Lecture 3

Fracture Toughness Testing Requirements

Fracture toughness

1. Resistance to crack extension under monotonic loading

2. Measured for LEFM by K_{Ic}

3. K_{Ic} test is ASTM E 399

4. Usual measurement is K_{Ic} versus temperature

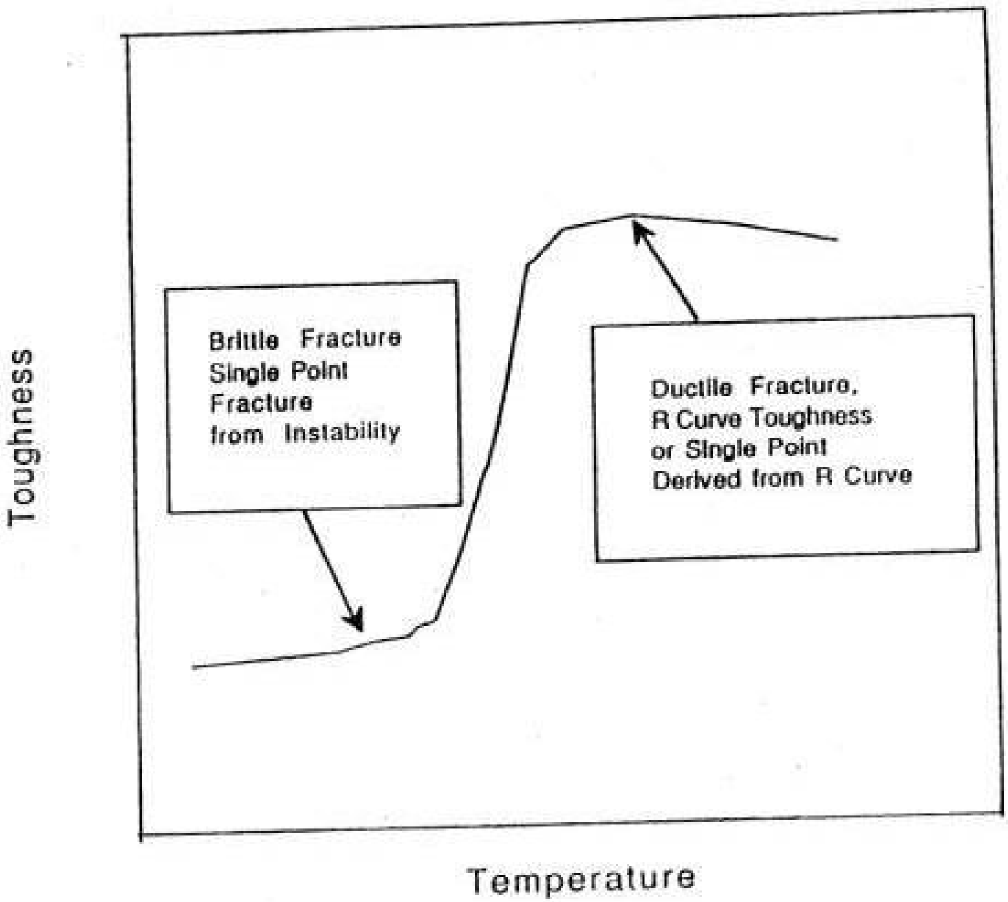


Fig. 1 - Schematic Showing Region of Ductile Fracture

Summary of an ASTM Standard Test Method

1. ASTM Standards have a set outline that the standard writers follow

2. It is difficult for a person to read and follow this outline when conducting a test

3. All standards for fracture testing have identical features that are as follows:

Test Method Summary; features

a. Specimen, preparation and precracking
b. Test fixtures and instrumentation
c. Test procedure
d. Test result evaluation
e. Validity checks
f. Reporting

ASTM Background

1. ASTM founded in 1898

2. By 2007 there were 80 volumes with 12,000 + standards

3. Standard writing – task group (or working group)

4. Consensus balloting – Subcommittee, Main committee and society review: one negative stops the standard

5. Website: www.astm.org

Fracture testing

- Goal – Test a laboratory specimen and relate its behavior to a structural component
- Result of a fracture test is called fracture toughness
- For linear-elastic behavior the result is characterized in terms of K

Fracture Testing:
components of a test

1. Choose a specimen
2. Introduce a crack into the specimen
3. Get test machine and instrumentation
4. Test to failure; get failure data
5. Relate failure data to a critical K
6. Repeat test for a range of temperatures

Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials[1]

This standard is issued under the fixed designation E 399; 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.

1. Scope

1.1 This test method covers the determination of the plane-strain fracture toughness (K_{Ic}) of metallic materials by tests using a variety of fatigue-cracked specimens having a thickness of 0.063 in. (1.6 mm) or greater.[2] The details of the various specimen and test configurations are shown in Annex A1-Annex A7 and Annex A9.

NOTE 1—Plane-strain fracture toughness tests of thinner materials that are sufficiently brittle (see 7.1) can be made with other types of specimens (1).[3] There is no standard test method for testing such thin materials.

1.2 This test method also covers the determination of the specimen strength ratio R_{sx} where x refers to the specific specimen configuration being tested. This strength ratio is a function of the maximum load the specimen can sustain, its initial dimensions and the yield strength of the material.

1.3 Measured values of plane-strain fracture toughness stated in inch-pound units are to be regarded as standard.

1.4 This test method is divided into two main parts. The first part gives general information concerning the recommendations and requirements for K_{Ic} testing. The second part is composed of annexes that give the displacement gage design, fatigue cracking procedures, and special requirements for the various specimen configurations covered by this method. In addition, an annex is provided for the specific procedures to be followed in rapid-load plane-strain fracture toughness tests. General information and requirements common to all specimen types are listed as follows:

	Sections
Referenced Documents	2
Terminology	3
Stress-Intensity Factor	3.1.1.2
Plane-Strain Fracture Toughness	3.1.2.3
Summary of Test Method	4
Significance and Use	5
Precautions	5.1.1-5.1.3
Practical Applications	5.2
Apparatus	6
Loading Fixtures	6.2
Displacement Gage Design	Annex A1
Displacement Measurements	6.3
Specimen Size, Configurations, and Preparation	7
Specimen Size Estimates	7.1
Standard and Alternative Specimen Configurations	7.2
Forms of Fatigue Crack Starter Notch	7.3.1
Fatigue Cracking	Annex A2
Crack Extension Beyond Starter	7.3.2.2
Measurements before Testing	
Thickness	8.2.1
Width	8.2.3
Starter Notch Root Radius	7.3.1
Specimen Testing	
Loading Rate	8.3
Test Record	8.4
Measurements after Testing	
Crack Length	8.2.2
Crack Plane Angle	8.2.4
Calculation and Interpretation of Results	9
Analysis of Test Record	9.1
Validity Requirements on P_{max}/P_Q	9.1.2
Validity Requirements on Specimen Size	9.1.3
Crack Plane Orientation Designations	9.2
Fracture Appearance Descriptions	9.3
Reporting	10
Precision and Bias	11
Special Requirements for Rapid Load $K_{Ic}(t)$ Tests	Annex A7

1.5 Special requirements for the various specimen configurations appear in the following order:

Bend Specimen *SE(B)*	Annex A3
Compact Specimen *C(T)*	Annex A4
Arc-Shaped Tension Specimen *A(T)*	Annex A5
Disk-Shaped Compact Specimen *DC(T)*	Annex A6
Arc-Shaped Bend Specimen *A(B)*	Annex A9

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 8 Test Methods for Tension Testing of Metallic Materials[4]

[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.07 on Linear-Elastic Fracture.

Current edition approved Nov. 30, 1990. Published April 1991. Originally published as E 399 – 70 T. Last previous edition E 399 – 83.

[2] For additional information relating to the fracture toughness testing of aluminum alloys, see Method B 645.

[3] The boldface numbers in parentheses refer to the list of references at the end of this test method.

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

Latest K_{Ic} Standard

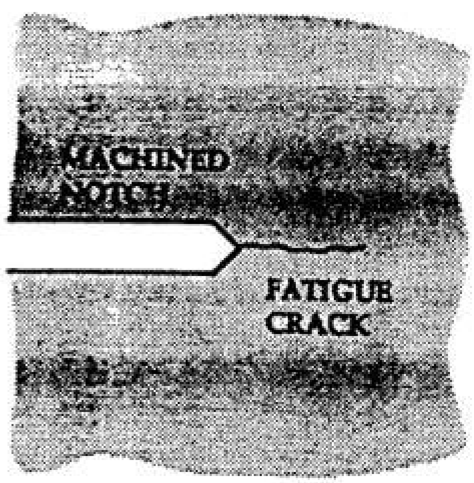
- ASTM E399 - 09 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K Ic of Metallic Materials

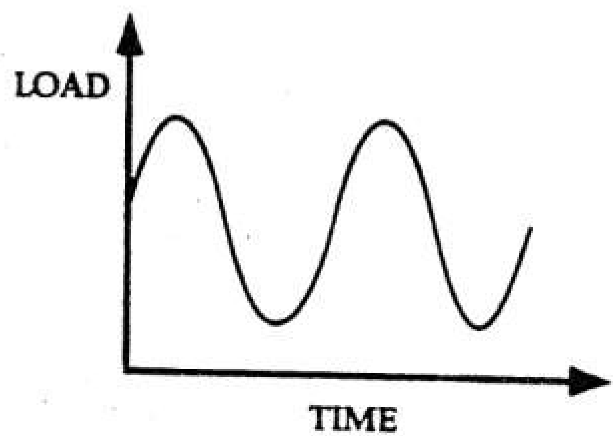
B. The K_{IC} Test

K_{IC} is a measure of the *plane strain, linear elastic* fracture toughness.

ASTM E 399:

1. Fatigue Precracking

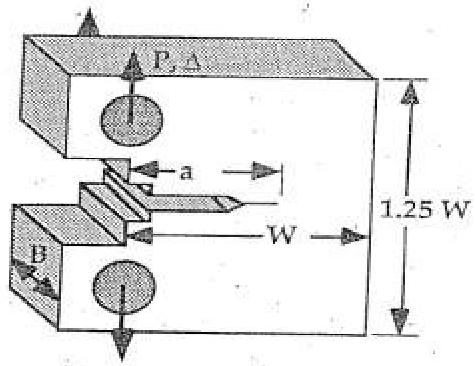




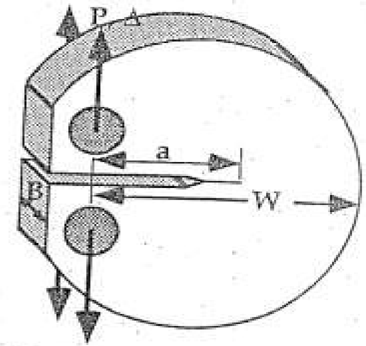
ASTM Test Specimen

1. Standard
   - Compact – C(T)
   - Single Edge Bend – SE(B)

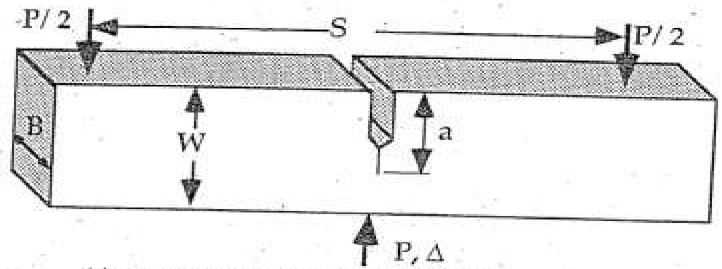
2. Special
   - Disk-shaped Compact DC(T)
   - Arc-shaped tensile – A(T)
   - Arc-shaped bend – A(B)



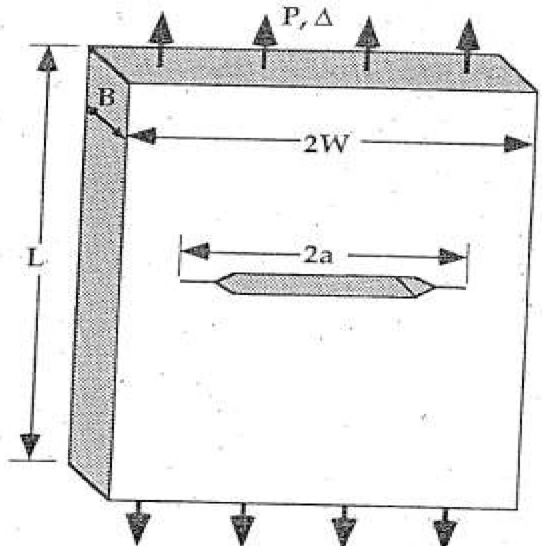
(a) Compact specimen.



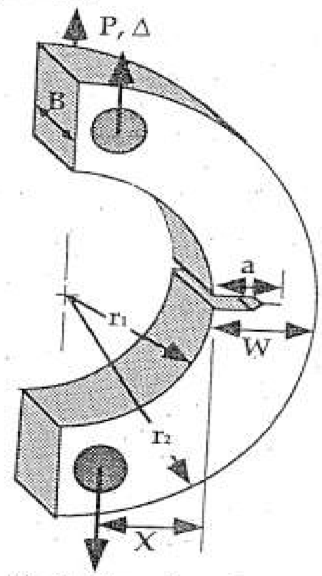
(b) Disk-shaped compact specimen.



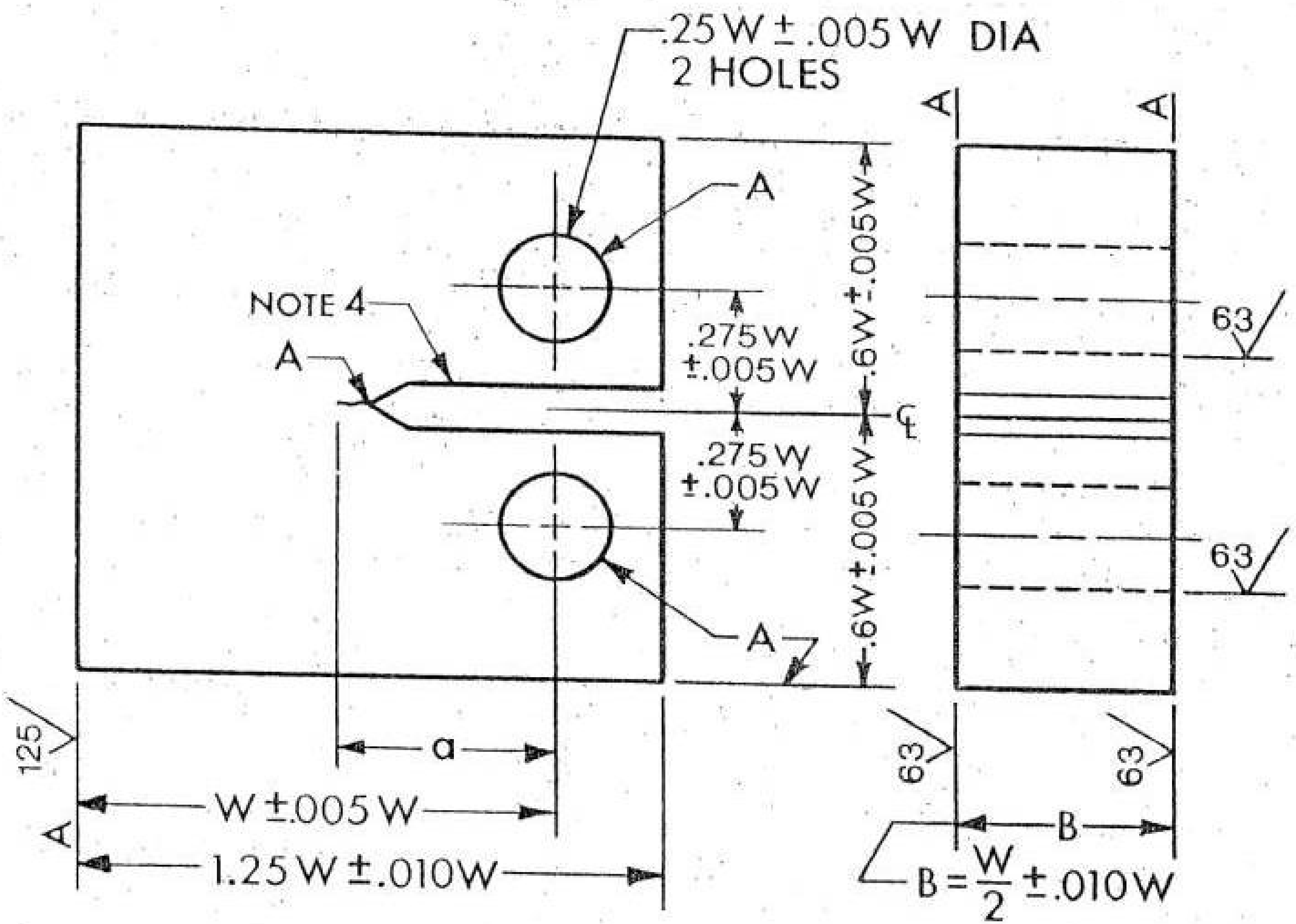
(c) Single edge notched bend (SENB) specimen.



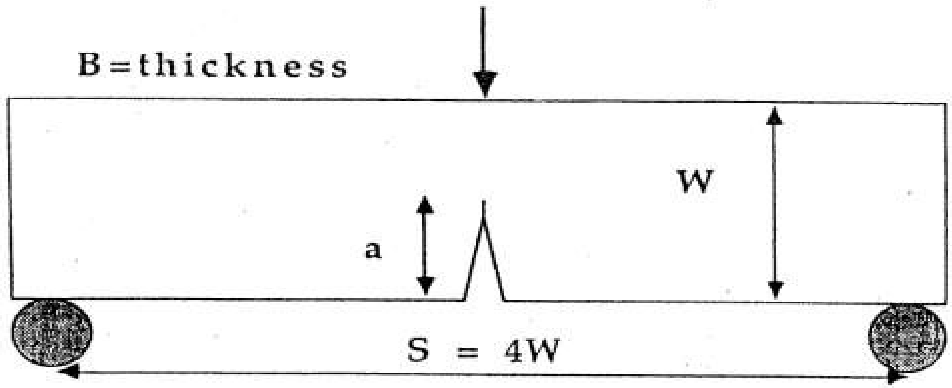
(d) Middle tension (MT) panel.



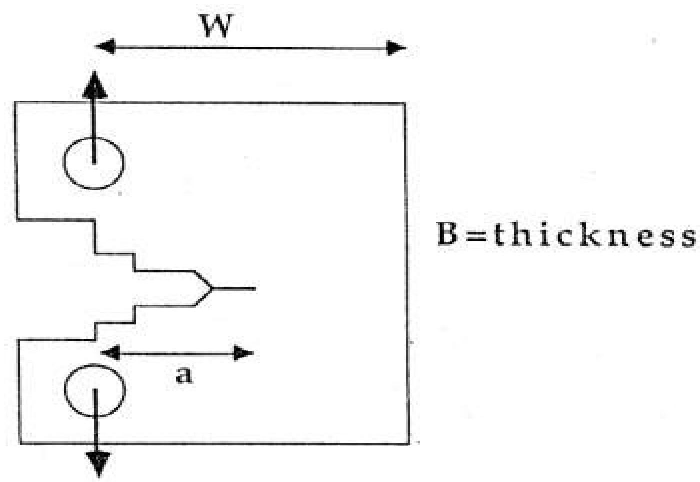
(e) Arc-shaped specimen.


.25 W ± .005 W DIA
2 HOLES
A
NOTE 4
.275 W
±.005 W
.6W ±.005W
.6W ±.005 W
A
63
125
a
W ±.005 W
1.25 W ±.010W
B
B = W/2 ±.010W

Fracture toughness test specimens



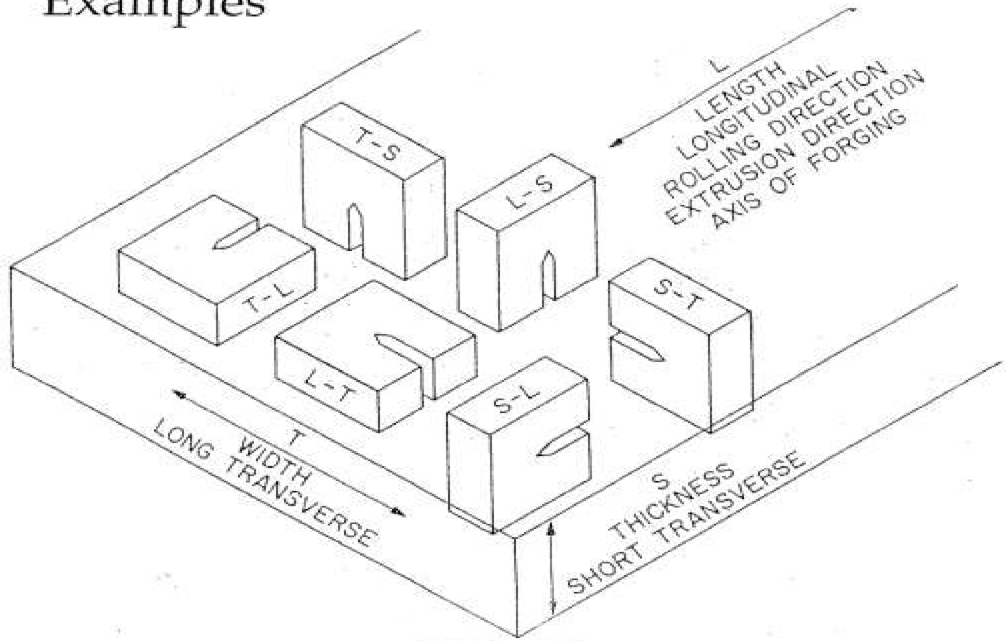
Single Edge Notched Bend Specimen
with Three Point Loading

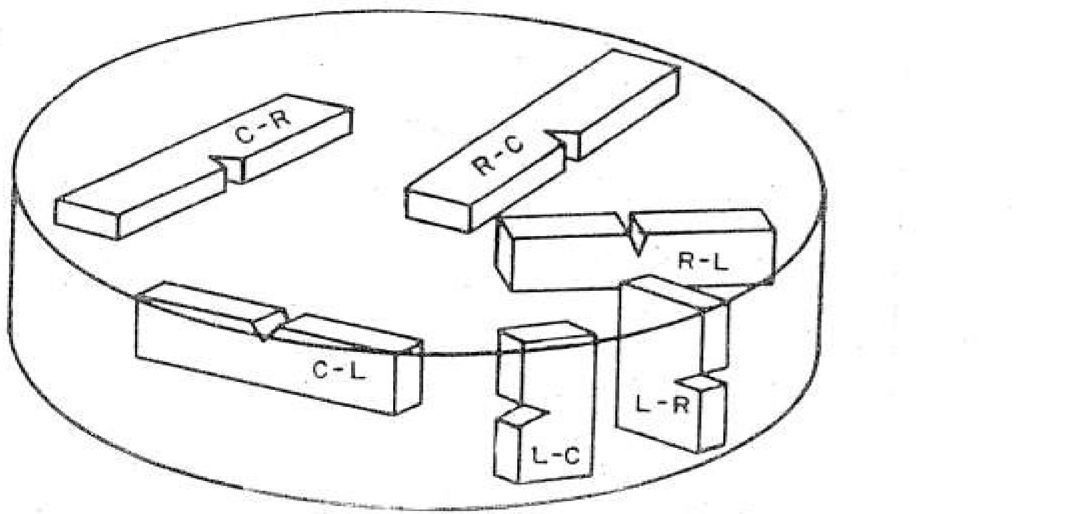


Compact Specimen
with Pin and Clevis Loading

Crack orientation must be specified

Examples





Precracking Requirements

1. E 399 – K_{Ic}

- $K_{max} \leq 0.6\ K_Q$
- $K_{max} \leq (0.00032\ m^{0.5})E$

1. E 1820

$$P_f = \frac{0.4B(W-a)^2\sigma_{ys}}{(2W+a_o)}$$

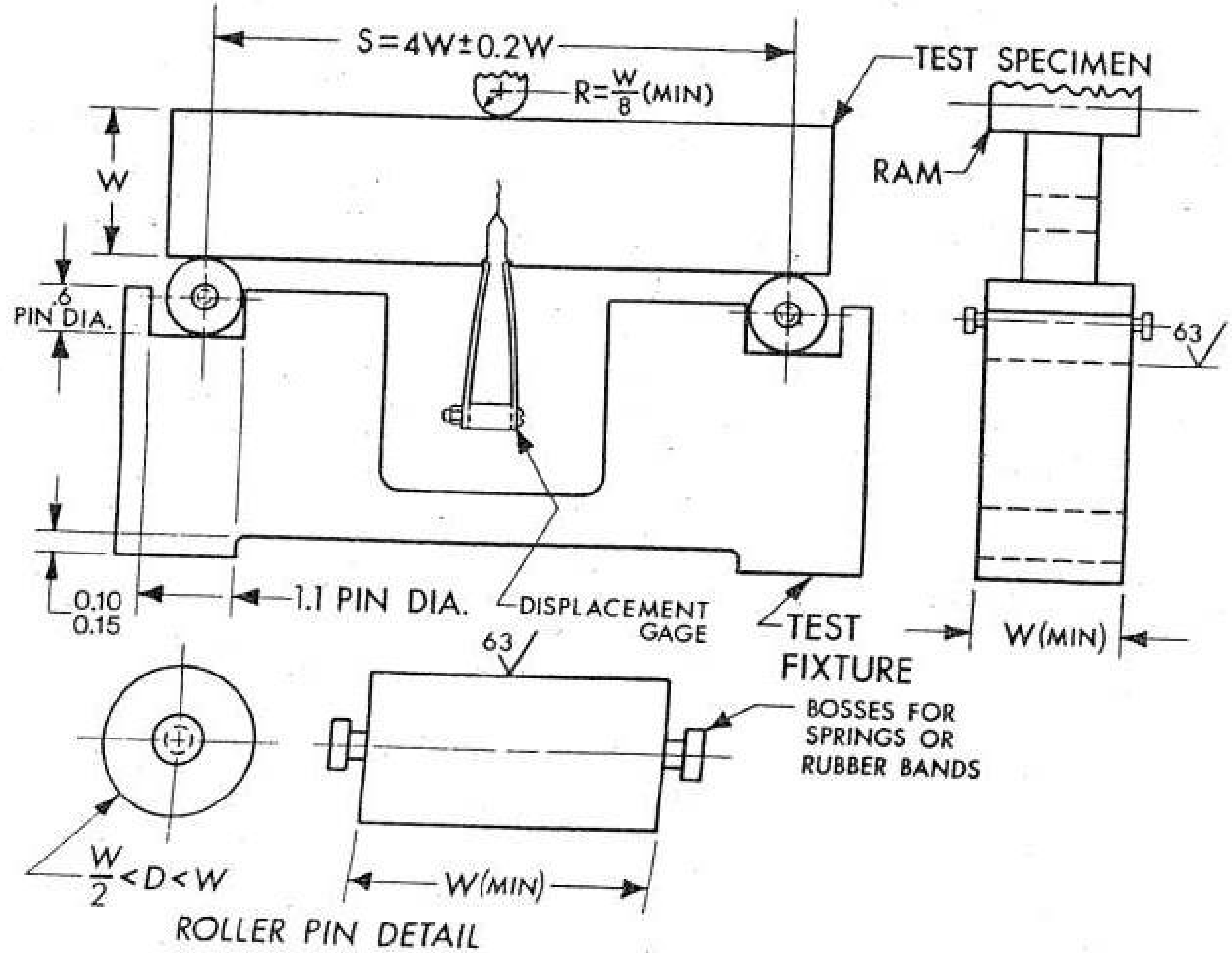
Fixtures

1. Bend fixture for bend testing

2. Pin and clevis for tension testing

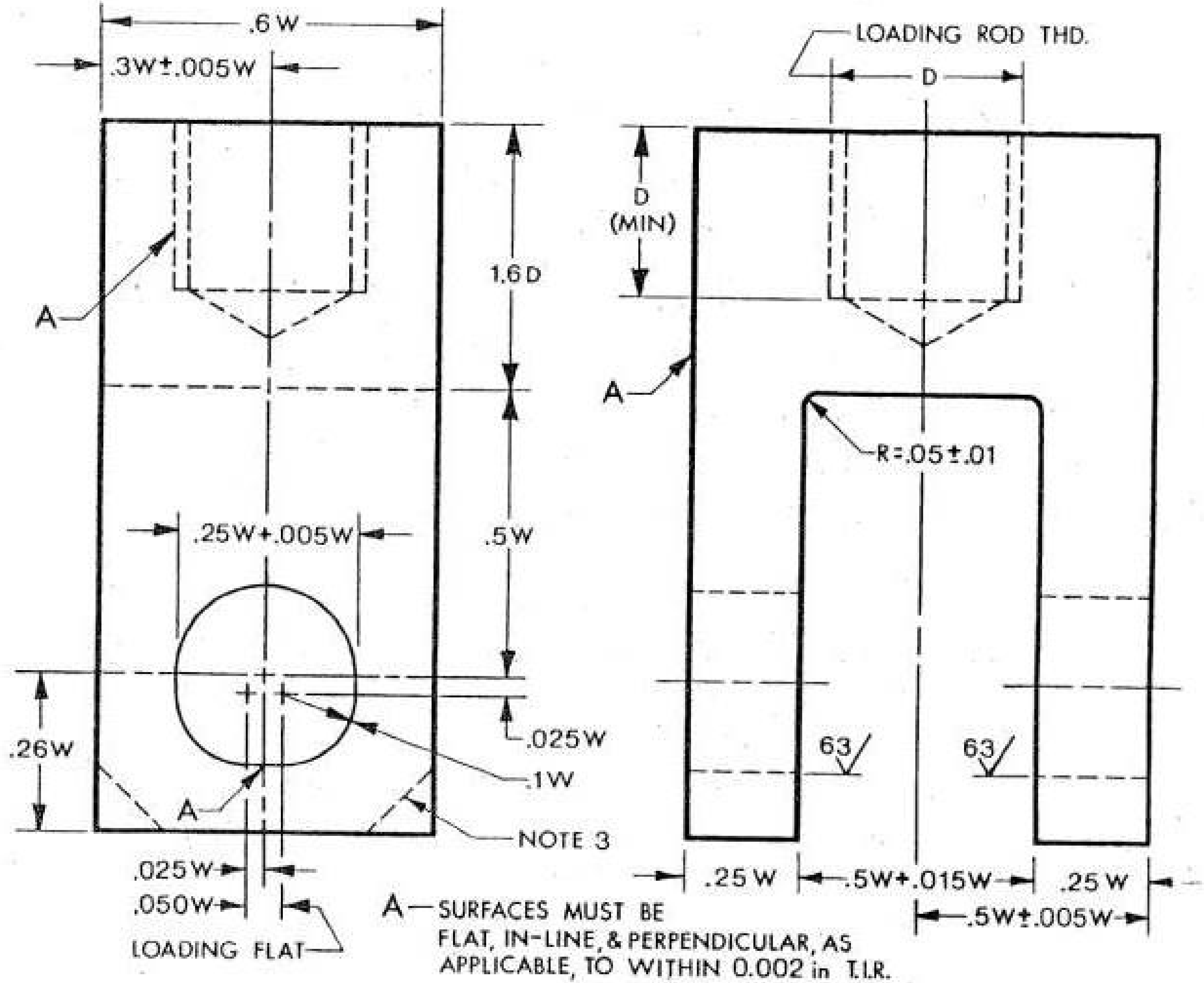
3. Some machines have clamps for tension testing

4. Fixtures must be designed for good mechanical performance



Roller pins and specimen contact surface of loading ram must be parallel to each other within 0.002 W.
0.10 in. = 2.54 mm, 0.15 in. = 3.81 mm.

FIG. A3.2 Bend Test Fixture Design



NOTE 1—Pin diameter = 0.24 *W* (+ 0.000 *W*/–0.005 *W*). For specimens with σ_{YS}> 200 ksi (1379 MPa) the holes in the specimen and clevis may be 0.3 *W* (+ 0.005 *W*/–0.000 *W*) and the pin diameter 0.288 *W* (+ 0.000 *W*/–0.005 *W*).

NOTE 2—0.002 in. = 0.051 mm.

NOTE 3—Corners of the clevis may be removed if necessary to accommodate the clip gage.

FIG. A4.2 Tension Testing Clevis Design

Test Machines

1. Servo-hydraulic – good for fatigue, rapid load, special control; can use for fracture testing but not necessary
2. Screw driven – good for fracture and tensile but lacks control for fatigue
3. Machine load cell must meet requirements in the standard
4. Use care for using servo-hydraulic

Instrumentation

1. Load cell – calibration and A/D conversion

2. Displacement gages
   - Mechanical
   - Clip gage
   - LVDT
   - Other – e.g. laser, capacitance
   - Gages have calibration and A/D conversion requirements

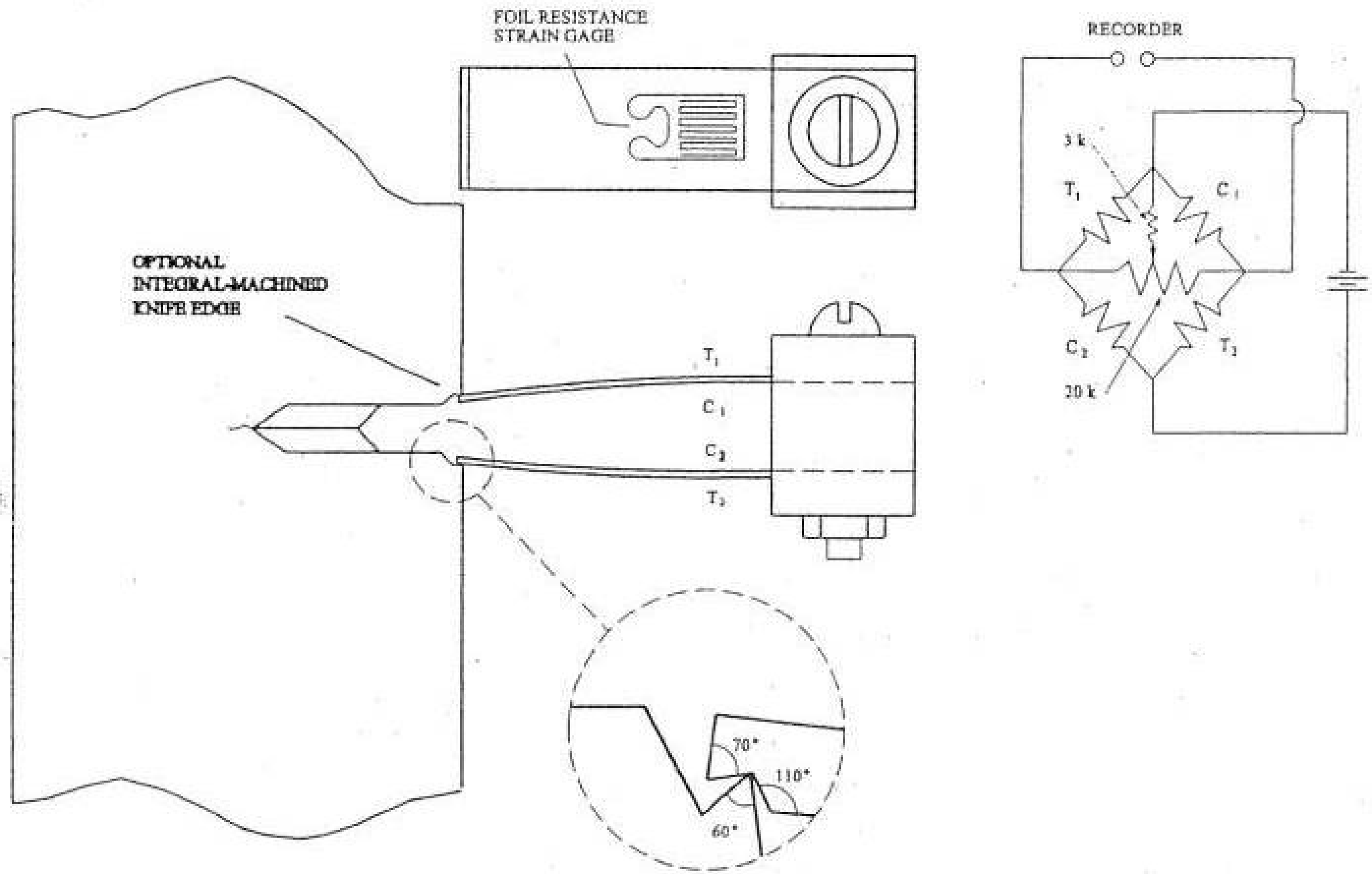


FIG. 1 Double-Cantilever Clip-In Displacement Gage Mounted By Means of Integral Knife Edges

Misc. details for testing

1. Precracking, cyclic loading in a servo-hydraulic machine should be done in load control
2. The test, monotonic loading, should be done in displacement or crosshead control
3. Side grooving should be done after precracking
4. Heating or cooling is done in a furnace or cold box. Soak times are a function of thickness (30 min/in)
5. Temperatures should be controlled to ± 3 °C

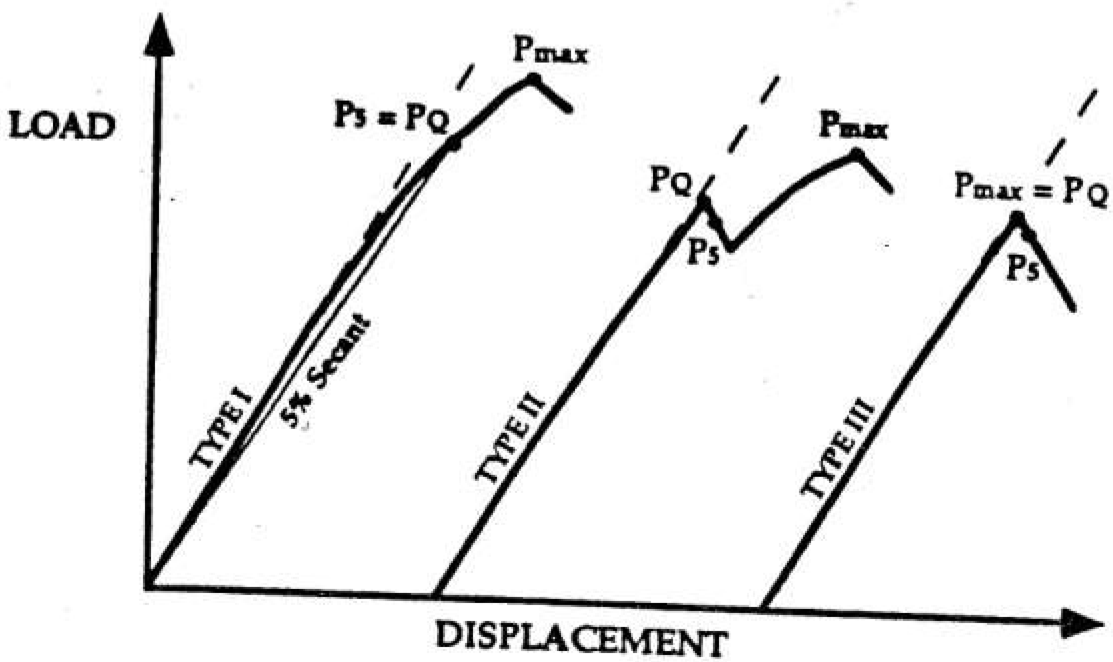
Test Procedure

1. Load in displacement control with a controlled rate while measuring load and displacement
   - Measurement is usually analog
   - Originally measured on a recorder
   - Now measured digitally with a computer
2. Loading rate must be between 30 and 150 $ksi*in^{0.5}/min$
   - Slow enough to avoid dynamic effects
   - Fast enough to avoid time dependent effects

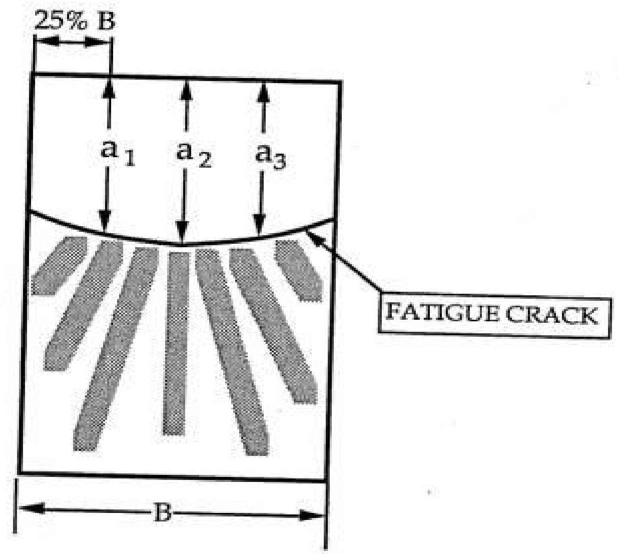
Test procedure (cont.)

3. Continue loading specimen until specimen fractures or a maximum load is passed
4. Identify P_Q and P_{max}
   - P_Q is the highest load up to a 5 % secant crossing
   - P_{max} is the highest load
5. Measure the fatigue crack length, a_o
6. Calculate K_Q from P_Q

2. Load to Failure and Determine P_Q.



3. Measure Crack Length at 3 Evenly Spaced Locations

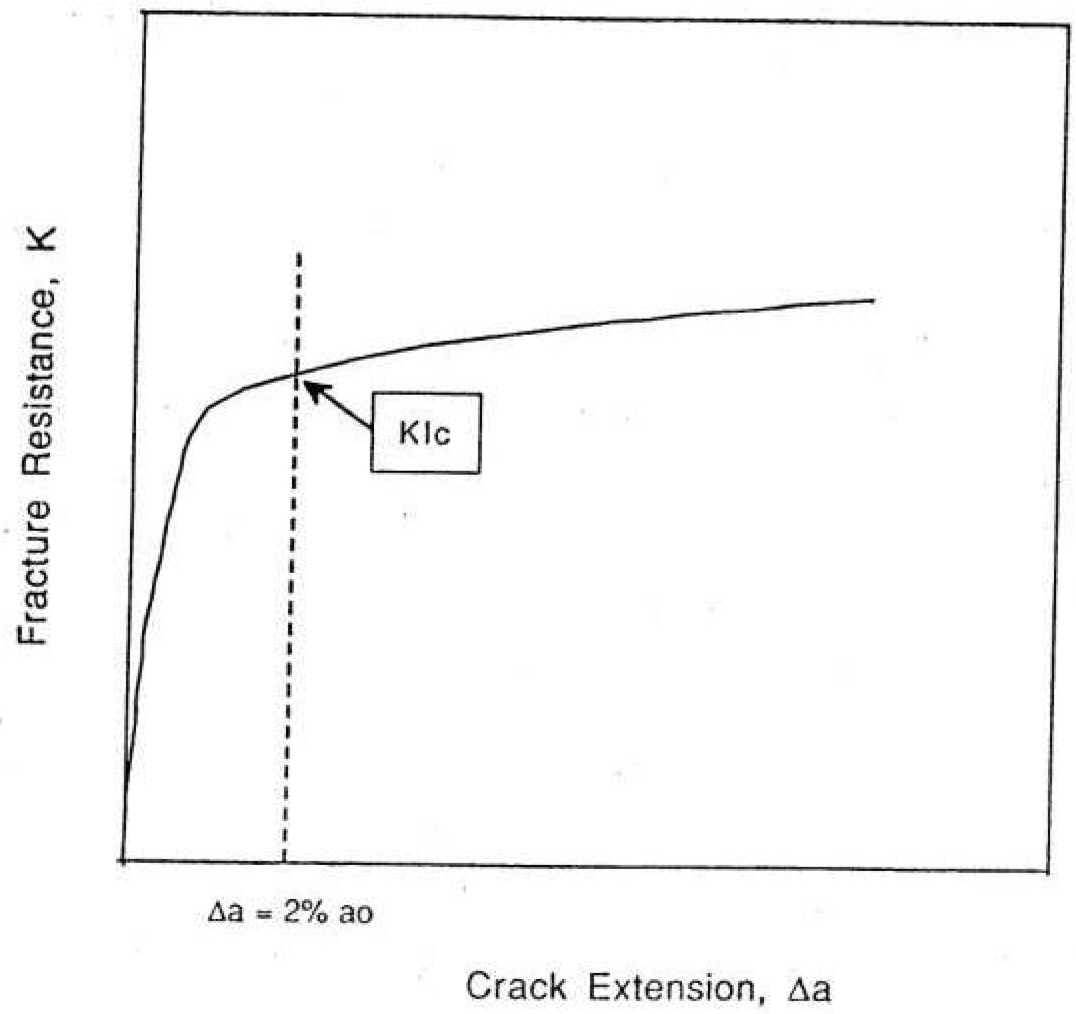


$$a = \frac{a_1 + a_2 + a_3}{3}$$

4. Calculate K_Q

$$K_Q = \frac{P_Q}{B\sqrt{W}} f(a/W)$$

where f is a dimensionless function of a/W.



Schematic R Curve Definition of KIc

Validity Checks

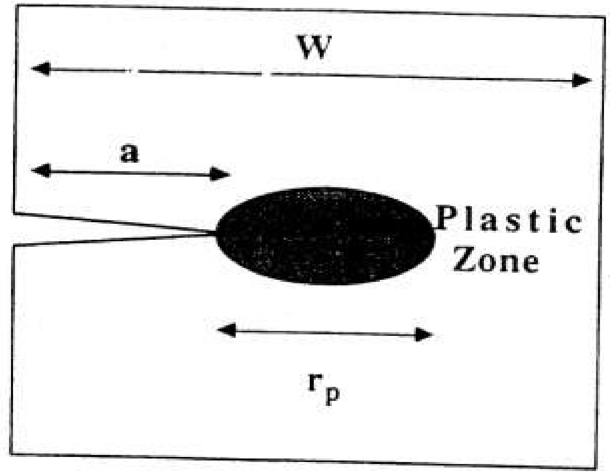
1. $0.45 \leq a/W \leq 0.55$

1. $P_{max} \leq 1.10\ P_Q$

3. $a,B \geq 2.5(K_Q/\sigma_{ys})^2$

If validity checks are satisfied, $K_Q = K_{Ic}$

Plastic Zone Size for Limit to LEFM



$$r_p = \frac{1}{2\pi}\left(\frac{K}{\sigma_{ys}}\right)^2$$

For LEFM to prevail r_p must be small with respect to specimen dimensions a, W, B

or use K_{Ic} test requirement

$$a, B \geq 2.5\left(\frac{K_{Ic}}{\sigma_{ys}}\right)^2$$

Stress ratios for E 399

1. When the K_{Ic} test is invalid, a stress ratio can be calculated to see how much the invalidity was
2. Stress ratio, R_s, is the mechanics of materials nominal stress at the crack tip divided by the yield strength
3. An example is the R_s for the compact specimen

Stress ratios for E 399 (cont.)

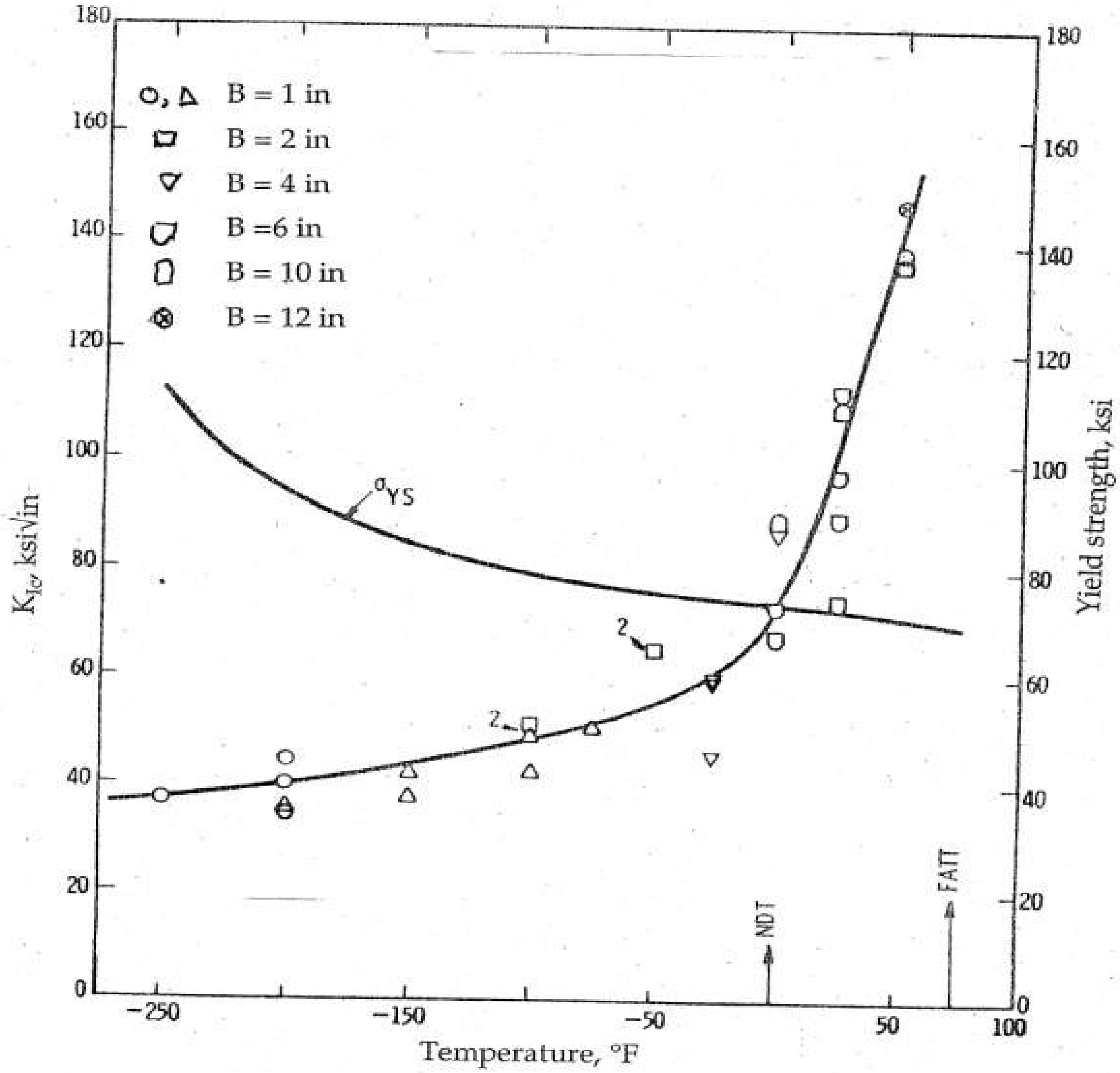
3. An example is the R_s for the compact specimen

$$R_{sc} = \frac{[2P_{\max}(2W + a)]}{[B(W - a)^2 \sigma_{ys}}$$

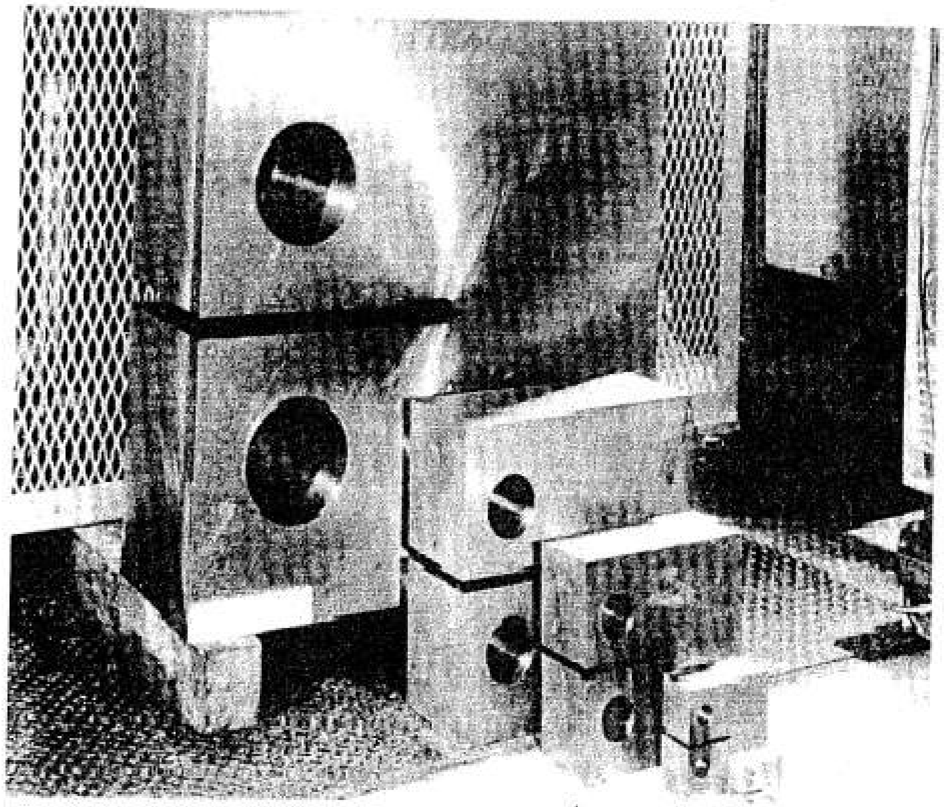
4. For
   - $R_{sc} < 1.0$ linear-elasticity holds
   - $R_{sc} > 2.0$ the result is nearly fully plastic
   - $1.0 < R_{sc} < 2.0$ the result ranges from nearly elastic to nearly fully plastic

Lecture 4

- Fracture Toughness Properties



Temperature dependence of K_{Ic} for A533B steel



Compact Specimens from 1 to 12 inches thick

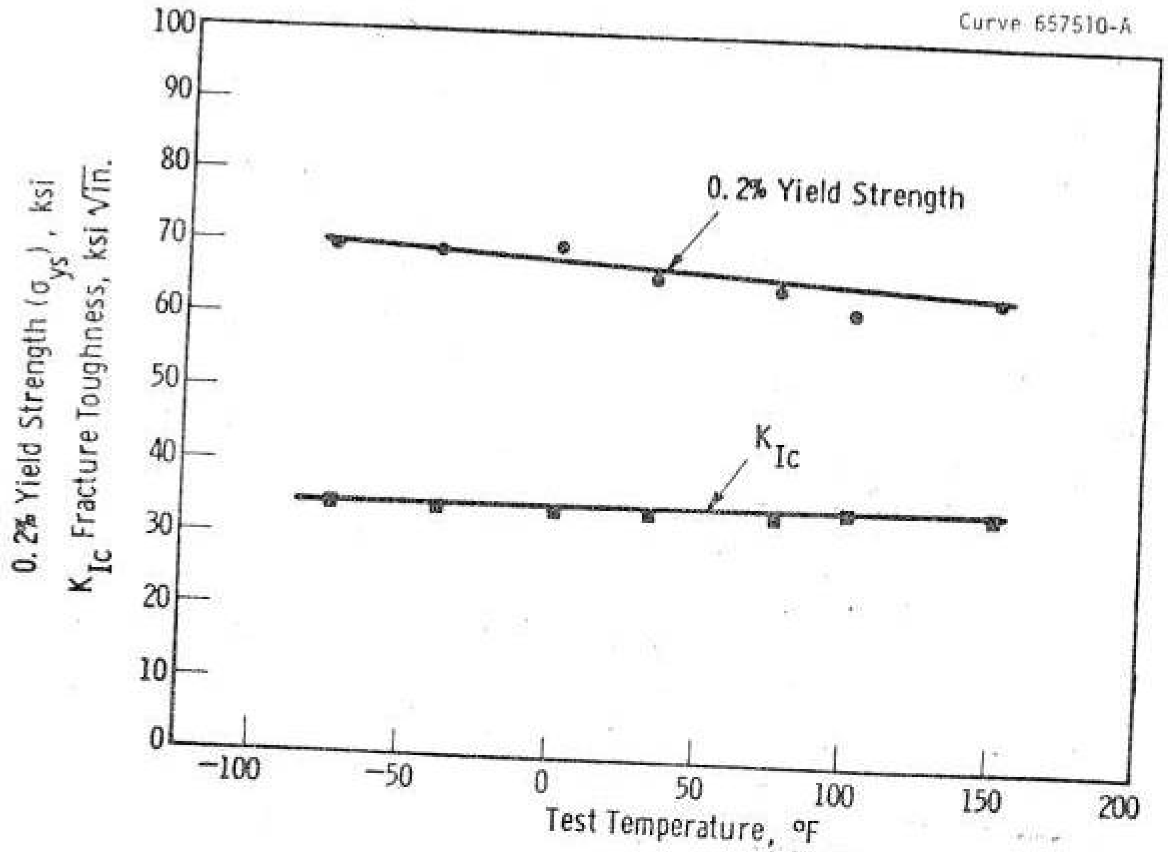


Fig. 24—Temperature dependence of 0.2% yield strength and K_{Ic} for 7079-T6 aluminum

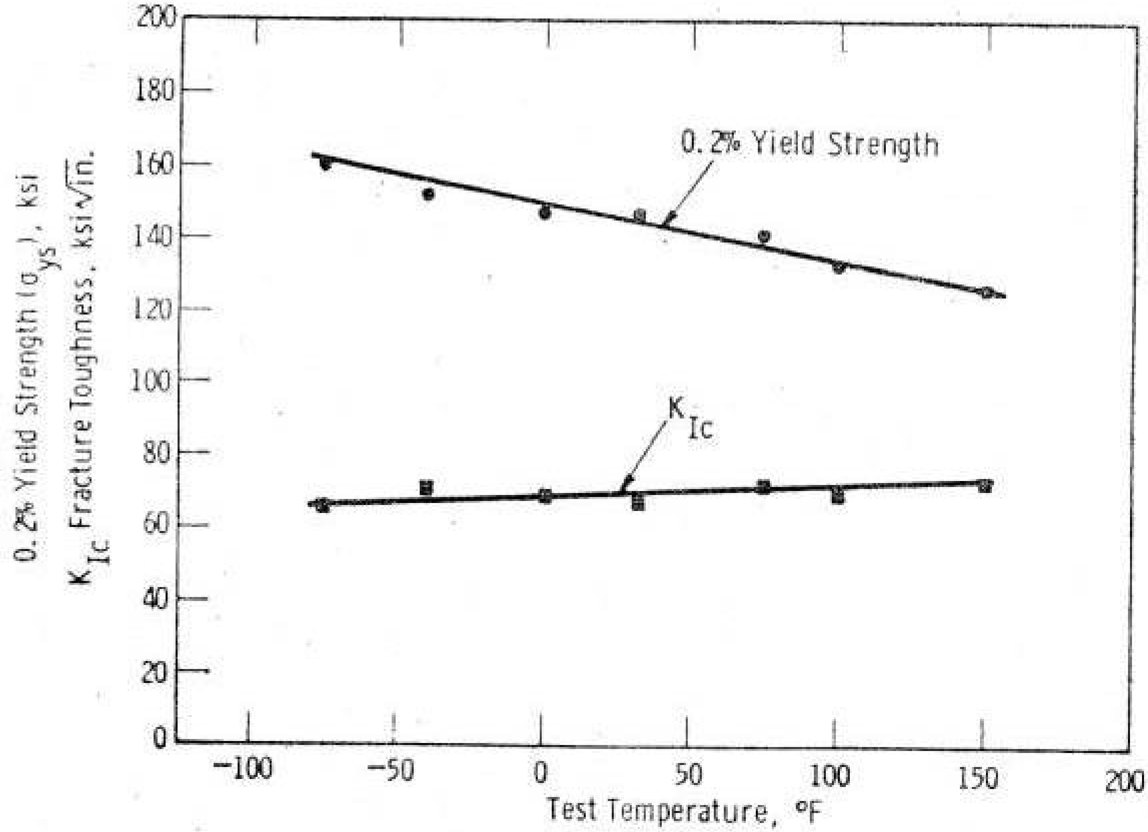


Fig. 25—Temperature dependence of 0.2% yield strength and K_{Ic} for Ti-6Al-4V titanium

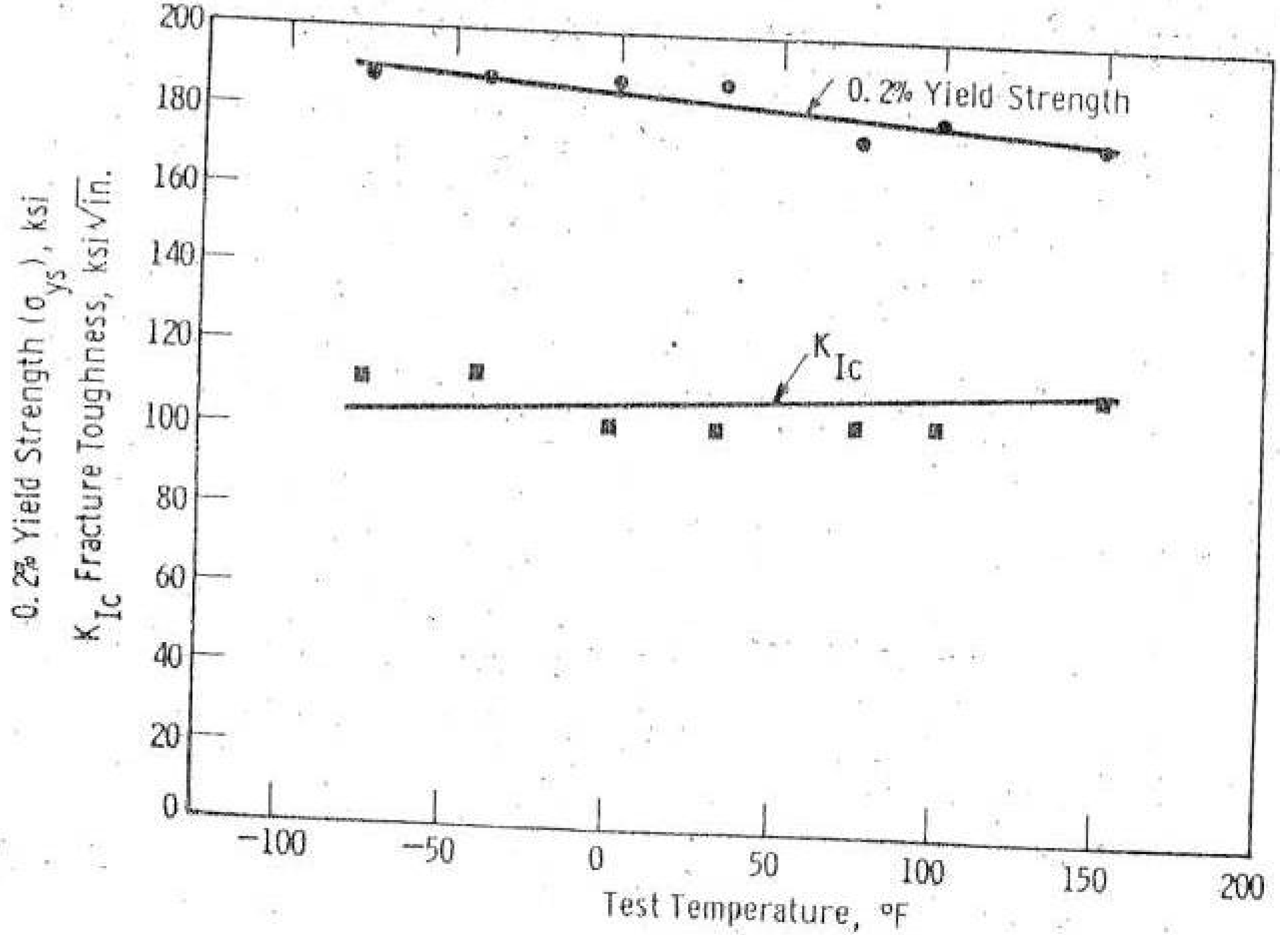


Fig. 26 — Temperature dependence of 0.2% yield strength and K_{Ic} for HP-9-4-25 steel

Sources of Fracture Toughness Data - N

- Fracture toughness data is needed to conduct a FM analysis for safety and reliability
- There are many sources of toughness data, but may not be easy to find.
- Also, there can be variability that makes the use uncertain

WL-TR-94-4052
Volume 1, Chapters 1, 2, 3 and 4

DAMAGE TOLERANT DESIGN HANDBOOK

D.A. Skinn, J.P. Gallagher, A.P. Berens,
P.D. Huber, J. Smith

University of Dayton Research Institute
300 College Park Dr
Dayton, OH 45469-0120

May 1994
Final Report for Period June 1991 - May 1994

2

DOT/FAA/CT-93/69.II
DOT-VNTSC-FAA-93-13.II

FAA Technical Center
Atlantic City Airport,
NJ 08405

Damage Tolerance Assessment Handbook

Volume II: Airframe Damage Tolerance Evaluation

Research and
Special Programs
Administration
John A. Volpe National
Transportation Systems Center
Cambridge, MA 02142-1093

Final Report
October 1993

PLANE STRAIN FRACTURE TOUGHNESS VALUES OF ALLOY STEELS AT ROOM TEMPERATURE

Alloy	Condition/ Heat Treatment	Product Form	Range of Product Thickness (in.)	K_{Ic} $(Ksi\sqrt{in})$ Specimen Orientation L-T				T-L				S-L			
				Min Spec Thk	n	Mean	Std Dev	Min Spec Thk	n	Mean	Std Dev	Min Spec Thk	n	Mean	Std Dev
HP9-4-.20	Unspecified	Forging	1.25	2.00	2	150.6	4.5	2.00	2	136.3	16.8	---	---	---	---
	1525F OQ -100F 1HR 1065F 4+4HR	Forging	4.00	---	---	---	---	1.50	2	111.7	2.0	---	---	---	---
	1650F 1-2HR AC 1-2HR 1-2HR AC -100F 1.5HR 1025F 4HR 1060F 4HR	Plate	2.50	2.00	2	123.5	12.0	---	---	---	---	---	---	---	---
	1650F 1-2HR AC 1525F 1-2HR OQ -100F 1-2HR 1025F 4HR	Forging	4.00-7.00	1.75	5	134.8	12.3	1.76	3	109.7	4.7	---	---	---	---
	1650F 1-2HR AC 1525F 1-2HR OQ -100F 2HR 1025F 4-6HR	Plate	2.50	2.00	2	121.5	29.0	---	---	---	---	---	---	---	---
		Forging	4.00	1.51	15	135.2	11.6	1.51	6	125.3	1.8	---	---	---	---
	1650F 1-2HR AC 1525F 1-2HR OQ -100F 2HR 1050F 4-6HR	Forging	1.70-3.25	1.50	5	133.2	3.9	---	---	---	---	---	---	---	---
	1650F 1-2HR ACX	Forging	4.00	1.55	2	125.5	3.5	---	---	---	---	---	---	---	---
	1650F 2HR AC 1525F 2HR OQ 1000F 2+2HR AC	Forging	4.00	1.24	3	94.4	4.4	---	---	---	---	---	---	---	---
	1650F 4.5HR AC TO 900F HELD 0.5HR AC -100F 1.5HR 1025F 5HR A-BQ	Forging	4.00	1.59	2	128.5	0.7	---	---	---	---	---	---	---	---
	1700F 4.5HR AC 1700F 1.5HR AC -100F 1.5HR 1025F 4HR	Forging	4.00	1.60	2	140.5	0.7	---	---	---	---	---	---	---	---
	ANNEALED	Forging	3.00	1.00	12	120.6	7.3	2.00	3	117.7	1.9	---	---	---	---
	HEAT TREATED	Forging	3.40-7.00	1.50	10	140.7	4.5	1.46	7	132.3	6.6	---	---	---	---

Figure 1.3 Sample Table (pg 8-13): Plane Strain Fracture Toughness Values (Material Summary)

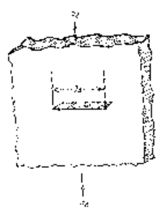
TABLE 8.0.2 (CONTINUED)

PLANE STRAIN FRACTURE TOUGHNESS VALUES OF ALUMINUM 7000/8000 SERIES ALLOYS AT ROOM TEMPERATURE

Alloy	Condition/ Heat Treatment	Product Form	Range of Product Thickness (in.)	K_{Ic} ($Ksi\sqrt{in}$)											
				Specimen Orientation											
				L-T				T-L				S-L			
				Min Spec Thk	n	Mean	Std Dev	Min Spec Thk	n	Mean	Std Dev	Min Spec Thk	n	Mean	Std Dev
7050 (Cont'd)	T74511	Extrusion	0.75-1.50	0.73	4	40.4	5.0	...	...	...	...	...	...	...	...
	T7452	Forging	4.00	1.00	2	31.1	1.2	1.00	3	23.6	3.0	...	...	...	...
	T7651	Plate	0.75-1.00	0.74	6	33.4	2.8	...	...	...	...	...	...	...	...
	T76511	Extrusion	0.75-1.50	0.73	3	34.8	5.5	...	...	...	...	...	...	...	...
	T7E56	Forging	5.00	...	...	...	...	0.75	4	28.9	3.9	...	...	...	...
7075	T6	Forging	0.50-0.89	0.50	2	24.3	0.1	0.25	2	20.9	1.7	0.50	4	16.8	0.4
		Extrusion	2.00	...	...	...	...	0.75	3	19.9	0.2	0.75	3	18.5	0.2
	T651	Plate	0.37-5.00	0.51	63	26.5	2.0	0.38	76	22.5	2.0	0.50	11	17.6	2.7
		Extrusion	3.00-5.00	1.50	4	31.1	0.5	1.50	5	20.2	0.2	...	...	...	...
		Rolled Bar	5.00	1.50	2	34.1	0.5	...	...	...	...	...	...	...	...
	T6510	Extrusion	0.68-3.50	0.50	12	27.5	2.1	0.50	18	23.3	1.6	0.25	3	20.0	1.3
		Forged Bar	0.68-5.00	0.62	13	29.2	3.4	0.50	13	21.4	1.5	0.25	7	18.7	0.9
	T6511	Extrusion	1.25	1.22	2	27.9	1.4	1.17	4	25.9	1.5	...	...	...	...
	T73	Forging	1.00	...	...	...	...	...	...	...	...	0.50	4	19.1	0.5
	T7351	Plate	1.00-4.00	0.61	47	29.4	2.2	0.51	38	26.2	3.2	0.50	7	18.5	0.4
	T73510	Extrusion	0.68-3.50	...	...	...	...	0.50	9	24.6	2.3	1.00	2	20.3	0.8
	T73511	Extrusion	3.50	1.63	4	39.6	3.1	1.75	3	26.8	1.1	1.00	2	21.9	1.1

Data from Hertzberg

TABLE 8.2 Plane Strain Fracture Toughness of Selected Engineering Alloys



$$\sigma_d = \frac{\sigma_{ys}}{2}\ ;\ K_{IC} = \sigma_a\sqrt{\pi a}$$

$$a_c = \frac{1}{\pi}\left(\frac{K_{IC}}{\sigma_{ys}/2}\right)^2$$

	K_{IC}		σ_{ys}		a_c	
Material	MPa$\sqrt{m}$	ksi$\sqrt{in.}$	MPa	ksi	mm	in.
2014-T651	24.2	22	455	66	3.6	0.14
2024-T3	~44.	~40	345	50	~21.	~0.82
2024-T851	26.4	24	455	66	4.3	0.17
7075-T651	24.2	22	495	72	3.0	0.12
7178-T651	23.1	21	570	83	2.1	0.08
7178-T7651	33.	30	490	71	5.8	0.23
Ti-6Al-4V	115.4	105	910	132	20.5	0.81
Ti-6Al-4V	55.	50	1035	150	3.6	0.14
4340	98.9	90	860	125	16.8	0.66
4340	60.4	55	1515	220	2.	0.08
4335 + V	72.5	66	1340	194	3.7	0.15
17-7PH	76.9	70	1435	208	3.6	0.14
15-7Mo	49.5	45	1415	205	1.5	0.06
H-11	38.5	35	1790	260	<0.6	<0.02
H-11	27.5	25	2070	300	0.23	0.009
350 Maraging	55.	50	1550	225	1.6	0.06
350 Maraging	38.5	35	2240	325	<0.4	<0.02
52100	~14.3	~13	2070	300	~0.06	<0.002

yield strength is elevated. Consequently, there is a price to pay when one wishes to raise the strength of a material. More will be said about this in Chapter Ten.

EXAMPLE 2 Assume that a component in the shape of a large sheet is to be fabricated from 0.45C-Ni-Cr-Mo steel. It is required that the critical flaw size be greater than 3 mm, the resolution limit of available flaw detection procedures. A design stress level of one-half the tensile strength is indicated. To save weight, an increase in the tensile strength from 1520 MPa to 2070 MPa

K_{Ic} Correlations - N

- A frequently used correlation is from Charpy Impact energy (CVN)
- The test is ASTM E 23
- Correlations between CVN energy and K_{Ic} is usually very material specific

Picture of Charpy Impact Tester - N

CVN Test Result

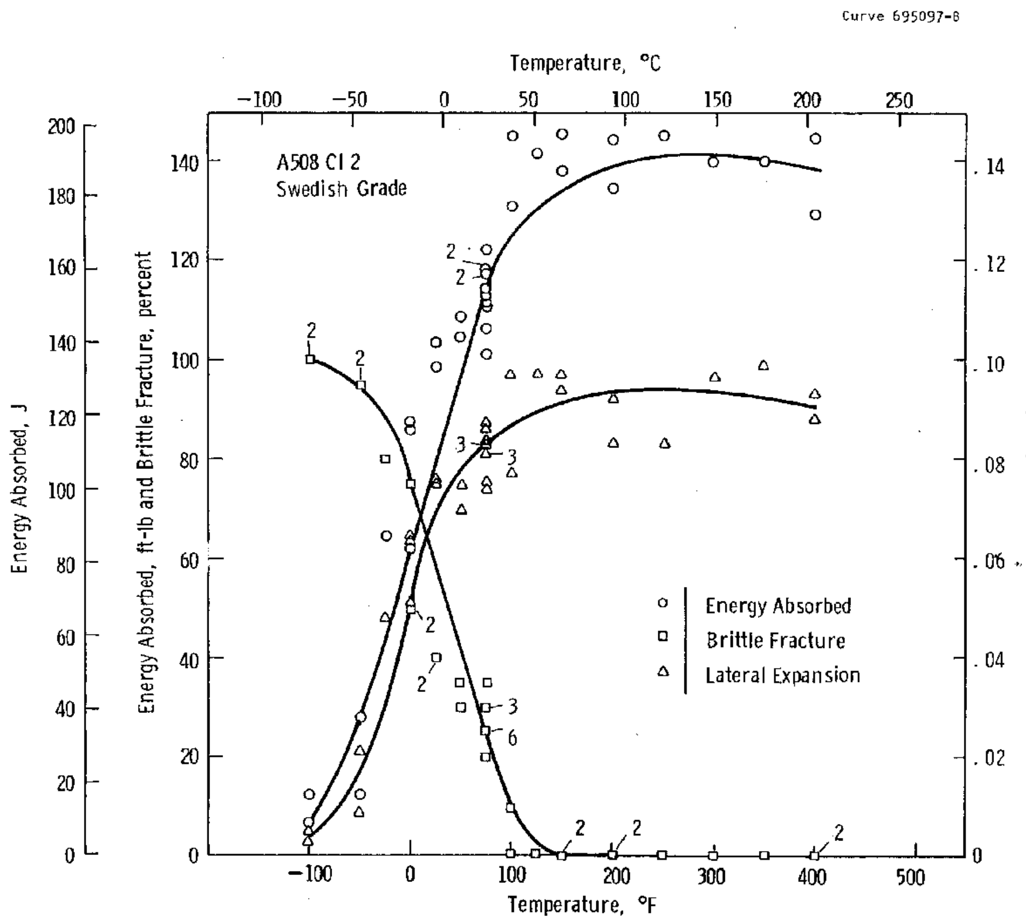


Fig. 5 – Charpy V-notch impact properties of A508 Cl 2(Swedish Grade) pressure vessel steel

Begley - Logsdon Correlation - N

- This was for steel alloys with a ductile to brittle transition
- Four points are determined on a K_{Ic} versus temperature plot
- All data are ksi-in$^{1/2}$ and º F

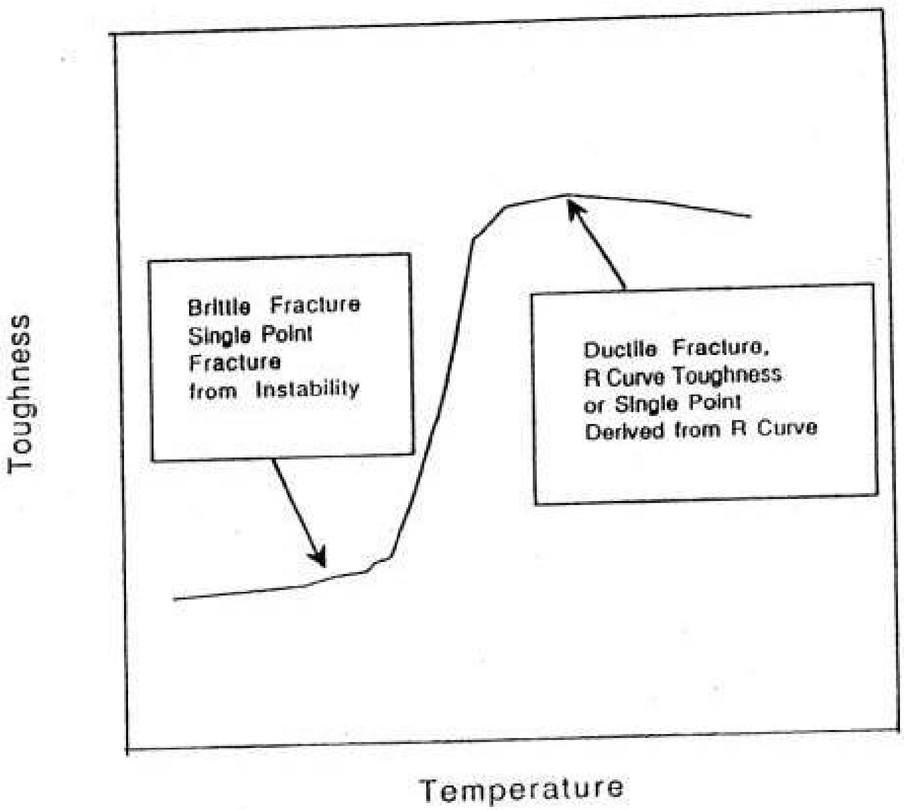


Fig. 1 - Schematic Showing Region of Ductile Fracture

Points - N

- *Point 1: K_{Ic} = 25 ksi-in$^{1/2}$ at - 320º F*
- *Point 2: K_{Ic} = 0.45 σ_{ys} at 0 % Ductile*
- *Point 3: Use the following correlation at 100 % ductile*

$$\left(\frac{K_{Ic}}{\sigma_{ys}}\right)^2 = 5\left(\frac{CVN}{\sigma_{ys}} - 0.05\right)$$

- *Point 4: At 50 % FATT average Points 2 and 3*

Begley Logsdon Prediction

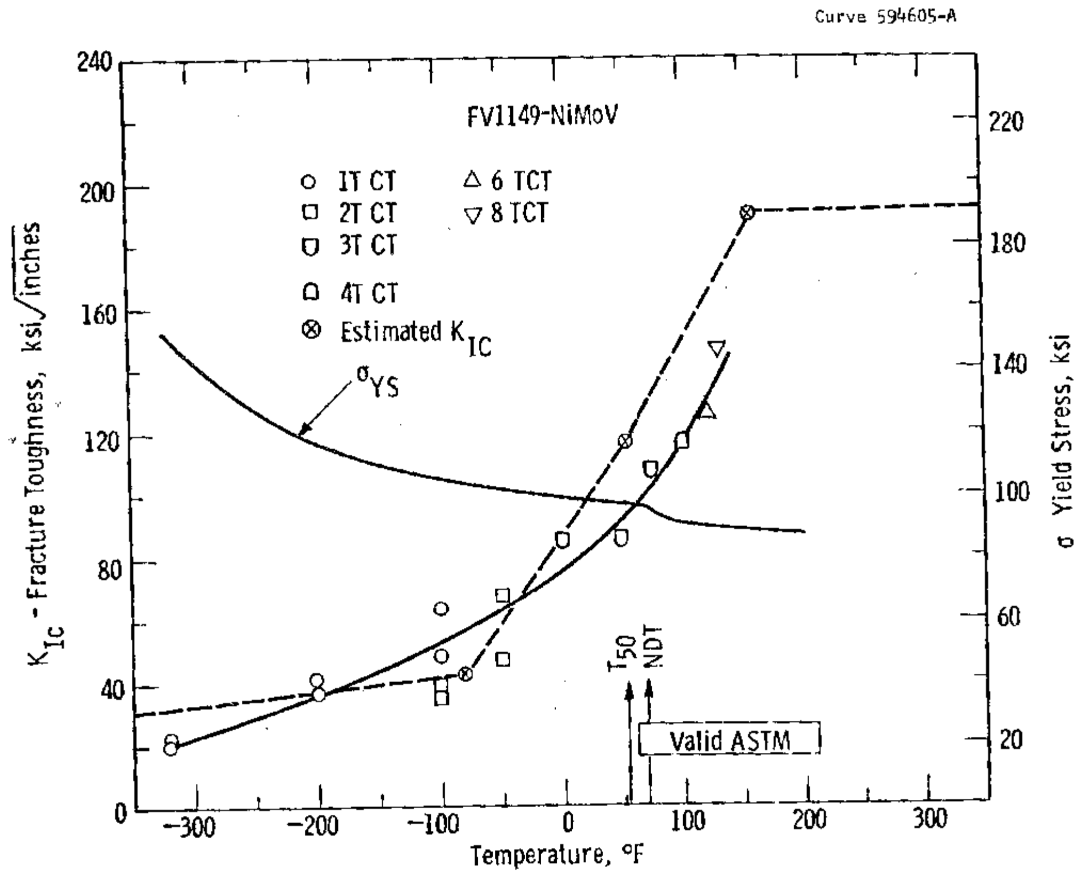


Fig. 13—Temperature dependence of the plain strain fracture toughness (K_{IC}) of a NiMoV steel (1149)

Other types of fracture behavior

1. K-R curve – used for thin sheet fracture toughness, mainly, aerospace

2. Dynamic fracture toughness, $K_{Ic(t)}$ – used for impact, seismic and other rapid loading

3. Crack Arrest, K_{Ia} – used for the arrest of a running crack

K-R curve testing - N

- ASTM E 561- 10 Standard Test Method for K-R Curve Determination
- Linear elastic based fracture toughness, K versus crack extension, Δa
- This work best for high strength sheet material, aircraft structures, etc.
- The K-R curve was one of the original methods, and influenced the non-linear FM methodology

Latest K-R Curve Standard

- **ASTM E561 - 10 Standard Test Method for K-R Curve Determination**

Dynamic fracture toughness, $K_{Ic}(t)$ - N

- $K_{Ic}(t)$ is used for rapidly loaded testing
- (t) is the loading time to K_Q in ms
- Test time is usually 1 to 10 ms
- A rapid load or impact machine is needed
- Most analysis like the E 399 K_{Ic} but dynamic yield strength, σ_{yD}, is used in the analysis (σ_{yD} equation in E399)

Rapid Loading Fracture Toughness - N

- $K_{Ic}(t)$ could be used for seismic, impact, explosive or attack loading
- In the lower shelf dynamic loading usually reduces fracture toughness
- See example

Rapid load test result - N

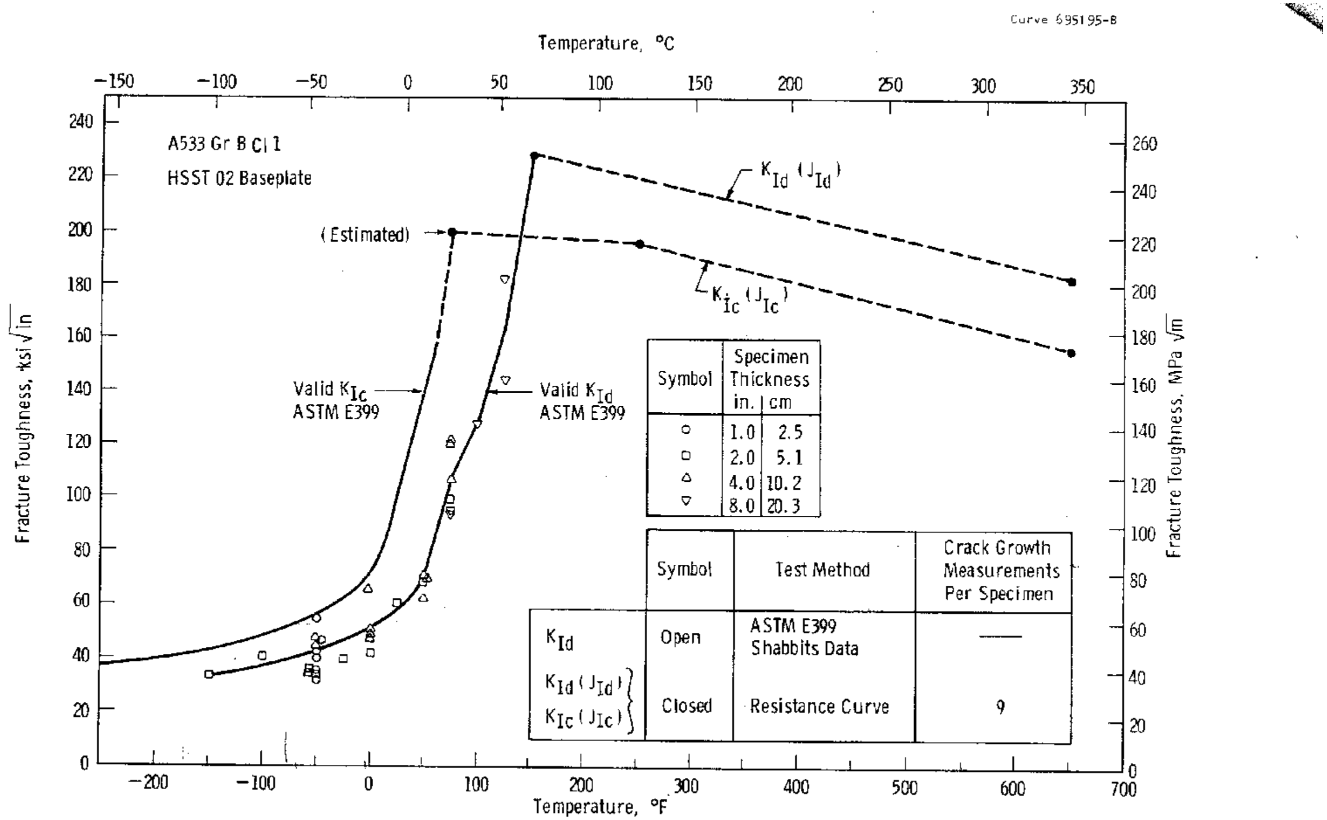


Fig. 9 —Static and dynamic fracture toughness of A533 Gr B Cl 1 pressure vessel steel

Effect of loading rate

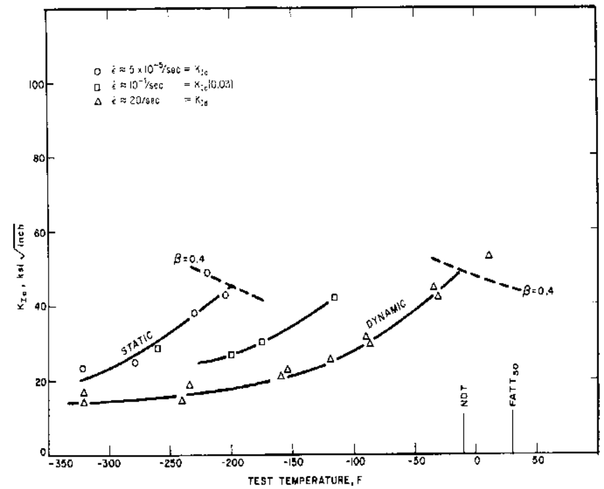


Figure 4.29 Effect of temperature and loading rate on fracture toughness of an ABS-C steel.

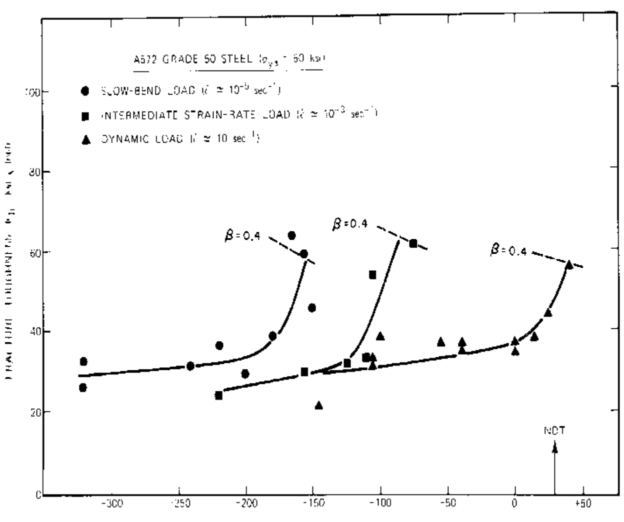


Figure 4.30 Effect of temperature and loading rate on fracture toughness of an A572 steel.

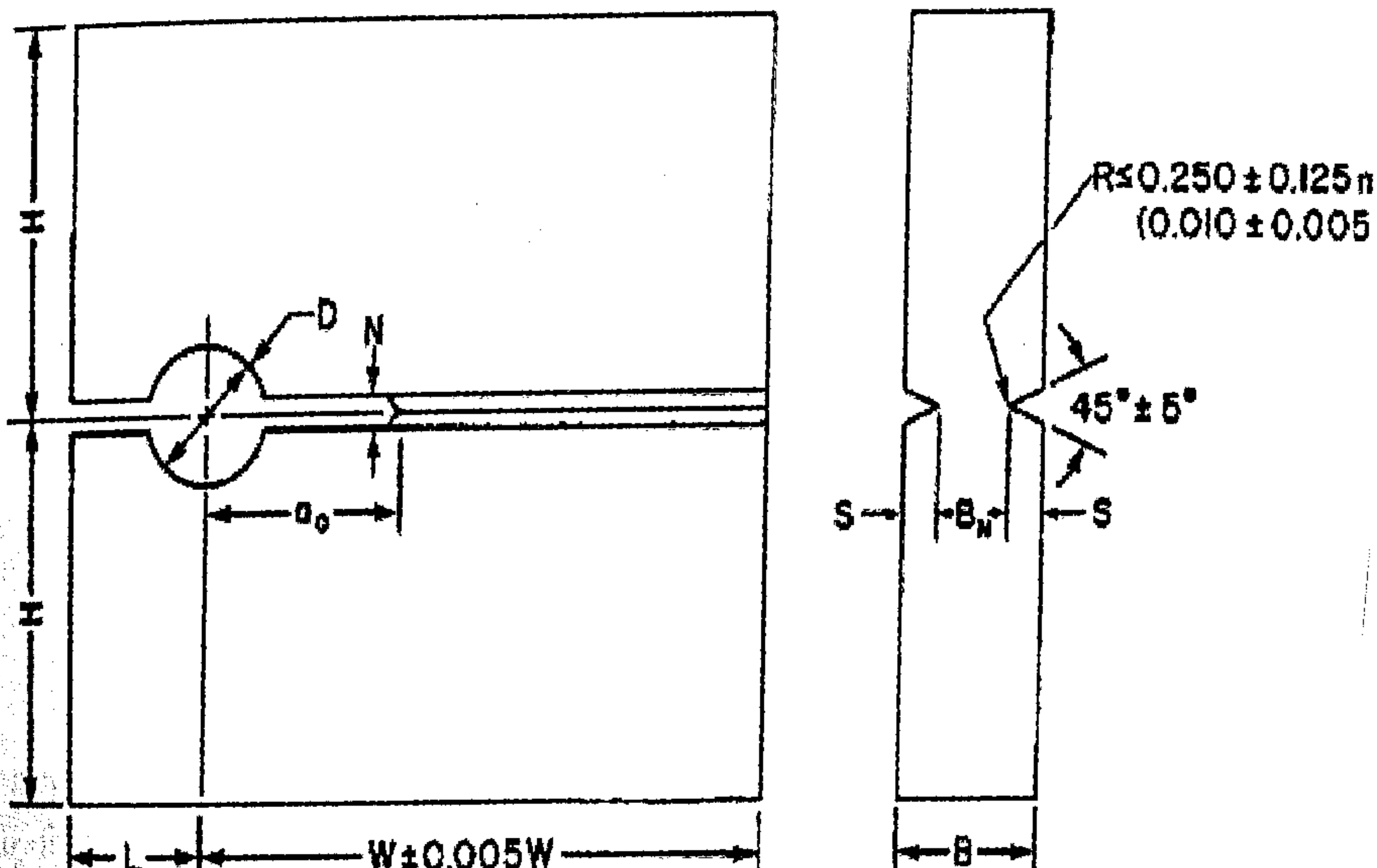
Crack arrest K_{Ia} Testing - N

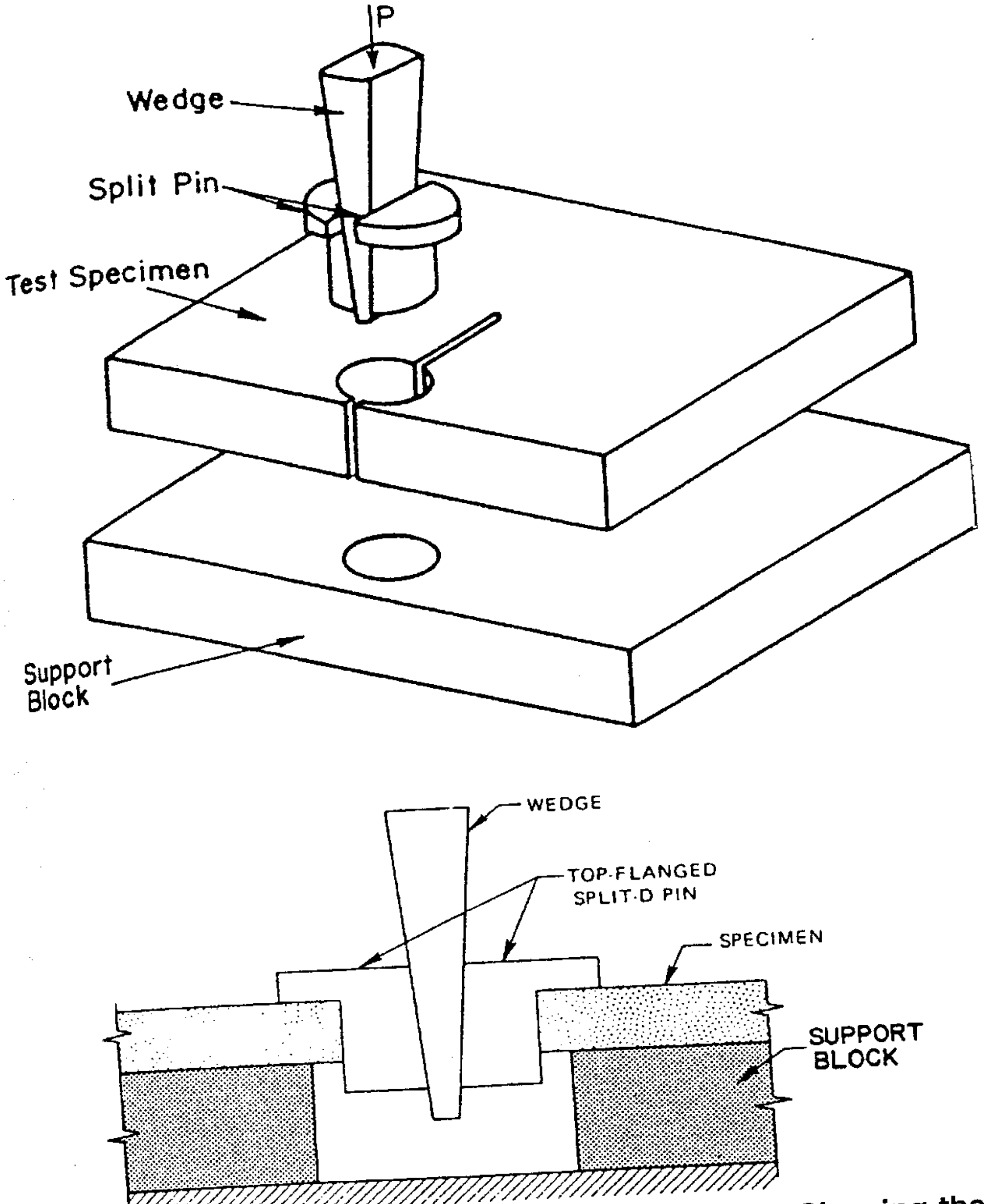
- K_{Ia} Testing is done by ASTM E 1221
- A crack is started in a weld bead and forced into the test material, where it arrests
- K_{Ia} is determined by the load and crack length at the arrest point
- This is one of the two fracture tests without a fatigue precrack

Crack Arrest Standard

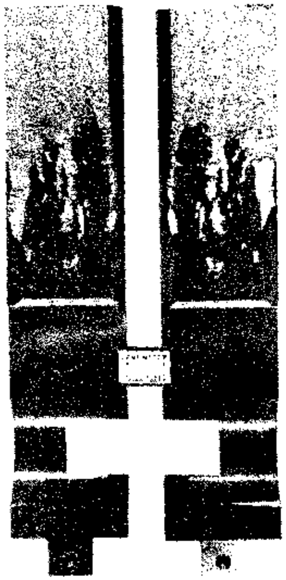
- **ASTM E1221 - 10 Standard Test Method for Determining Plane-Strain Crack-Arrest Fracture Toughness, K_{Ia}, of Ferritic Steels**

Crack Arrest Specimen





Pictorial and Sectional Views Showing the



racture Surface of a CCA Specimen Showing Extensive Ligamentation

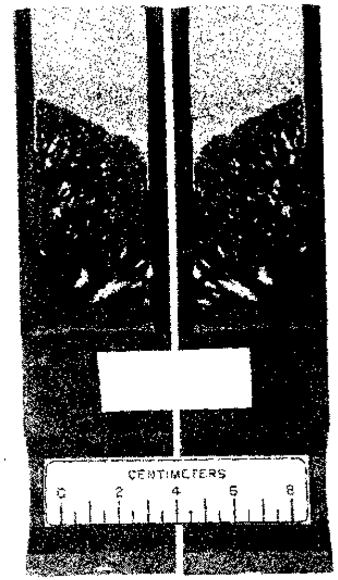
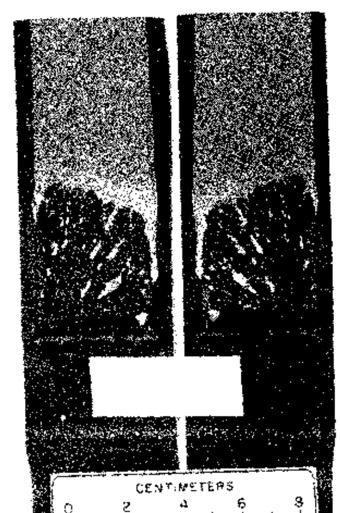


FIG. A1.9 Fracture Surface of a CCA Specimen with a Slanted and Nearly Straight Crack Front



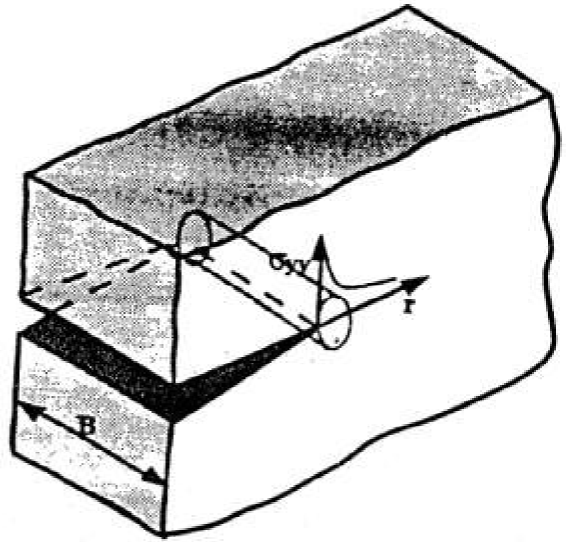
Effect of thickness

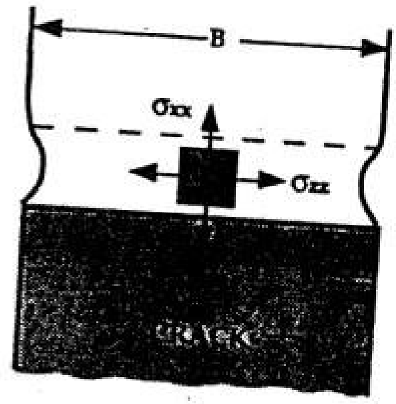
- Thick specimens or structures are in plane strain and have lower fracture toughness

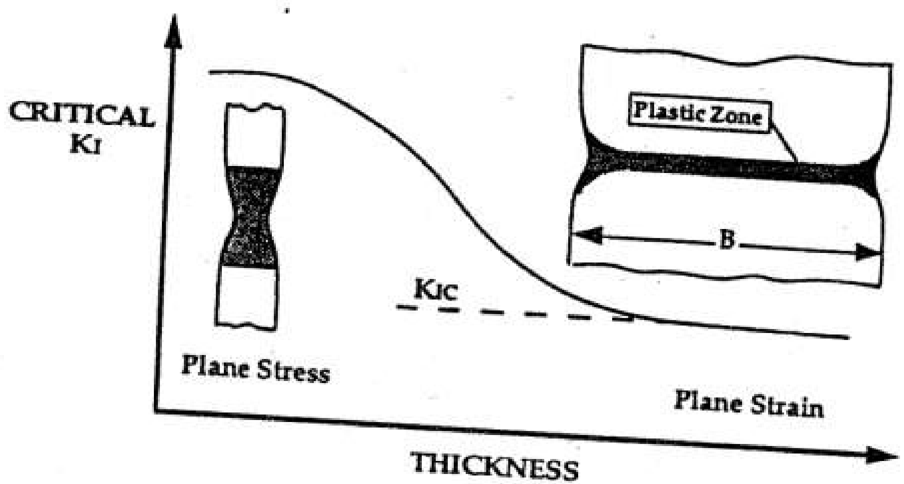
- Thin specimens or structures are in plane stress and have higher fracture toughness

- Between plane stress and plane strain is a transition in toughness

A. Effect of Thickness







Terminology Standard

- **E 1823 – 11, Standard Terminology relating to Fatigue and Fracture testing**

- Updated regularly