MODULE 03

MATERIALS PROPERTIES

Metallic and Nonmetallic Materials

- Metallic materials
  - Iron, steel, copper, aluminum, magnesium, etc.
  - General properties
    - Luster, high thermal conductivity, high electrical conductivity, ductile
- Nonmetallic materials
  - Wood, brick, concrete, glass, rubber, plastic, etc.
  - General properties
    - Weaker, less ductile, less dense

Physical and Mechanical Properties

- Physical properties:
  - Density, melting point, optical properties, thermal properties, electrical properties, magnetic properties
- Mechanical properties:
  - A property that dictates how a material responds to applied loads and forces
  - Determined through specified testing
  - It is important to take the testing methodology

Testing Standards and Concerns

- American Society of Testing and Materials (ASTM) has standardized the testing methodologies for determining physical and mechanical properties
- Important that the tests are standardized and reproducible
- ASTM maintains and updates testing standards

Stress and Strain

- Strain is the distortion or deformation of a material from a force or a load
- Stress is the force or the load being transmitted through the material's cross sectional area
- Stress and strain can occur as tensile, compressive or shear

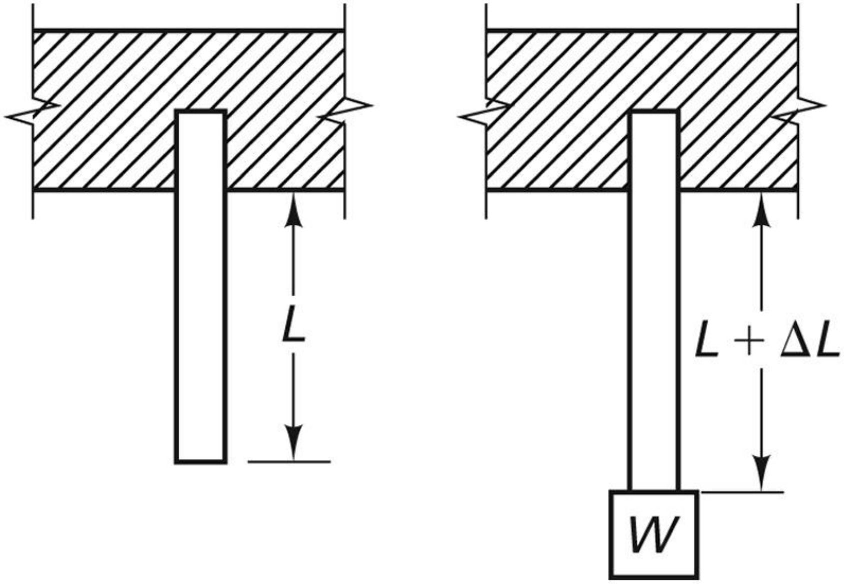
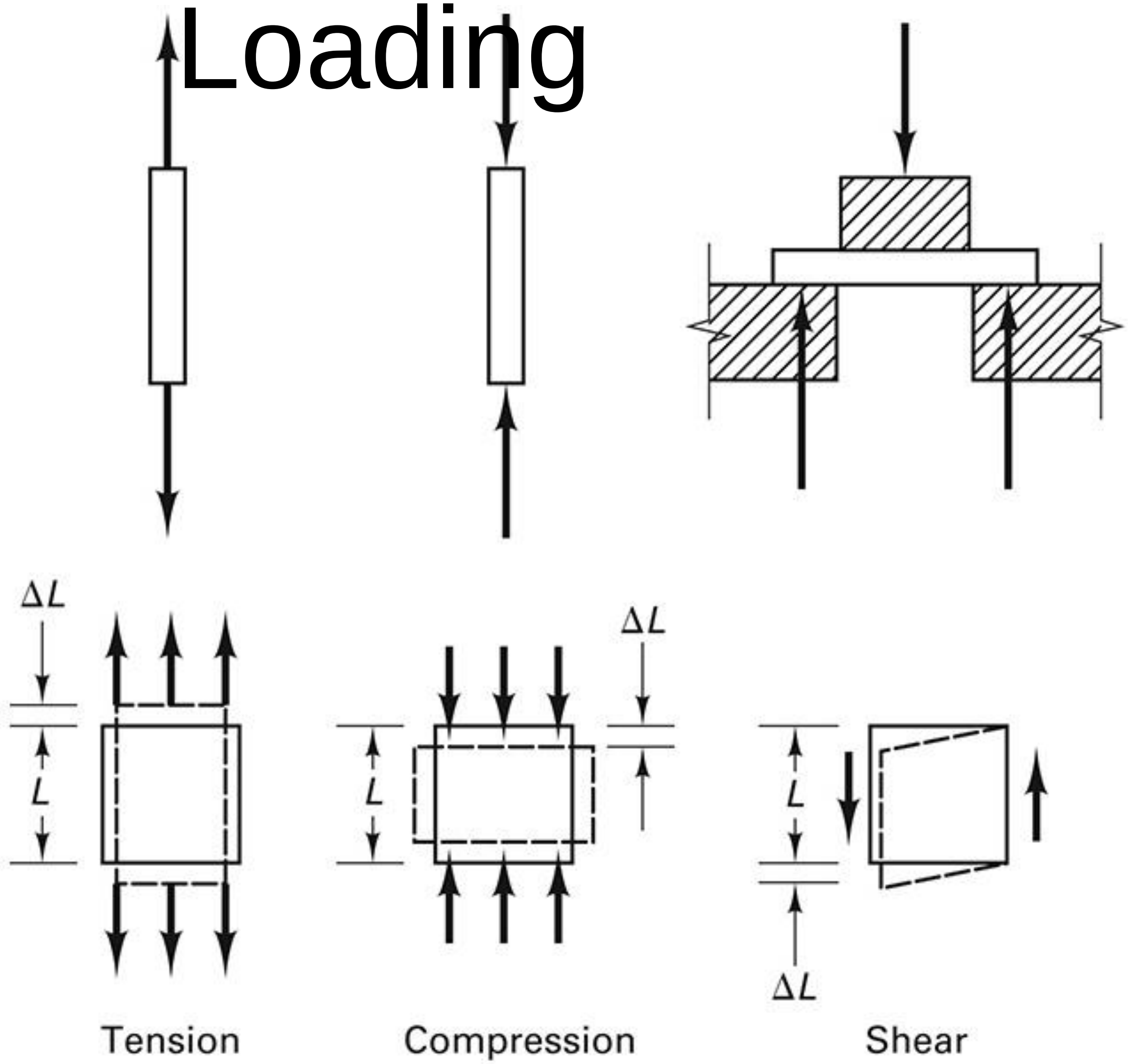


Figure 2-2 Tension loading and the resultant elongation.

Tension, Compression, Shear Loading

Figure 2-3 Examples of tension, compression, and shear loading, and their response.



Engineering Stress-Strain Curve

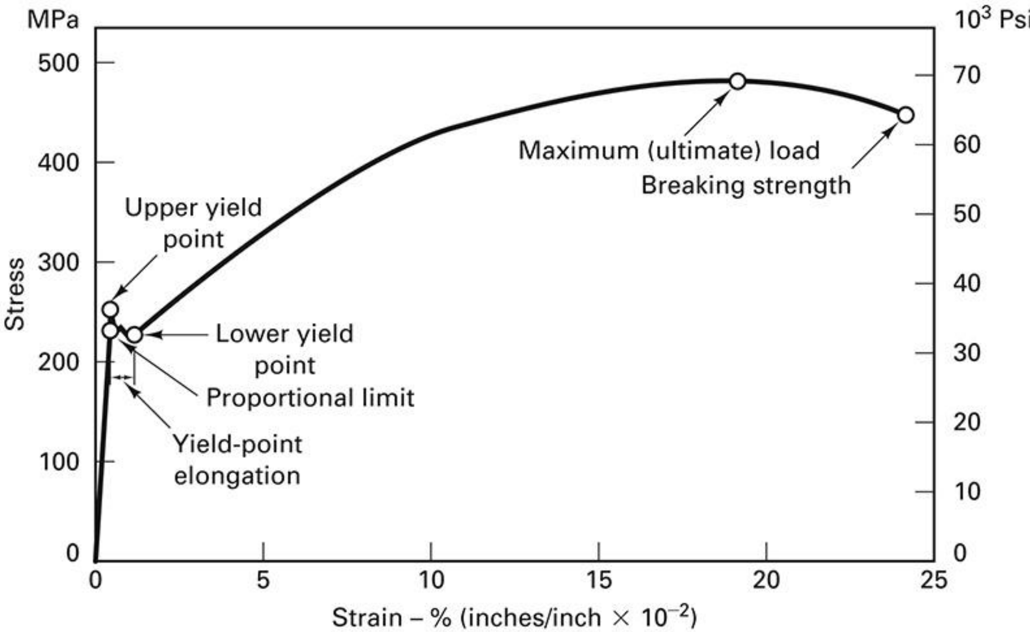


Figure 2-6 Engineering stress-strain diagram for a low-carbon steel.

– Key features
- Proportional limit (below this limit, the strain is directly proportional to stress)
- Ratio of stress to strain is Young's Modulus
  – Measures stiffness
  – Designated by E
- Ultimate Strength
  – Stress at which the load-bearing ability peaks

PROPERTIES DETERMINED BY THE STRAIN-STRESS CURVE

- Engineering stress-strain diagram
- Proportionality limits (Hooke’s law)
- Elastic limit
- Young’s modulus (E)
- Measure of Stiffness
- Resilience
- Yield point, upper and lower
- Maximal load
- Breaking stress

Additional Properties from the Stress-Strain Curve

- Modulus of resilience- amount of energy per unit volume that a material can absorb
- Plastic deformation- permanent change in shape due to a load that exceeded the elastic limit
- Yield point- stress value where additional strain occurs without an increase in stress
- Offset yield strength- the stress required to produce an allowable amount of permanent strain

TOUGHNESS

- Toughness- work per unit volume to fracture a material
- Total area under the stress-strain curve
- The toughness is the product of yield strength and uniform elongation

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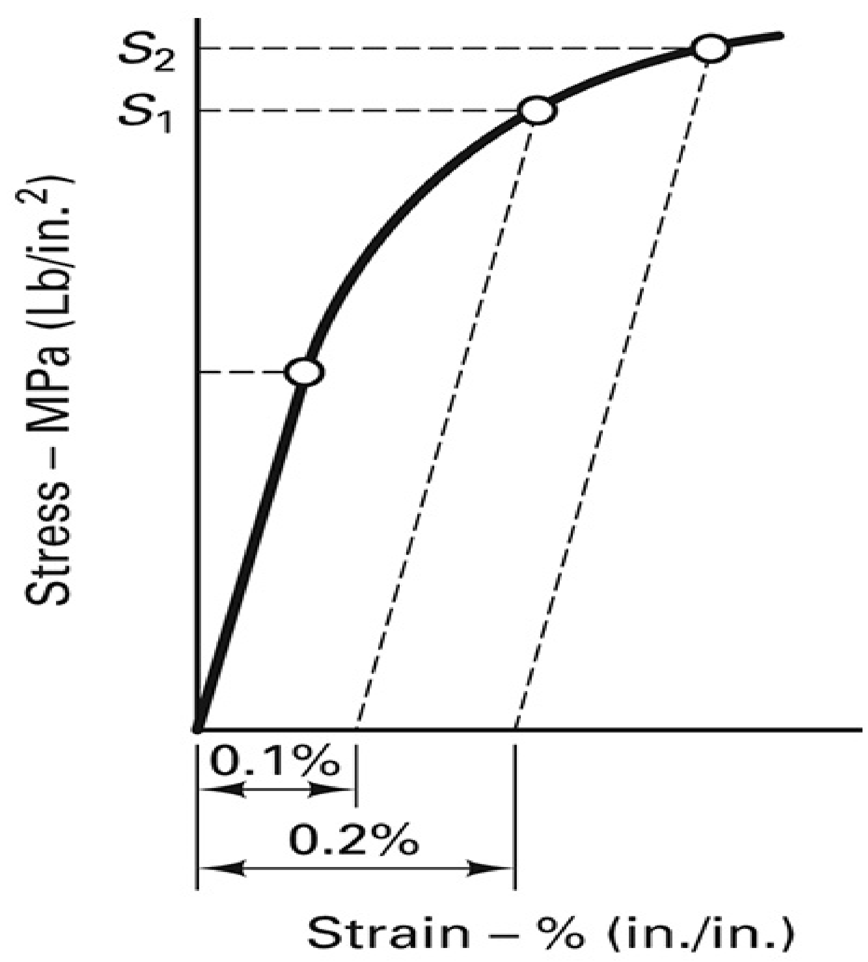
NO WELL-DEFINED YOILD POINT



TRUE VS ENGINEERING STRESS-STRAIN

- Instantaneous stress versus the summation of the incremental strain
- $\varepsilon = \ln(L/L_o) = 2\ln(D_o/D)$

True Stress-Strain Curve

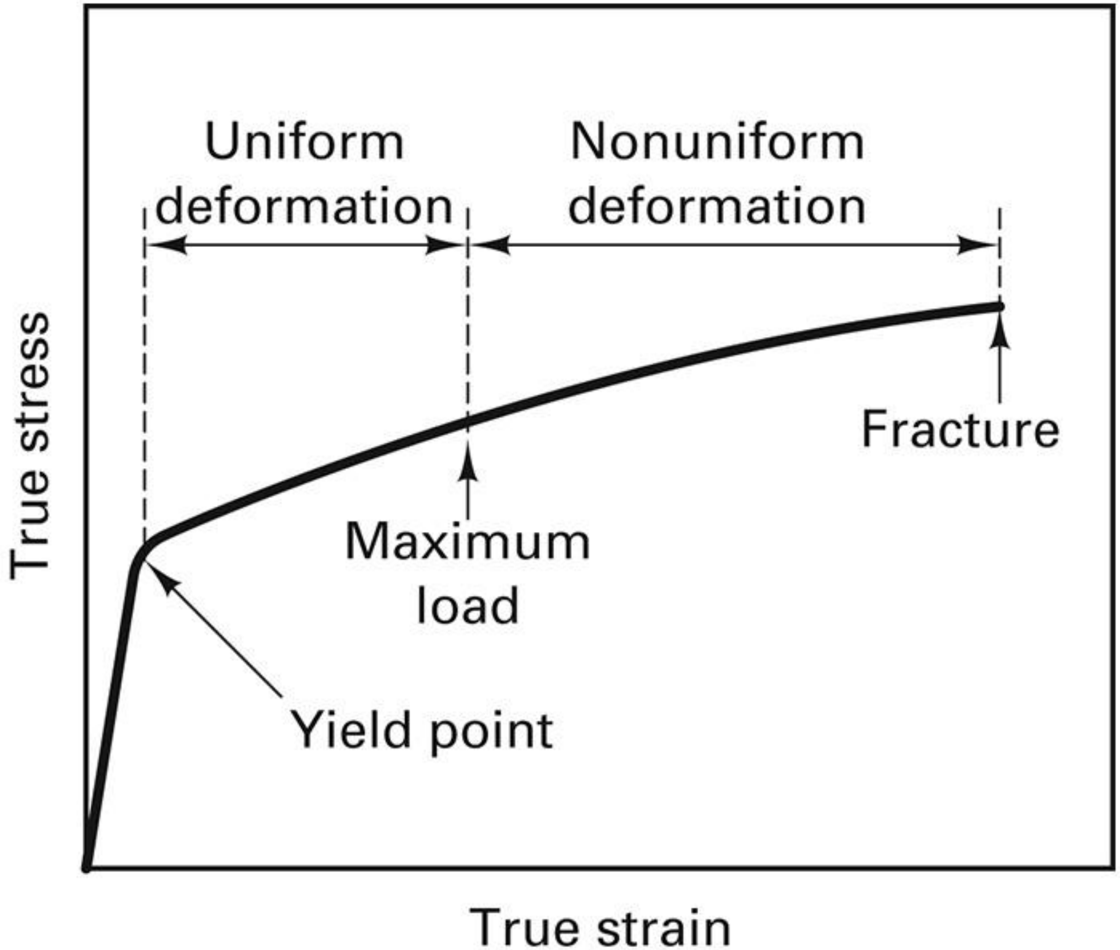
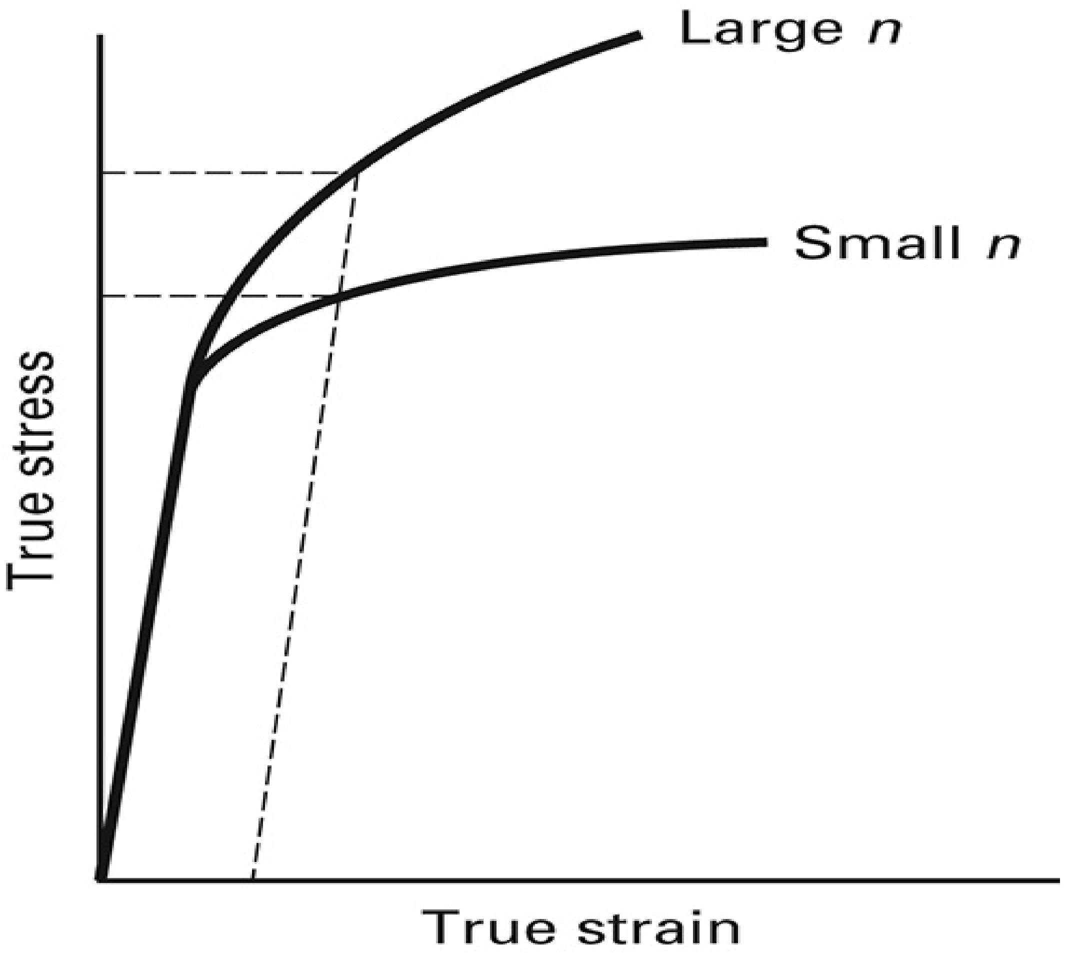


Figure 2-10 True stress-strain curve for an engineering metal.

STRAIN HARDENING EXPONENT

- $\sigma = K\varepsilon^{**}n$
- N-strain hardening exponent

TRUE STRESS-STRAIN CURVES AT LARGE AND SMALL HARDENING



DUCTILITY AND BRITTLENESS

- Ductility-amount of deformation that precedes fracture
- A brittle material fails with no plastic deformation

Ductility and Brittleness

- Necking is a localized reduction in cross sectional area
- For ductile materials, necking occurs before fracture
- For brittle materials, fracture ends the stress strain curve before necking
- Percent elongation is the percent change of a material at fracture
- Material failure is the onset of localized deformation or necking

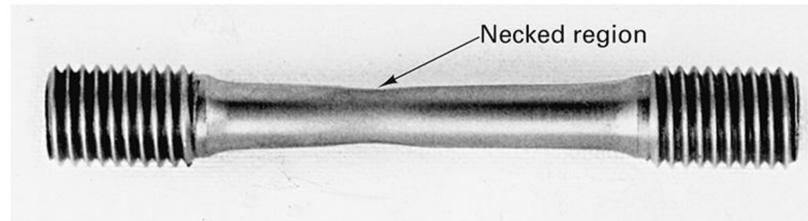


Figure 2-8 A standard 0.505-in diameter tensile specimen showing a necked region developed prior to failure.

Percent Reduction in Area:

$$R.A. = \frac{A_0 - A_f}{A_0} \times 100\%$$

Hardness Testing

- Hardness is the resistance to permanent deformation in the form of penetration or indentation
  - Brinell Hardness Test
    - Measures the indentation of a steel ball
    - Yields a Brinell hardness number based on diameter of indentation
  - Rockwell Test
    - Small steel ball or diamond tip cone (called a brale) causes an indentation
    - Indentation is measured based on depth
  - Vickers Hardness Test-a diamond pyramid as indenter
  - Knoop Microhardness Test-micro indentation
  - Test
- Hardness testing can provide a close approximation of tensile strength (~500 times the Brinell hardness number for psi)

Hardness Testing

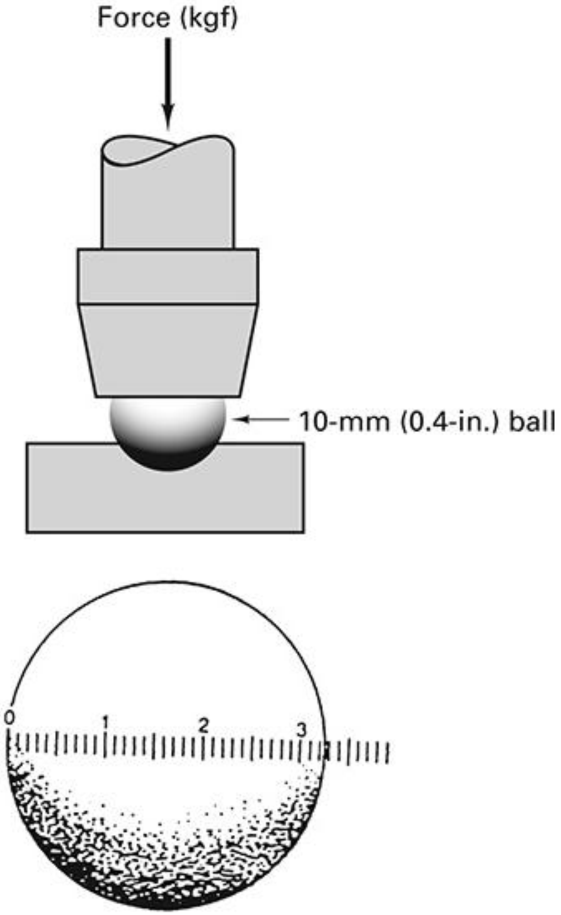


Figure 2-14b Brinell test sequence showing loading and measurement of the indentation under magnification with a scale calibrated in millimeters.

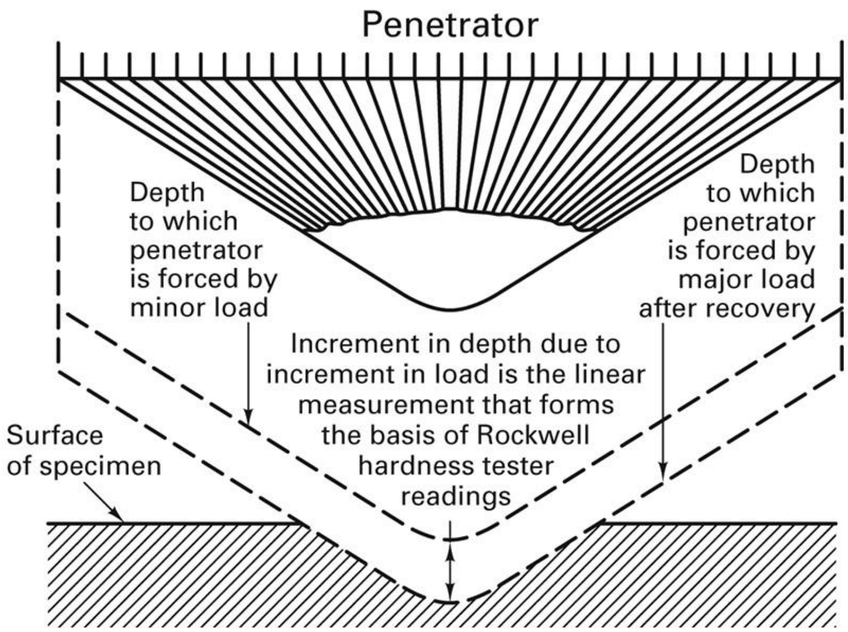
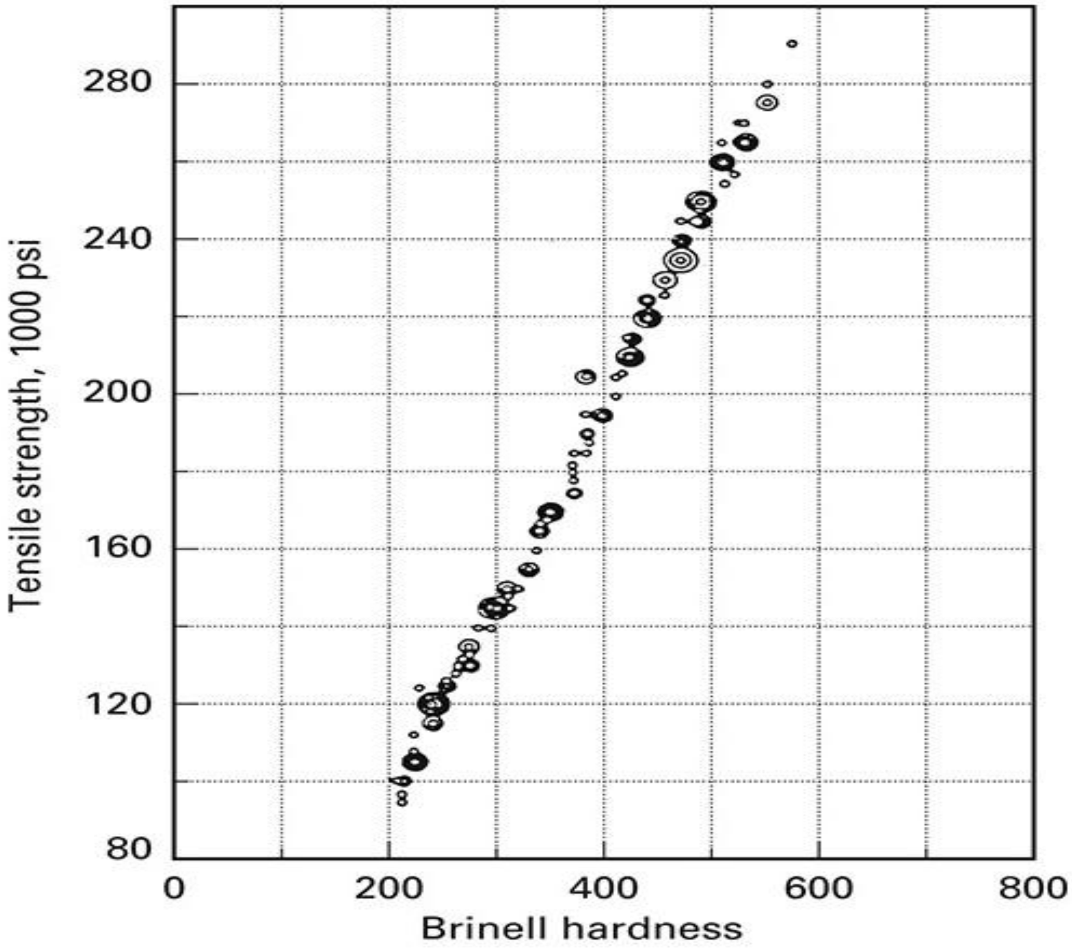


Figure 2-15a Operating principle of the Rockwell hardness tester. (Courtesy of Wilson Instruments Division, Instron Corp., Norwood, MA.)

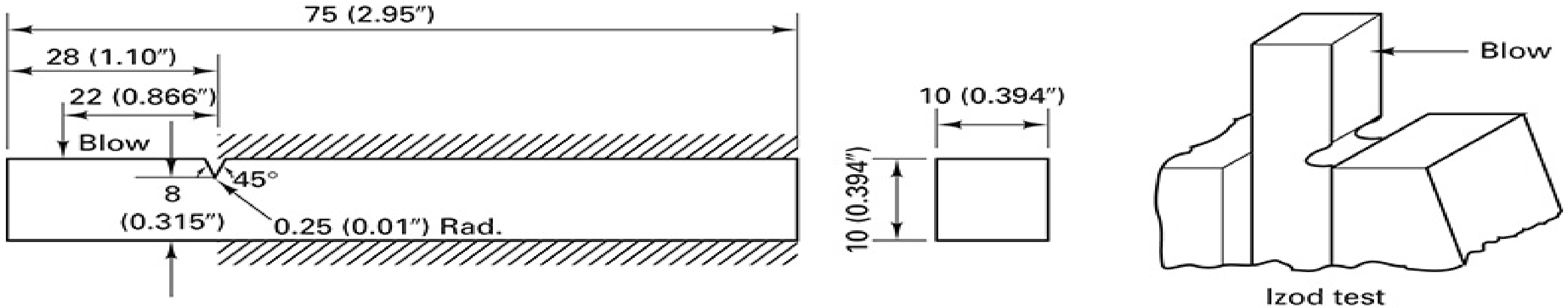
HARDNESS VS TENSILE STRENGTH



Dynamic Properties

- Bending impacts
  - Charpy and Izod tests
- Tension impacts
- Fatigue and endurance limit
  - Materials can fail if they are subjected to repeated applications of stress
  - Fatigue is cyclic repetition of a load
  - Stress versus number of cycles curves are useful in determining endurance limits
    - Endurance limit is the stress below which the material will not fail regardless of the number of cycles
    - Fatigue strength is the maximum stress that can be sustained for a number of loading cycles

IZOD SPECIMEN



(a) (b)

SHARPY SPECIMEN

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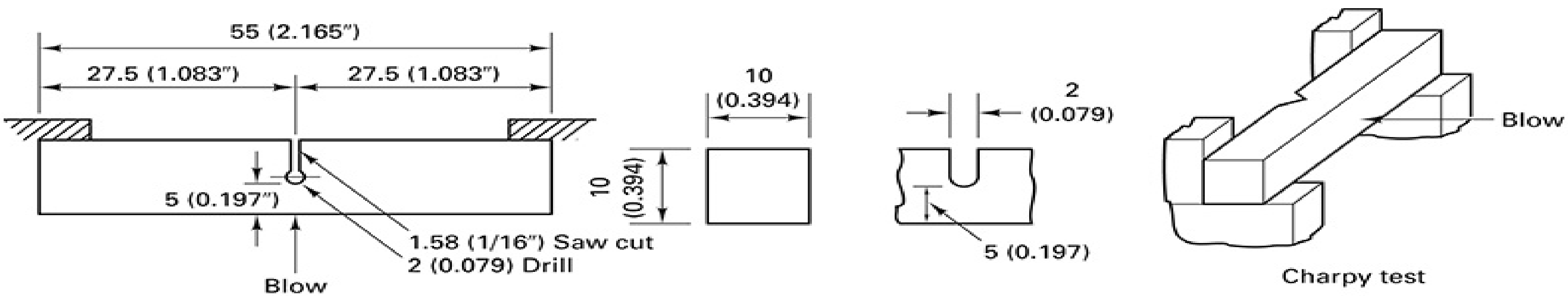
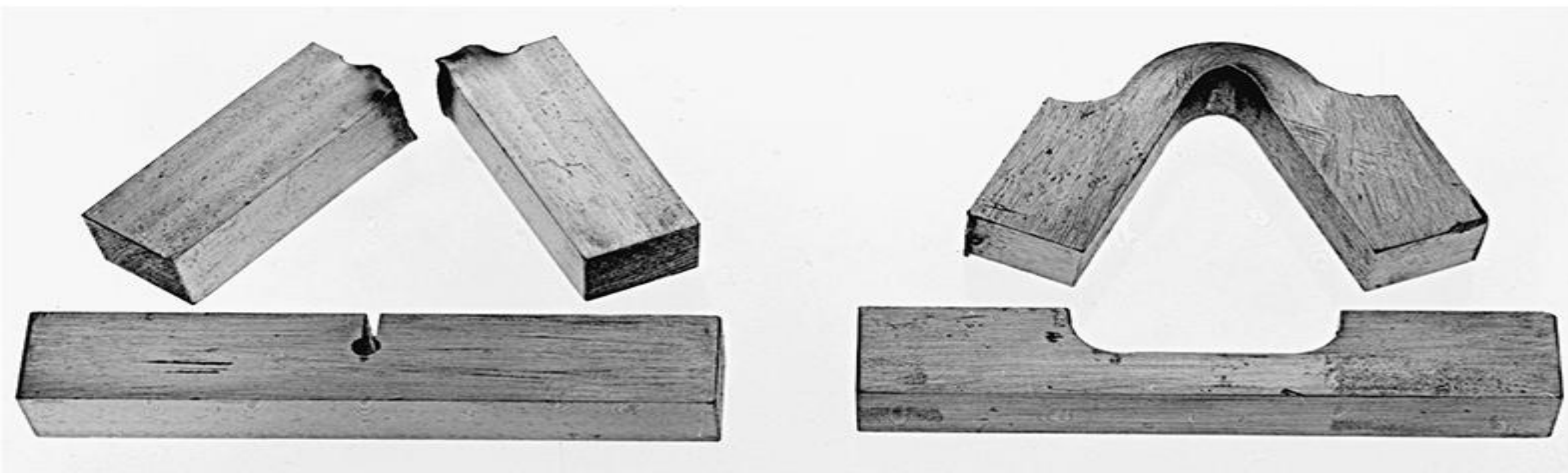
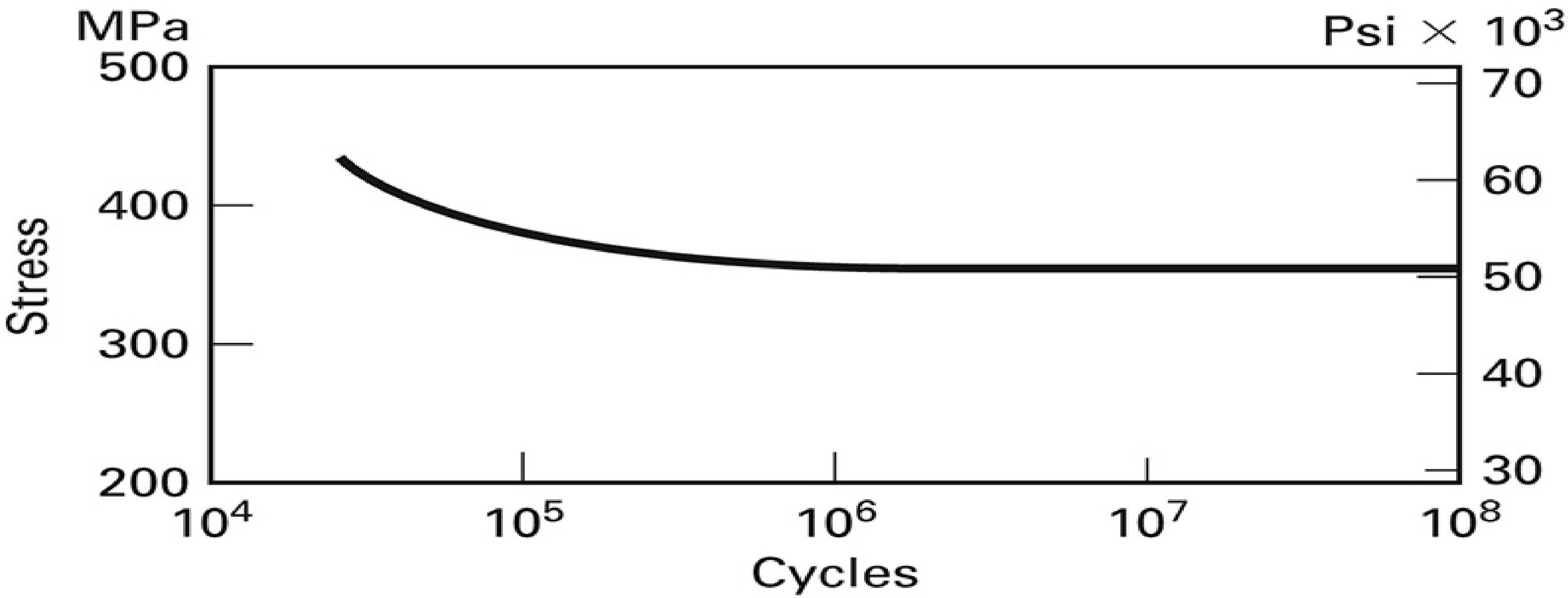


(a) (b)



S-N CURVE SHOWING AN ENDURANCE LIMIT



Fatigue Failures

- Fatigue resistance is sensitive to sharp corners, surface cracks, gouges, etc.
- Fatigue life can be affected by changes in the environment (corrosion)
- Residual stresses can negatively impact fatigue life
- Crack growth continues with each successive application of the load until failure

Fracture Toughness

- All materials contains flaws or defects
- Material defects:
  - Pores
  - Cracks
  - Inclusions
- Manufacturing or Design defects
  - Abrupt section changes
  - Excessively small fillets
  - Small holes

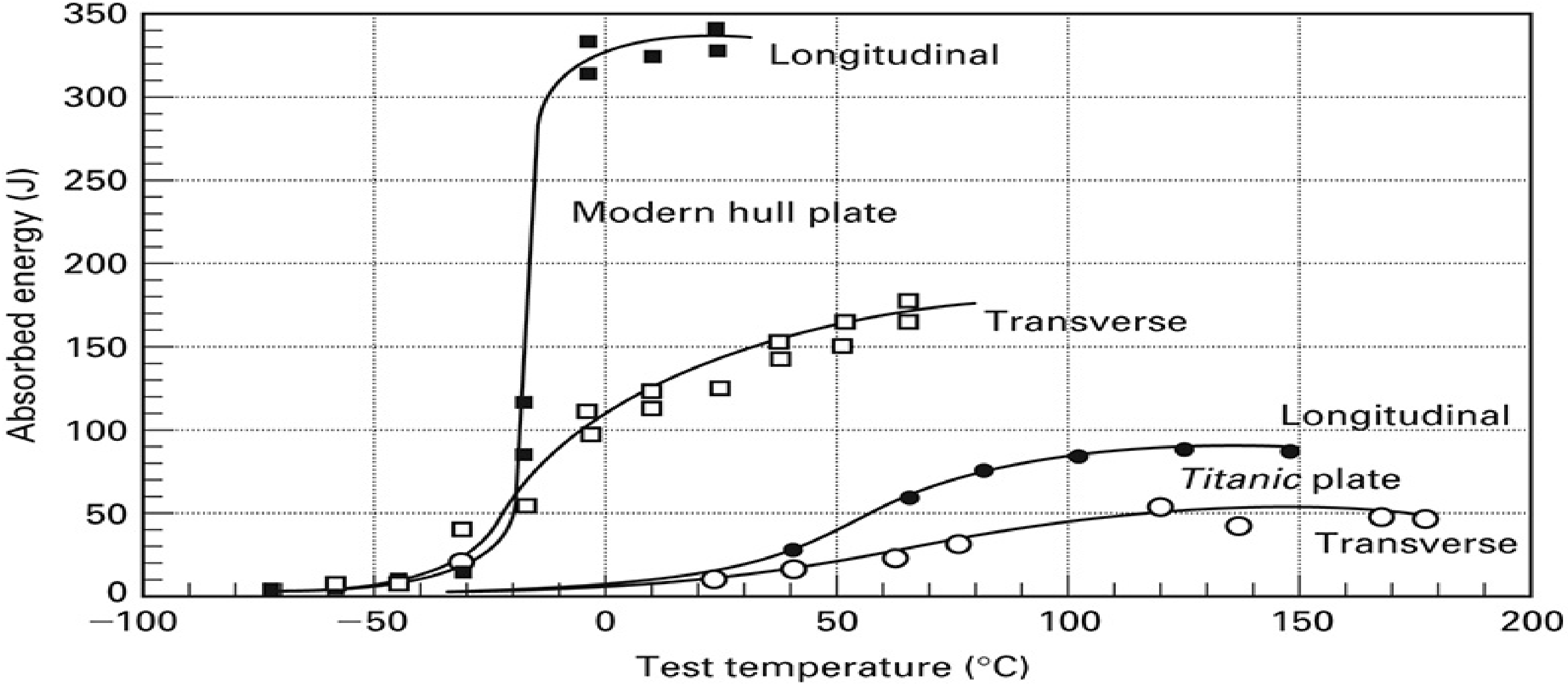
Fracture Toughness

- Fracture toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present.
- If a material has a large value of fracture toughness it will probably undergo ductile fracture.
- Brittle fracture is very characteristic of materials with a low fracture toughness value.

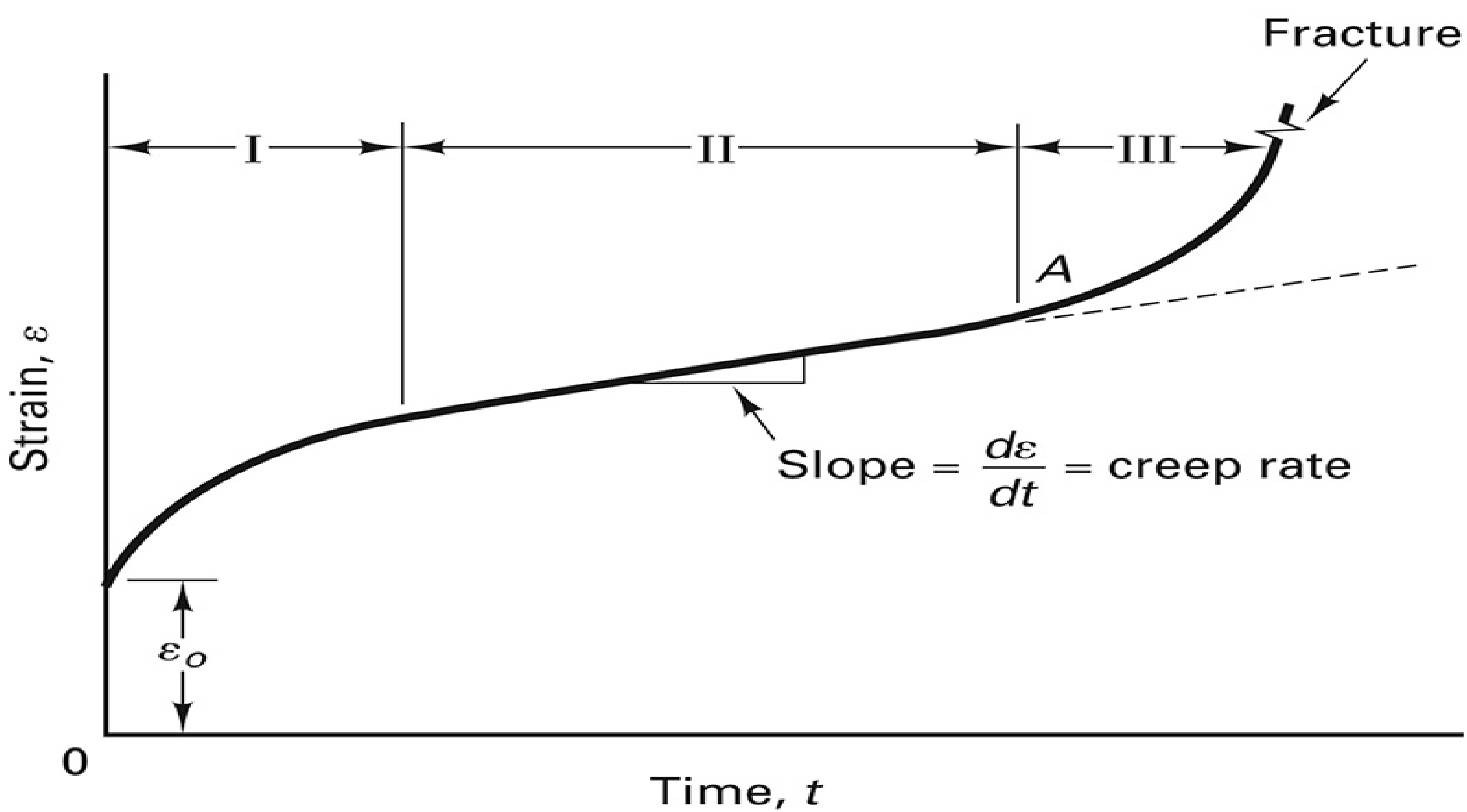
Fracture Mechanics

- Identify the conditions under which defects will grow
  - Size of the largest or most critical flaw
  - Applied stress
  - Fracture toughness
- Dormant defects are those whose size remains unchanged through the lifetime of the part
- Dynamic defects change through the life of the part

NOTCH TOUGHNESS IMPACT DATA

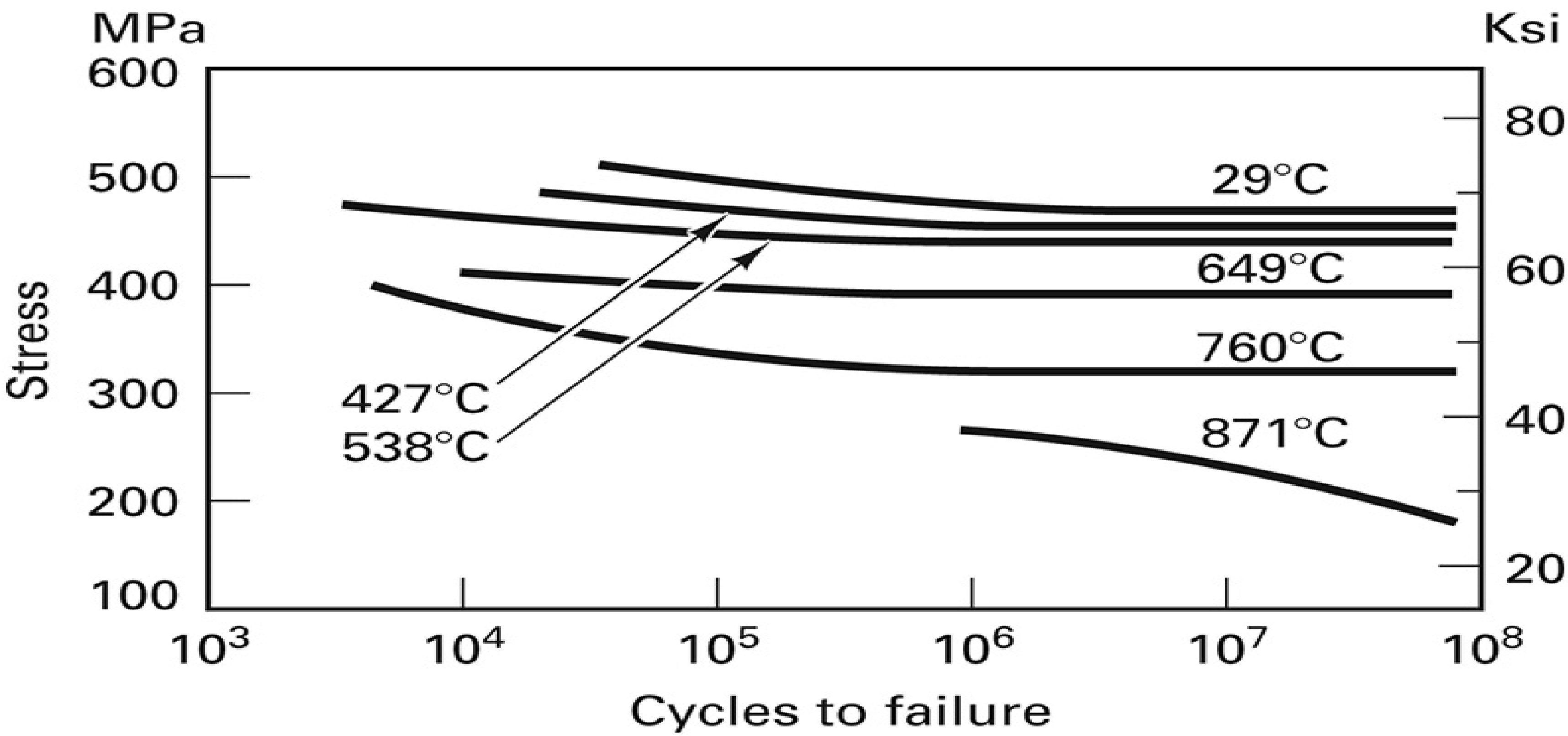


CREEP CURVE

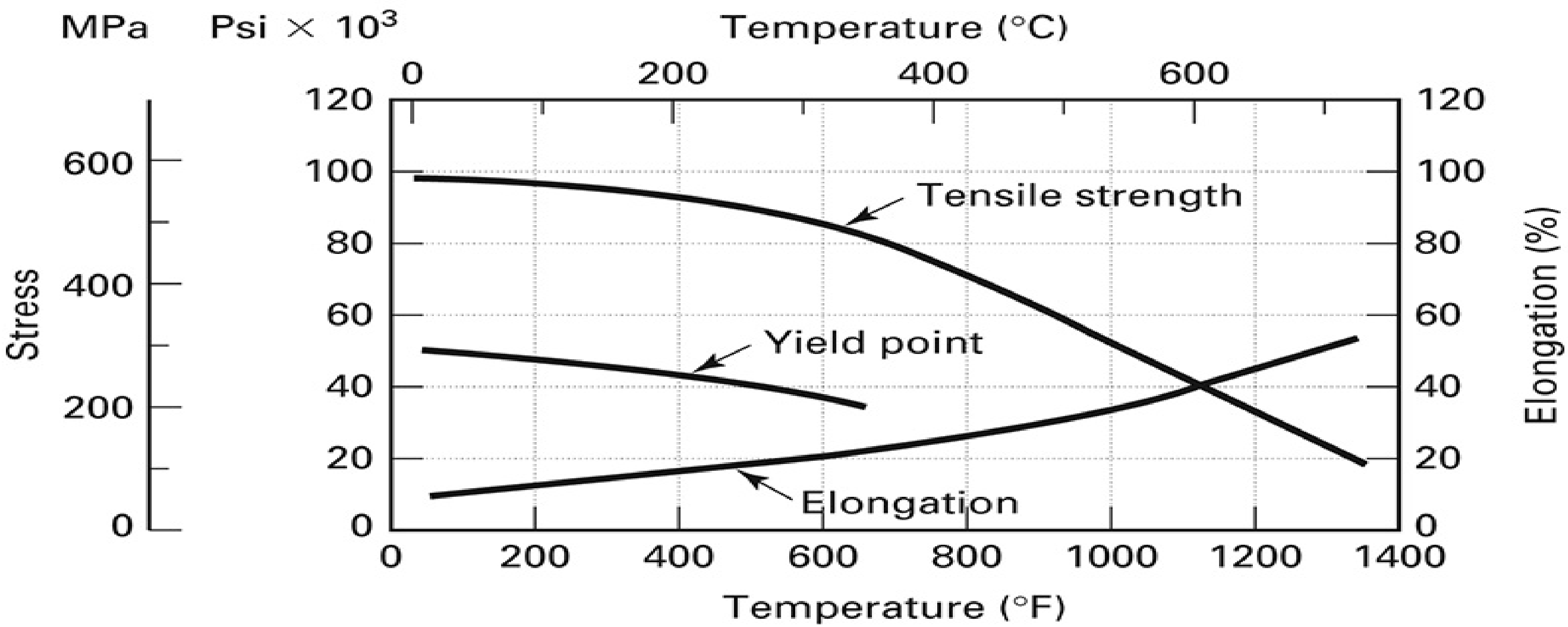


Fracture
I
II
III
A
Strain, ε
Slope = $\frac{d\varepsilon}{dt}$ = creep rate
ε_o
0
Time, t

FATIGUE STRESS AT VARIOUS TEMPERATURE



TEMPERATURE EFFECT ON TENSILE PROPERTIES



2.5 Machinability, Formability, and Weldability

- Machinability,
- Formability-, Capability of a material to be shaped by plastic deformation.
- Weldability-suitability of a metal to be welded under specified conditions

MACHINABILITY

- the ease with which a metal can be machined to an acceptable surface finish.
- Require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much;
- Such materials are said to be **free machining**.

MACHINABILITY

- Machinability can be based on the measure of how long a tool lasts.
- Higher specific energies equal lower machinability
- The surface finish is sometimes used to measure the machinability of a material.
- The surface finish is sometimes used to measure the machinability of a material. Soft, ductile materials tend to form a built up edge

SUMMARY

- Most important properties determined material integrity
- Techniques for properties determination are given.