\frac{\left[K_{Jc(med)} - 30\right]}{70}$$



Evaluation Confidence Limits from Weibull Plot



Master Curve with Confidence Limits

Standard Test Method for Determination of Reference Temperature, T_o, for Ferritic Steels in the Transition Range[1]

This standard is issued under the fixed designation E 1921; 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 method covers the determination of a reference temperature, T_o, which characterizes the fracture toughness of ferritic steels that experience onset of cleavage cracking at elastic, or elastic-plastic K_{Jc} instabilities, or both. The specific types of ferritic steels (3.2.1) covered are those with yield strength ranging from 275 to 825 MPa (40 to 120 ksi) and weld metals, after stress-relief annealing that have 10 % or less strength mismatch relative to that of the base metal.

1.2 The specimens covered are fatigue precracked single-edge notched bend bars, SE(B), and standard or disk-shaped compact tension specimens, C(T) or DC(T). A range of specimen sizes with proportional dimensions is recommended. The dimension on which the proportionality is based is specimen thickness.

1.3 Requirements are set on specimen size and the number of replicate tests that are needed to establish acceptable characterization of K_{Jc} data populations.

1.4 The statistical effects of specimen size on K_{Jc} in the transition range are treated using weakest-link theory **(1)**[2] applied to a three-parameter Weibull distribution of fracture toughness values. A limit on K_{Jc} values, relative to the specimen size, is specified to ensure high constraint conditions along the crack front at fracture. For some materials, particularly those with low strain hardening, this limit may not be sufficient to ensure that a single-parameter (K_{Jc}) adequately describes the crack-front deformation state **(2)**.

1.5 Statistical methods are employed to predict the transition toughness curve and specified tolerance bounds for 1T specimens of the material tested. The standard deviation of the data distribution is a function of Weibull slope and median K_{Jc}. The procedure for applying this information to the establishment of transition temperature shift determinations and the establishment of tolerance limits is prescribed.

1.6 The fracture toughness evaluation of local brittle zones that are located in heat-affected zones of multipass weldments is not amenable to the statistical methods employed in the present test method.

1.7 *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 Machines[3]
E 8M Test Methods for Tension Testing of Metallic Materials (Metric)[3]
E 74 Practice for Calibration of Force Measuring Instruments for Verifying the Force Indication of Testing Machines[3]
E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels[3]
E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[3]
E 436 Test Method for Drop-Weight Tear Tests of Ferritic Steels[3]
E 561 Practice for R-Curve Determination[3]
E 812 Test Method for Crack Strength of Slow-Bend, Precracked Charpy Specimens of High-Strength Metallic Materials[3]
E 813 Test Method for J_{Ic}, A Measure of Fracture Toughness[3]
E 1152 Test Method for Determining J-R Curves[3]
E 1823 Terminology Relating to Fatigue and Fracture Testing[3]

3. Terminology

3.1 Terminology given in Terminology E 1823 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *ferritic steel*— carbon and low-alloy steels, and higher alloy steels, with the exception of austenitic stainless, martensitic, and precipitation hardening steels. All ferritic steels have body centered cubic crystal structures that display ductile-to-cleavage transition temperature (see also Test Methods E 208 and E 436).

NOTE 1—This definition is not intended to imply that all of the many

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[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of E08.08 on Elastic-Plastic Fracture Mechanics Technology.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

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

Latest Transition Toughness Standard

- **ASTM E1921 - 09a Standard Test Method for Determination of Reference Temperature, To, for Ferritic Steels in the Transition Range**

da/dN vs ΔJ

- For cyclic loading that occurs at load levels above a LEFM limit, a da/dN vs ΔJ characterization can be used

- There is no standard test method for this