

Behavior of Solids In Simple Mechanical Tests

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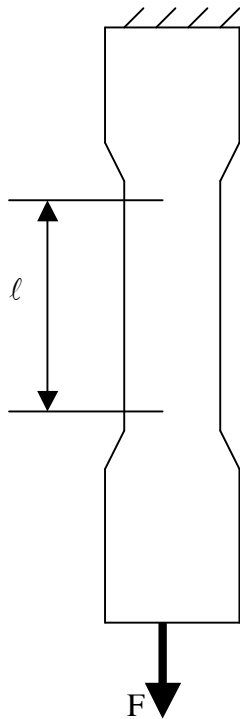
1 Purpose.

The purpose of these notes is to describe in a brief introductory manner:

- Some simple mechanical tests that are used to characterize the behavior of structural materials;
- The kinds of physical behavior that is observed during the tests ; and
- Some of the quantities which are extracted for input to structural mechanics analysis.

2 Tensile Test (Uniaxial)

Test



Units are given in Parenthesis –SI Units

F = Axial force (N) imposed on the test specimen

ℓ = gage length (m)

m =Meter = length

s = second (time)

N = Newton = Force

Pa = Pascal = Stress or Pressure = N/m^2

$^{\circ}C$ = Celsius Degrees

ℓ =Distance between fiducial marks on the test specimen

A = minimum cross sectional area (m^2) of the test specimen

o = Subscript denoting the initial unloaded condition

f = subscript denoting the final condition of the broken specimen

Measurements and Data Reduction

- measure l vs. F while pulling the specimen
- Also obtain A_f by reassembling the pieces after the specimen has broken
- Define strain (“engineering strain”) to be e , where:

$$e = (l - l_0) / l_0 \quad (1)$$

Define stress (“engineering Stress”) to be S , where:

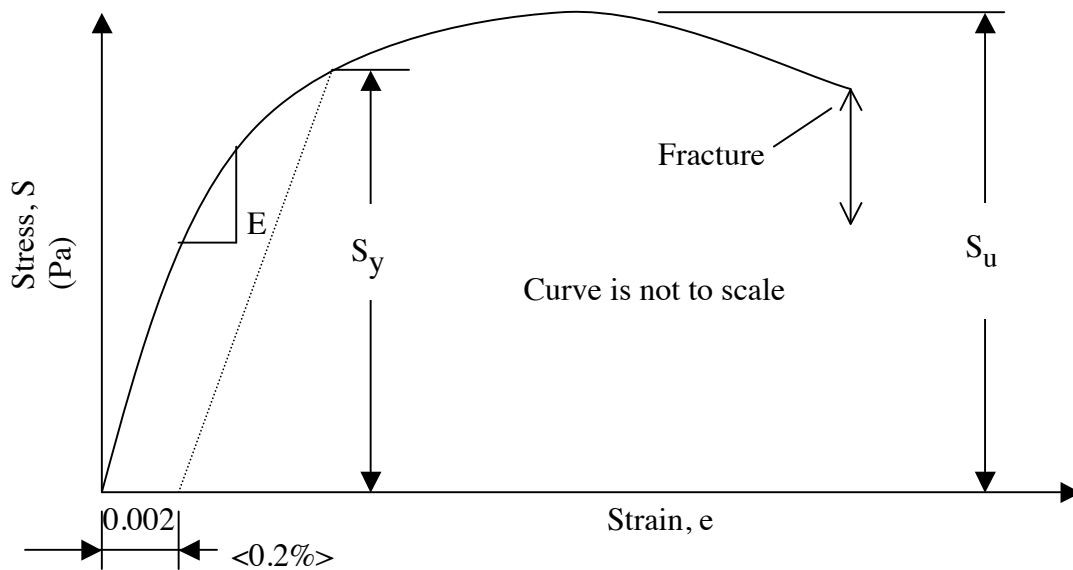
$$S = (F / A_0) \quad (2)$$

-Define reduction of Area, R_A , to be:

$$R_A = \left(\frac{A_0 - A_f}{A_0} \right) \quad (3)$$

Material Property Information Obtained

- Stress-Strain curve and Derived quantities



- Derived Quantities

- E = Young’s modulus (Pa), slope of the stress- strain curve at low strains
- S_y = Yield Stress (Pa), “Stress at 0.2% offset”
- S_u = Ultimate Stress (Pa), maximum stress reached during the test

3 Creep Test:

Test

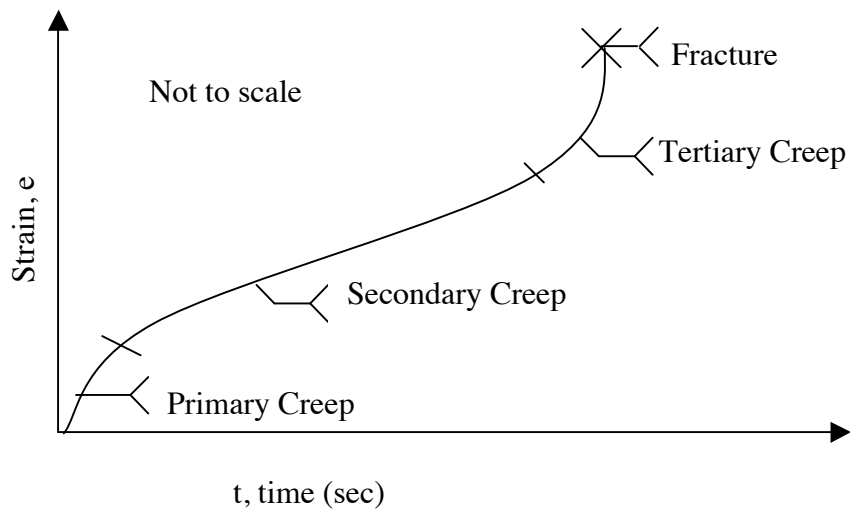
Define stress and strain as above. Conduct test at elevated temperature, maintaining stress constant.

Measurement

Obtain length ℓ vs. time

Material property Information

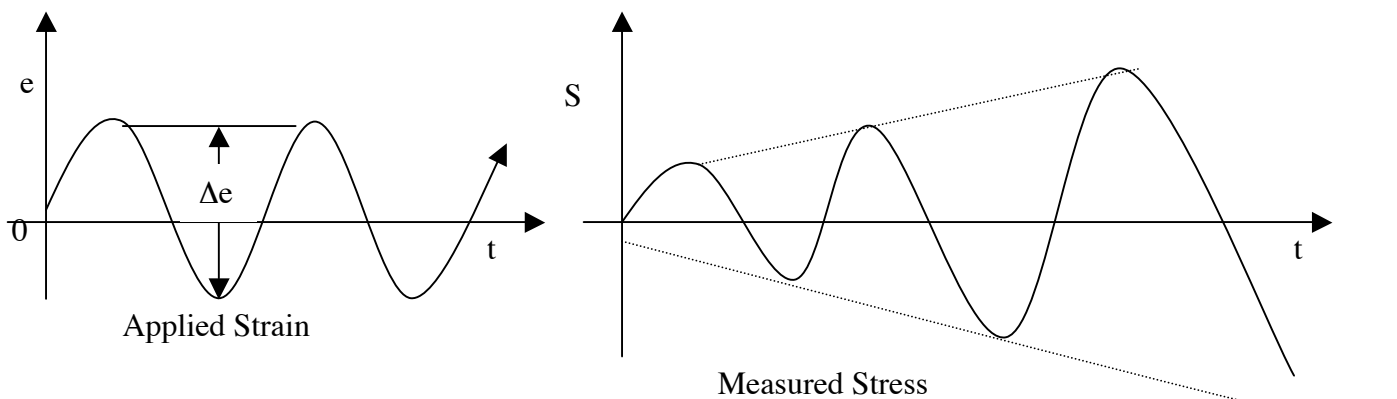
- Creep Curve



4. Strain controlled Fatigue Tests.

Test

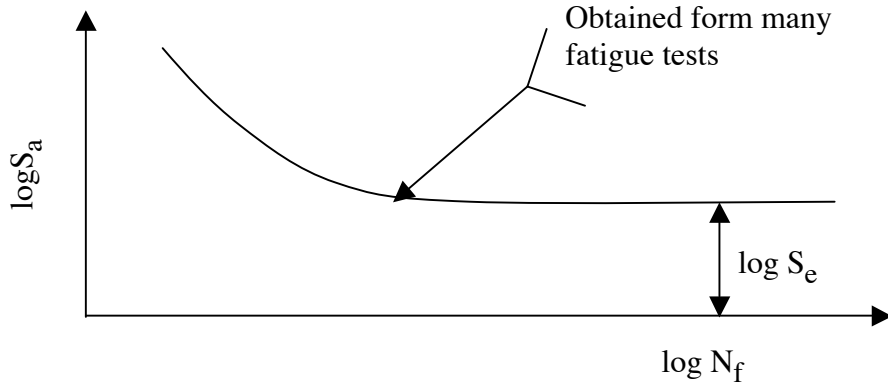
- Alternatively Stretch and Compress the Specimen



Measure

N_f = number of cycles to failure

Material property Information



Where S_a = equivalent alternating stress (Pa),

or, $S_a = E\Delta\epsilon/2$, (4)

and S_e = endurance stress (Pa)
= maximum alternating stress after a large number of cycles ($\sim 10^6$ or more) without failure.

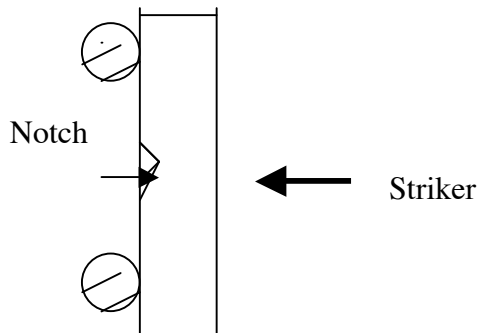
5. Notched Impact Tests.

Test (e.g., V-Notch Charpy Impact Test)

Measure

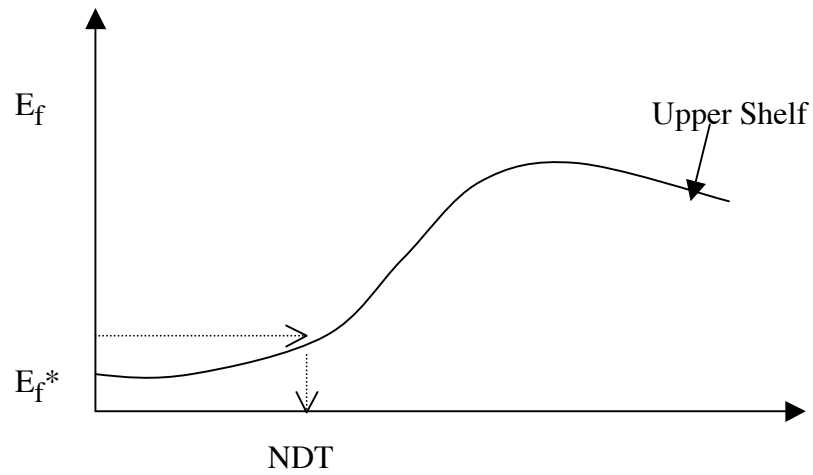
E_f = Energy loss (J) by the striker upon an impact which produces failure

J = Joules = N.m



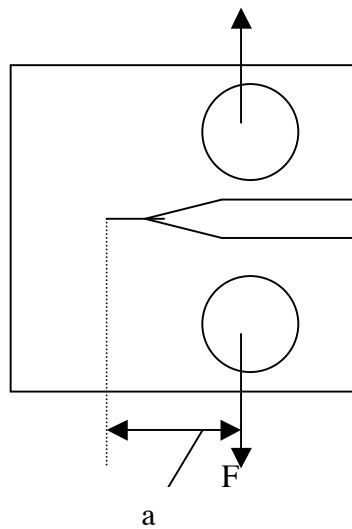
Material Property Information

NDT = Nil- Ductility Temperature, based on a reference energy loss E_f



6. Crack Growth and Brittle Fracture

Test (* e.g. , Compact Tensile Specimen)



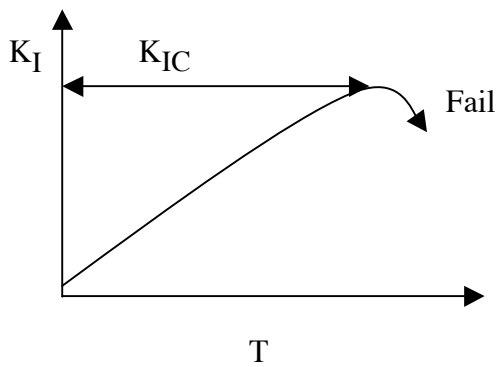
For this test, a characteristic stress \bar{S} can be defined which is linearly related to F (actually, directly proportional to F). Then by calculations of linear elastic fracture mechanics (LEFM), the characteristic stress is related to a stress intensity factor, K_I

Where:
$$K_I = Y\bar{S} \sqrt{\pi a} . \tag{5}$$

The quantity Y is dimensionless and depends on geometry. The stress intensity factor K_I is for the ‘opening mode’ of crack extension, is defined to indicate how intense the applied load is with regard to such crack extension, and as indicated in Eq. (5), has the units $\text{Pa (m)}^{1/2}$

Measure

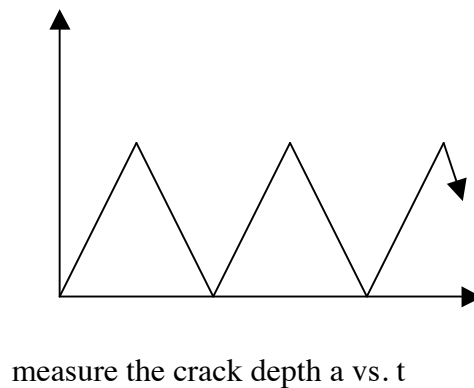
(1) Single Pull to Failure



K_{IC} = fracture toughness

$K_{IC}(\text{Pa (m)}^{1/2})$ = significant deviation from linearity

(2) Cyclic Loading

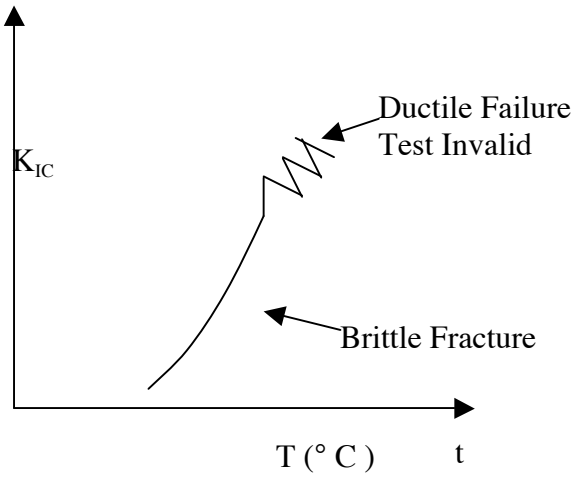


ΔK_I = range of K_I (zero to a value) from Eq. (5) and applied F.

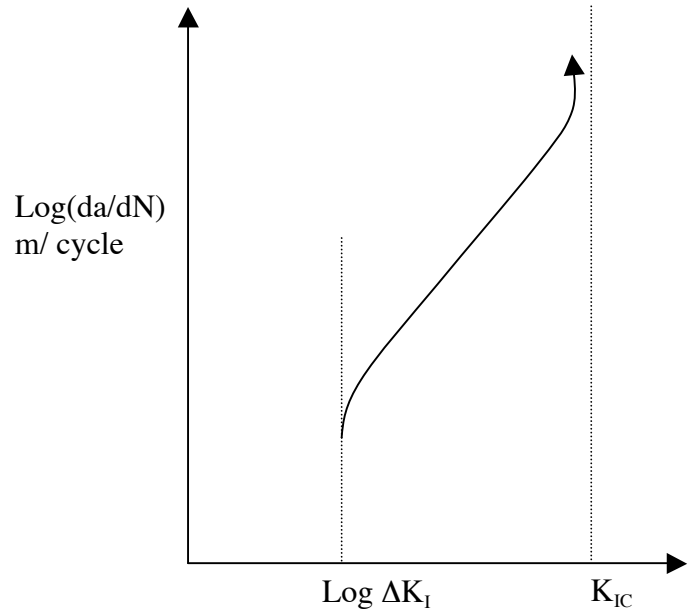
The mode of loading here (forces perpendicular to crack length) is referred to as mode I. Other modes of loading have been identified, and are referred to as II and III.

Material Properties

(1) Brittle Fracture



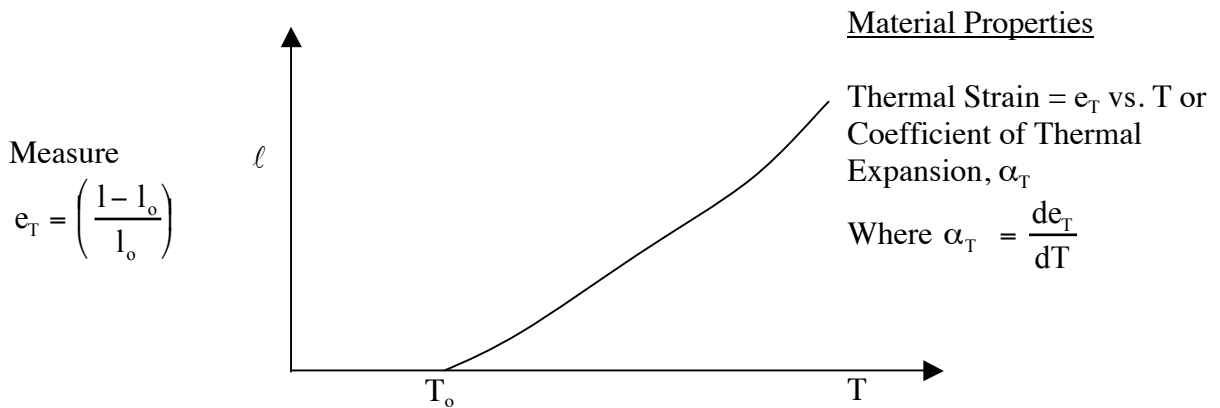
(2) Crack Growth



7. Thermal Expansion

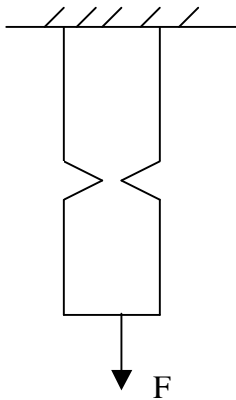
Test

Measure length, ℓ , between fiducial marks on an unstressed specimen as a function of temperature, T .



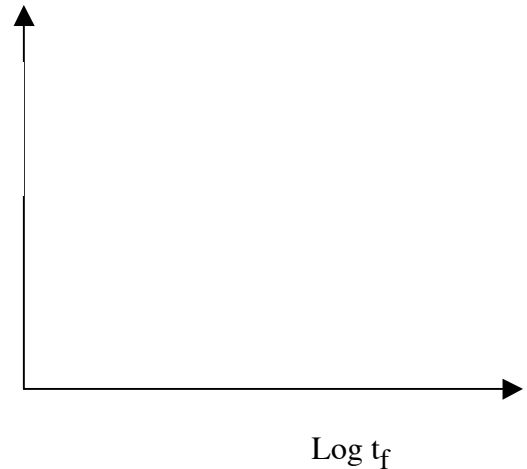
8. Stress – Corrosion Cracking

Test Sharp- Notched Rectangular Bar keep
F constant for some time in environment of interest
(hot water, halides, etc)



Measure – time to fail t_f

Material property Information



9. Irradiation Effects

Material properties are observed to change with fast neutron irradiation:

- growth – dimensional changes without stress or temperature change
- embrittlement – increase in S_u and decrease in RA or E_f
- radiation induced creep – at low stresses, the material elongates more quickly than in out of pile situations.

10. Cautions.

The summarized are the most important tests which are used to characterize the behavior of structural materials. Remember:

- There are many subtleties involved in conducting the tests described above that have not been covered.
- There are a number of other tests that pertain to important behavior, such as anisotropy.
- There are other ways of extracting information.
- The sketches are only for illustration purposes and are not to scale, thus may show the wrong shape or the wrong directions.

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22.312 Engineering of Nuclear Reactors
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