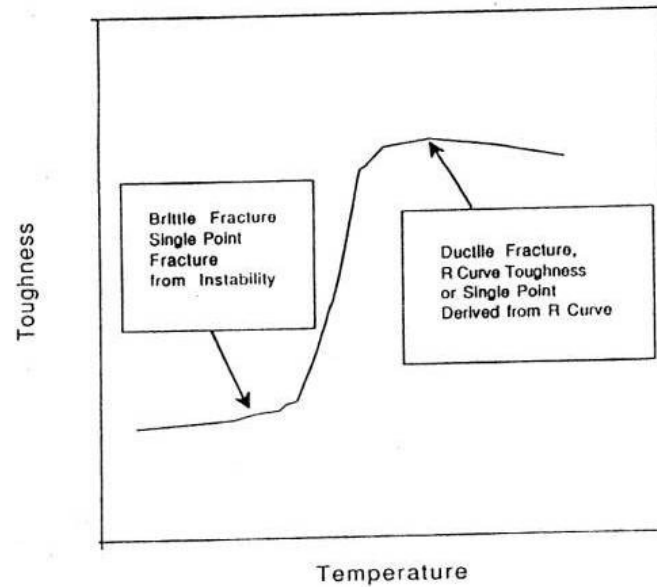# Lecture 14

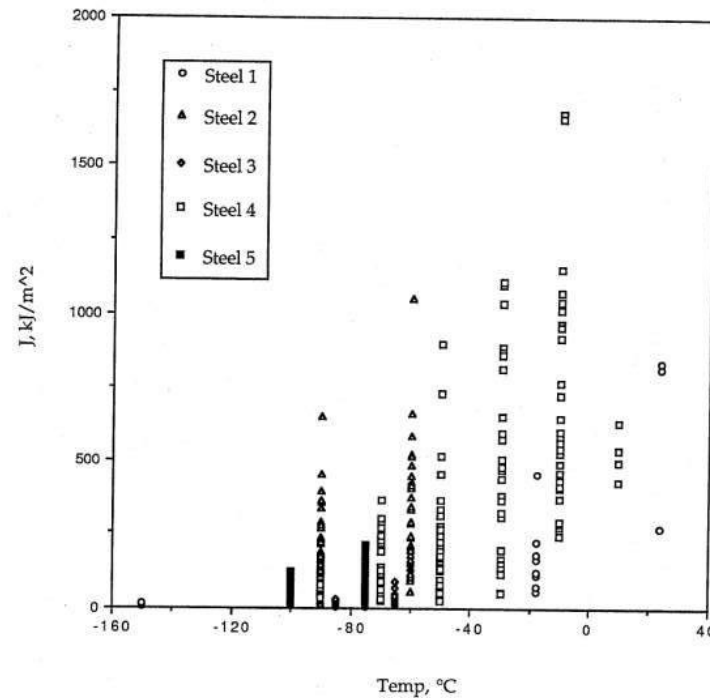## Transition Fracture Toughness Testing and Analysis

Idealized Transition Toughness

Fig. 1 - Schematic Showing Region of Ductile Fracture

Some Actual Transition Data

Transition Toughness Results for five steels

Transition Problems

- Scatter in Toughness is very large
- Doing three tests may give high end or low end toughness values
- How can a conservative toughness value be determined
- Some statistical analysis is needed
- Use Weibull statistical analysis, weak link analysis

Statistical Approach

- Use Weibull statistical analysis, weak link analysis

- This is combined with a master curve analysis

- This works for steels that have a transition and have σ_{ys} in the range of 400 to 800 MPa

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

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

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

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

Some Changes

- $K_{Jc} =$
- $K_{Jc} = \sqrt{\dfrac{J_c E}{1 - \nu^2}}$
- Above Equation should be:
- Above Equation should be:
- $\ln\left(\dfrac{K_{Jc} - K_{min}}{K_0 - K_{min}}\right)$
- $\ln\left(\dfrac{T - T_0}{0.019}\right) = \ln\left(\dfrac{K_{Jc(med)} - 30}{70}\right)$
- Size adjustment is for weak link distribution
- Size adjustment is for weak link distribution
- Size N versus 1 has N time the chance of a of finding a weak link
- Size N versus 1 has N time the chance of a of finding a weak link

Graphical setup

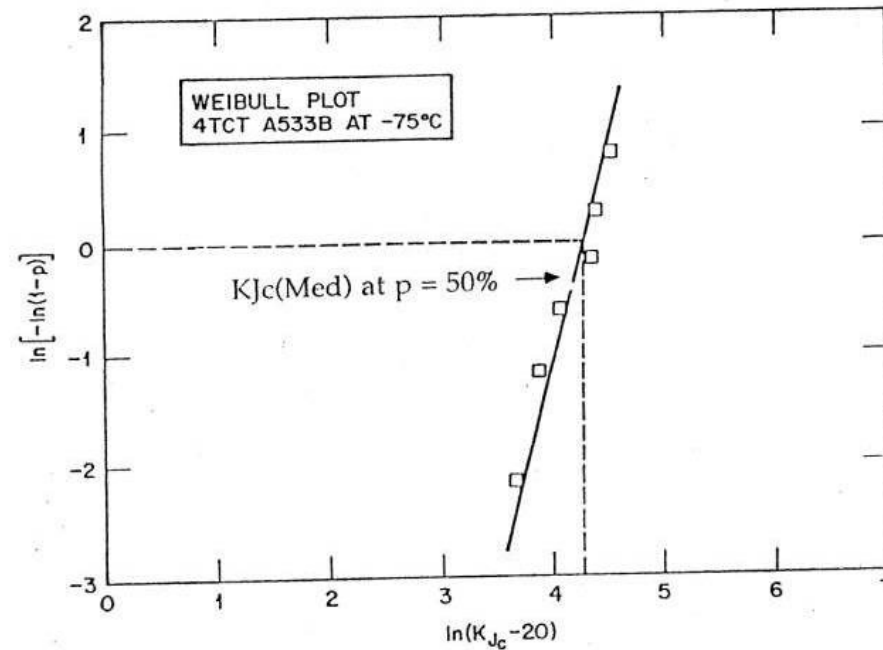- $1 - P_f = \exp\left[-\left(\frac{K_c - 20}{K_o - 20}\right)^4\right]$

- $-\ln() =)^4]$
  - $-\ln(1 - P_f) = \left[\left(\frac{K_c - 20}{K_o - 20}\right)^4\right]$

- $\ln(-\ln() = 4\ln\ )$
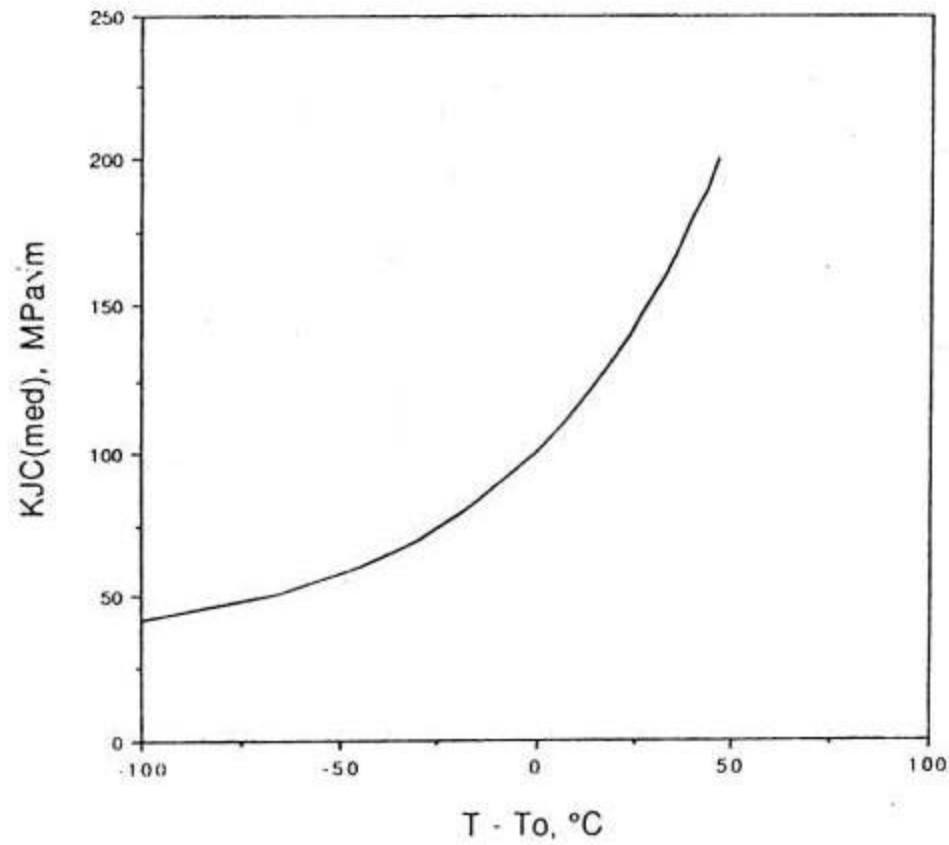 - $\ln(-\ln(1 - P_f) = 4\ln\left(\frac{K_c - 20}{K_o - 20}\right)$

Plotting of Test Values

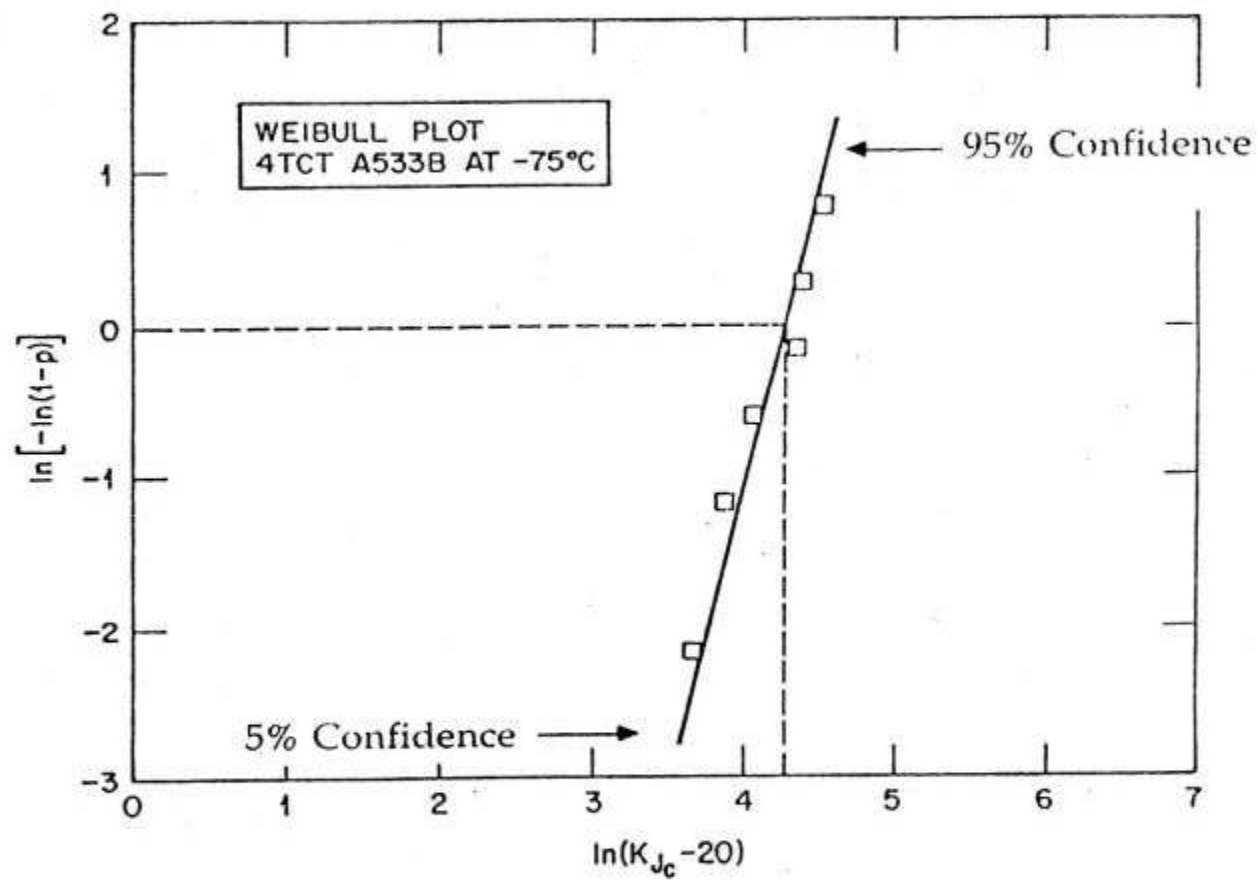Evaluation of KJc(Med) from Weibull Plot

P_f for test points

- Original $P_f = \frac{i}{N+1}$
- i is the single value
- N is the total number of points
- 9 tests (0.1, 0.2, 0.5, ... 0.9)

- Spread $P_f = \frac{i - 0.3}{N + 0.4}$
- 9 tests (0.074, 0.189, ..., 0.5, ... 0.926)
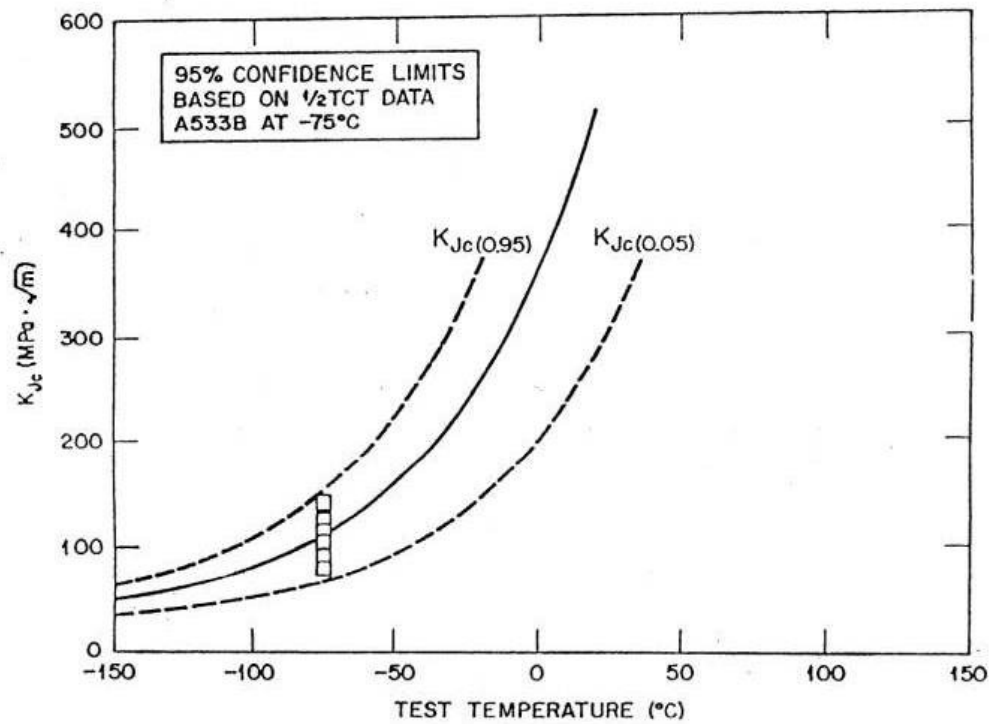
**Master Curve of KJC(med)
Values in the Transition**

Choosing Conservative Bounds

- Master curve is $P_f = 0.5$, 50%

- To pick a lower bound choose $P_f =$ desired confidence

- Example $P_f = 0.05$ gives a 5% lower bound

Evaluation Confidence Limits from Weibull Plot

Master Curve with Confidence Limits

Transition Toughness Testing Standard

ASTM Designation: E 1921 – 97

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

---

[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.
Current edition approved Dec. 10, 1997. Published February 1998.
[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.

Transition testing Standard

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

Examples

- Conduct a test at – 100 C,
- get $K_{Jc(med)}$ = 120 MPa√m
- Then $T - T_O = (\frac{1}{0.019})\ln(\frac{120-30}{70}) = 13.2$ MPa√m
- T_o = -100 – 13.2 = - 113.2 C
- T = -150, $K_{Jc(med)}$ = 30 + 70exp[0.019(T – T_o)]
- = 30 + 70exp[0.019(-150+113.2)] = 64.8 MPa√m
- T = -70 C, $K_{Jc(med)}$ = 189