CIVE.3110 Engineering Materials Laboratory
Fall 2017

Tensile/Tension Test
– Fundamentals –

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Outline

- Introduction
- Definition – Terminologies
- Theoretical basis
- Experimentation
  - Standards
  - Specimens
  - Equipment
  - Procedure
- Tasks

Introduction

- *Q: Why do civil engineers test materials?*
  - Material properties indicate the performance of engineering structures.
  - True material properties must be experimentally obtained/ developed
- In design, mechanical properties such as elastic modulus and yield strength are important in order to resist permanent deformation under applied stresses. Thus, the focus is on the elastic properties.
- In manufacturing, the goal is to apply stresses that exceed the yield strength of the material so as to deform it to the required shape. Thus, the focus is on the plastic properties.

Introduction

- *Q: Why do civil engineers test the **tensile** behavior of materials?*
  - Materials behave/fail differently under various stress states (e.g., compression, tension, flexural, torsion). → *Compressive property cannot be used to predict tensile property.*
  - To understand how materials perform under tension → *Service condition*
  - To predict how materials fail under tension → *Ultimate condition*
  - To develop quantitative measures/parameters for design and manufacturing purposes

Introduction

- *Q: How do different materials fail under tension?*
  – Brittle failure: Ceramics (e.g., concrete)
  – Ductile failure: Metals (e.g., steel, aluminum)

- Engineering materials can be very different.
  – Concrete’s tensile strength is ~1/10 of its compressive strength.
  – Steel’s tensile strength is 2~3 times of its compressive strength.
  – Timber’s tensile strength is ~3 times of its compressive strength.

- Result of tensile/tension test
  – Load vs. elongation (P-δ) curve
  – Stress vs. strain (σ-ε) curve

(Q: How to convert a P-δ curve to a $\sigma-\varepsilon$ curve?)

Introduction

- Destructive testing changes the dimensions or physical and structural integrity of the specimen.
  → Specimens are essentially destroyed during the test (e.g., tensile, compression, shear and Rockwell hardness).
- Non-Destructive testing does not affect the structural integrity of the sample.
  → A test that does not affect the specimen in any way (e.g., weighing, measurements).

→ *To understand how materials fail, destructive testing is necessary.*

→ *Test result is represented by load-deformation curve.*

(Q: How to convert a load-deformation curve to a stress-strain curve?)

Definition

- **Load** (force) – Applied force either pounds (lb) or Newtons (N).

- **Stress** – The intensity of the internally-distributed forces or components of forces that resist a change in the form of a body. Commonly measured in units dealing with force per unit area, such as pounds per square inch (psi or lb/in^2) or Newtons per square meter (N/m^2 or Pascals or Pa). Three basic types of stress are tension, compression, and shear. The first two, tension and compression, are called direct stresses.

- **Strain** – Unit change of dimension due to the application of a corresponding stress in a specified direction. Strains are in the unit of inch/inch or meter/meter (both dimensionless).

- Engineering stress-strain vs. true stress-strain

Definition

- Engineering stress-strain (defined relative to the original area and length) –
  - The engineering stress (σ_e) at any point is defined as the ratio of the instantaneous load or force (F) and the original area (A_0).
  - The engineering strain (e) is defined as the ratio of the change in length (L-L_0) and the original length (L_0).

$$\sigma_e = \frac{F}{A_0} \qquad\qquad e = \frac{L - L_0}{L_0}$$

- True stress-strain (defined relative to the true/varying area and length) –
  - The true stress (σ) uses the instantaneous or actual area of the specimen at any given point, as opposed to the original area used in the engineering values.
  - The true strain (ε) is defined as the instantaneous elongation per unit length of the specimen.

$$\sigma = \frac{F}{A} \qquad\qquad \varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0}$$

Definition

- Engineering stress and strain are different from true stress and strain.
  - The true stress is the load divided by the true area, which continues to be smaller by the tensile load.
  - The true stress continues to increase to the point of fracture, while the engineering stress decreases to the point of fracture due to the increasing load and the constant cross-sectional area.

- Conversion between engineering stress-strain to true stress-strain:

$$\sigma = \sigma_e (1 + e)$$

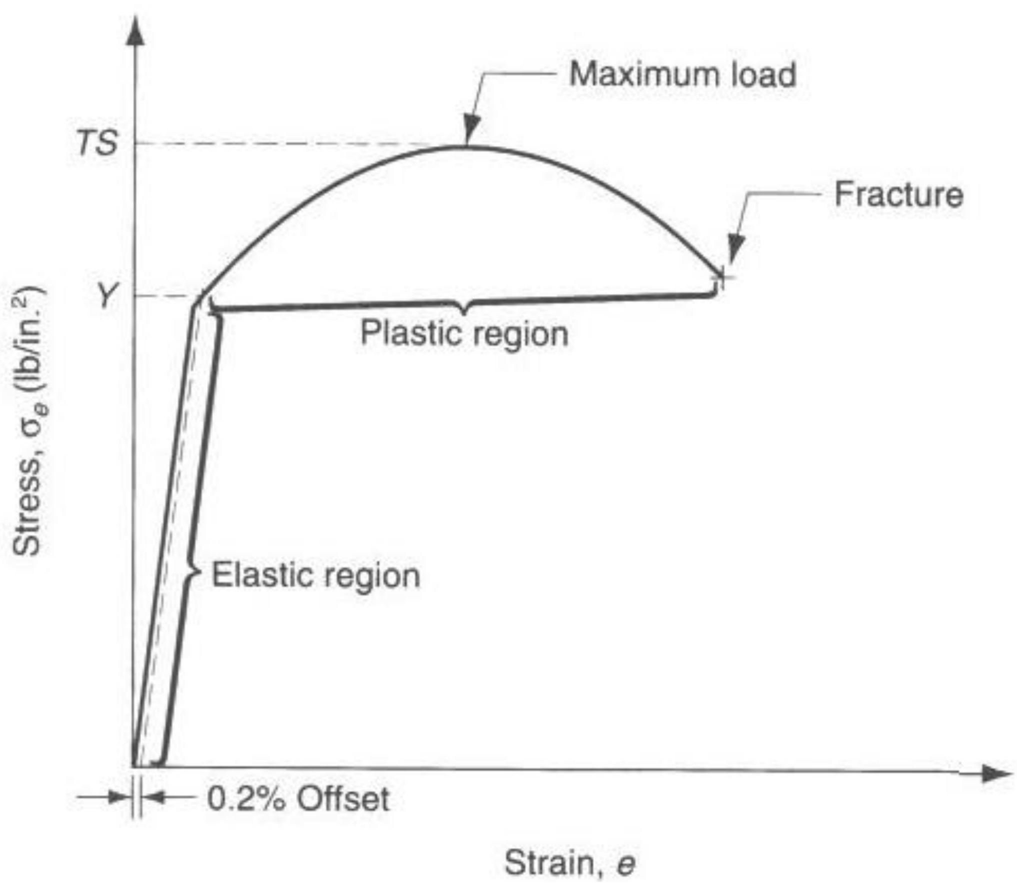
$$\varepsilon = \ln(1 + e)$$

→ *For a given value of the load and elongation, the true stress is higher than the engineering stress, while the true strain is smaller than the engineering strain.*

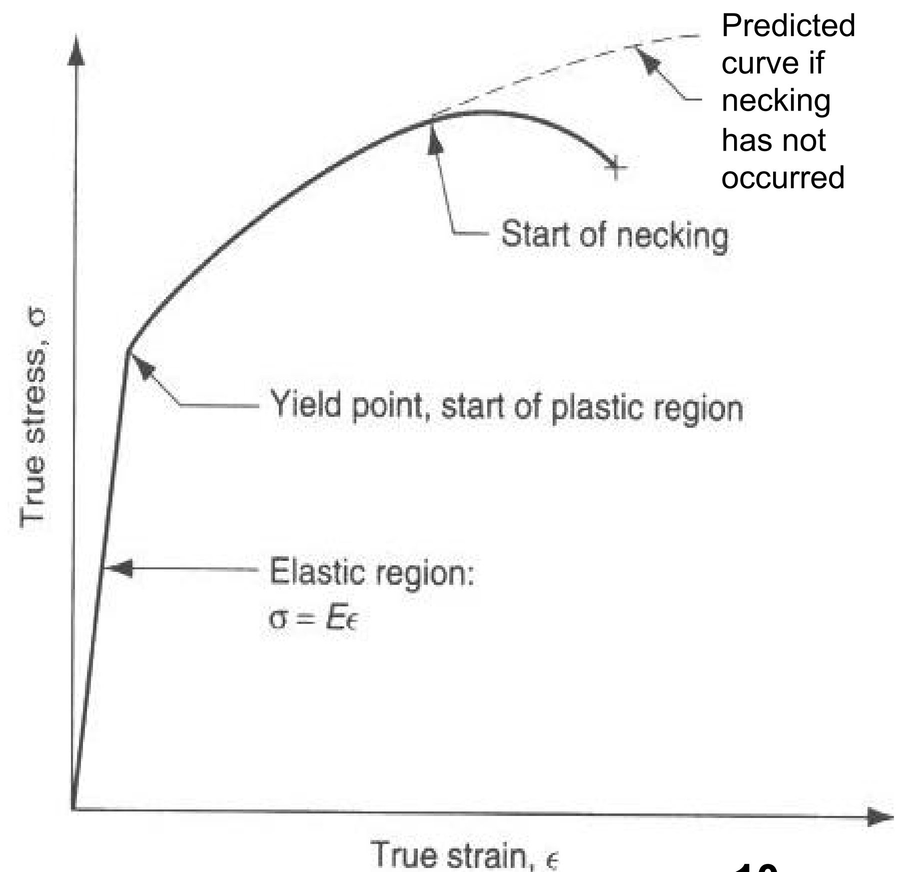
Definition

- Engineering stress-strain curve vs. true stress-strain curve –

Engineering stress-strain curve



True stress-strain curve



Definition

- **Percent Reduction in Area** (dimensionless) – The difference between the original and final cross-sectional areas of a test piece, expressed as a percentage.

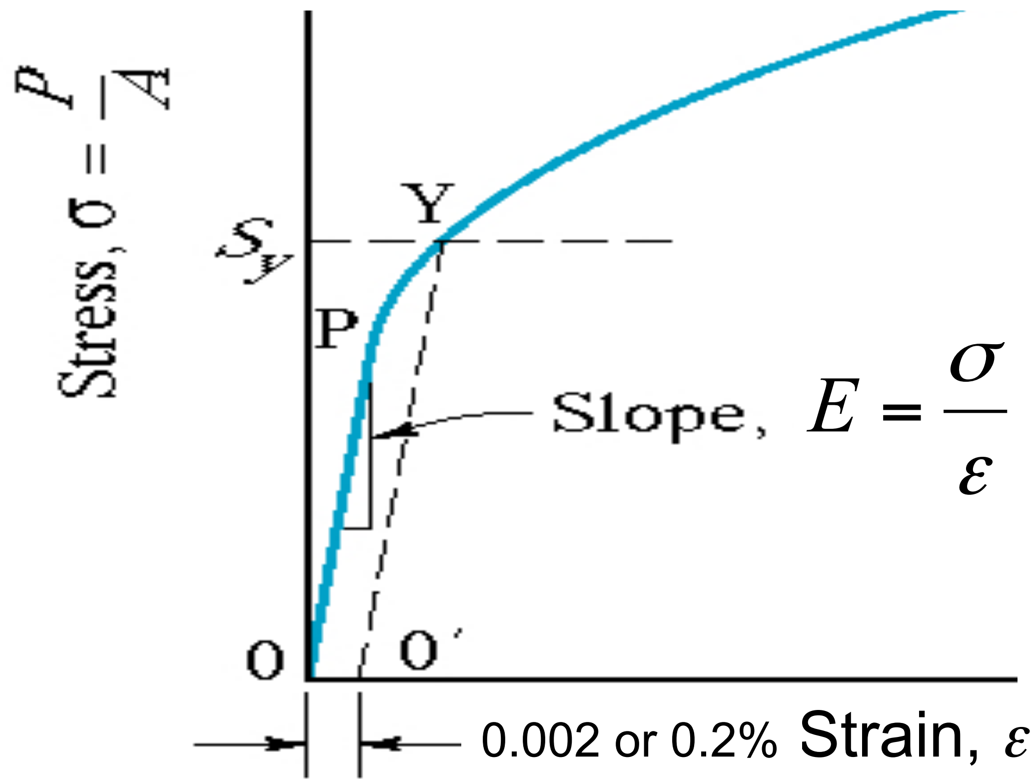
$$AR = \frac{A_0 - A_f}{A_0}$$

- **Percent Elongation** (strain or dimensionless) **–** The total percent strain that a specimen develops during testing.

$$EL = \frac{L - L_0}{L_0}$$

Definition

- **Yield point (Y)** – The point where plastic region starts → 0.2% offset
- **Proportional limit (P)** – The point where linear elastic region ends

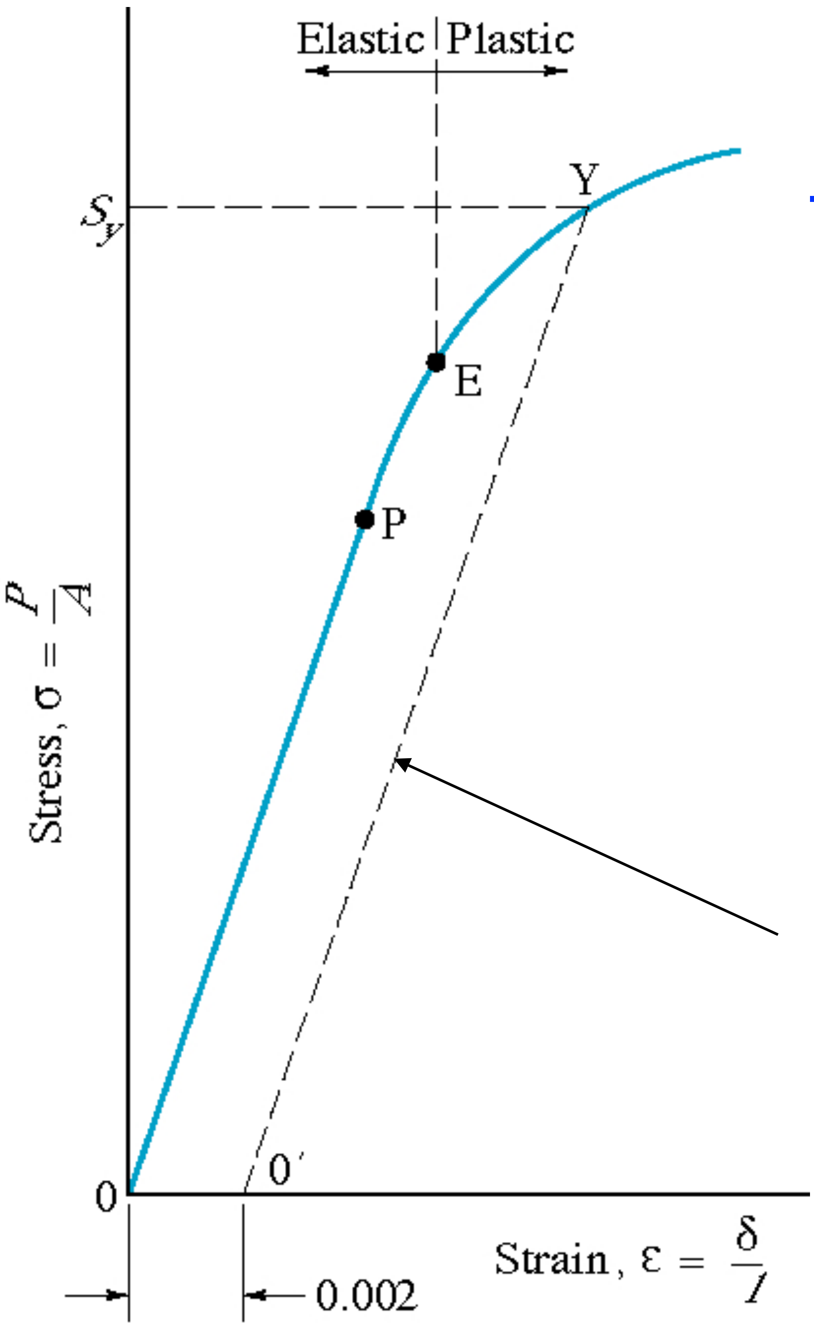


Linearity vs. Elasticity

- Linear elastic
- Nonlinear elastic
- Linear plastic
- Nonlinear plastic

Definition

- **Offset Yield Strength** –
- Defining the yield stress as the point separating elastic from plastic deformation is easier than determining that point.
- The elastic portion of the curve is not perfectly linear, and microscopic amounts of deformation can occur.
- As a matter of practical convenience, the yield strength is determined by constructing a line parallel to the initial portion of the stress-strain curve but offset by 0.2% from the origin.



Definition

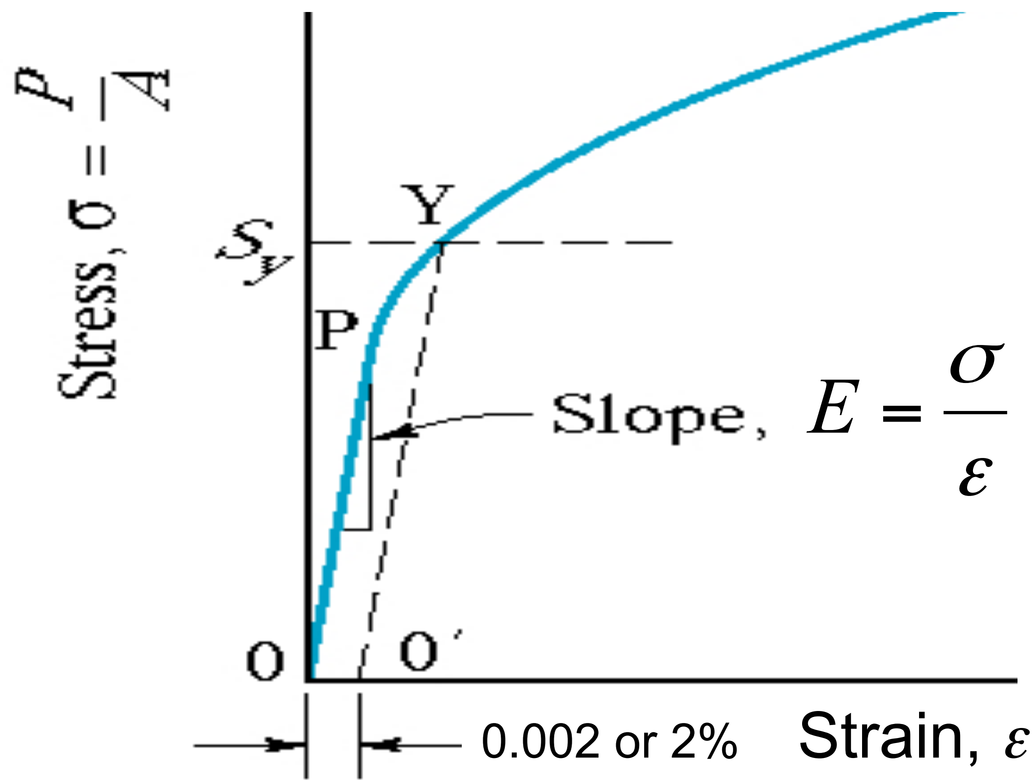
- *0.2% Offset Yield Strength* *(S_f)* / Stress (σ_f) –

Typical stress-strain behavior for ductile metal showing elastic and plastic deformations and yield strength S_y.

Notice that it is a straight line

Definition

- **Modulus of Elasticity** (stress) - Also known as Young's modulus; calculated by finding the slope of the stress-strain curve for a given material within the range of its linear proportionality between stress and strain.

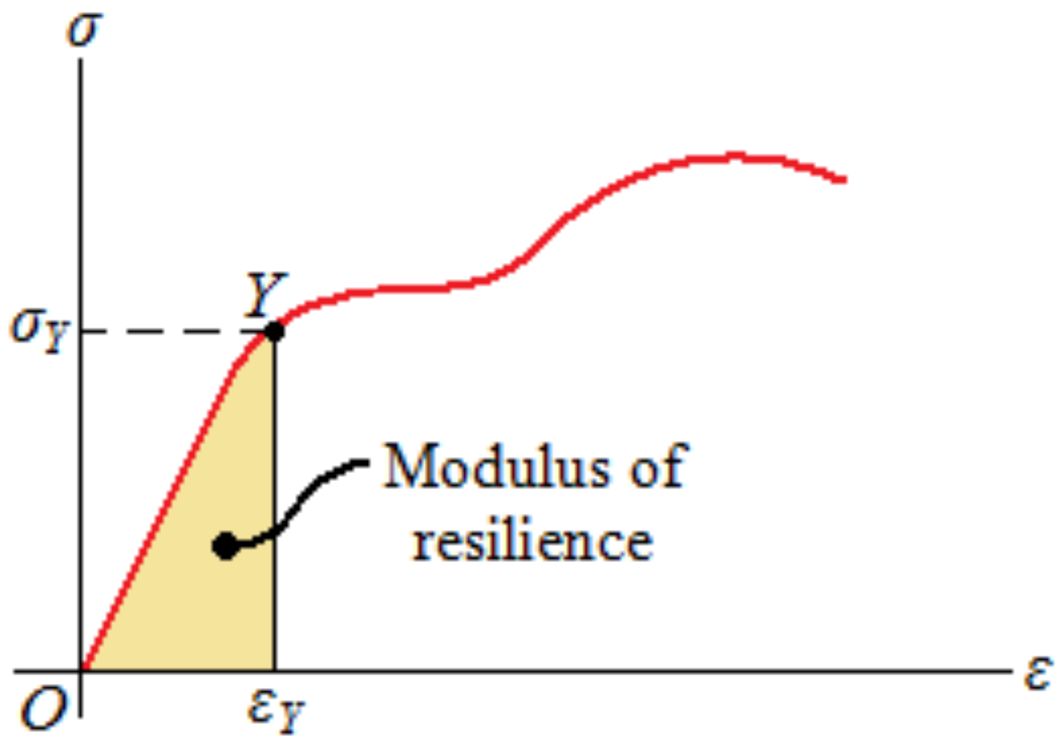


- Engineering stress and strain are "gross" measures:
- $\sigma = F/A \rightarrow \sigma$ is the average stress ≠ local stress
- $\varepsilon = \delta/L_o \rightarrow \varepsilon$ is average strain (engineering)

(Q: What is the unit of E?)

Definition

- **Modulus of Resilience** (energy): the area under the linear response (before yielding) of the curve, measuring the stored elastic energy. (Unit: stress; ; inch-pound-force per cubic inch or (Joule per cubic metre)



Definition

- **Ductility** (deformation) – The percent elongation of the specimen due to plastic deformation, neglecting the elastic stretching (the broken ends snap back and separate after failure). For metal forming processes, increasing the ductility increases the material formability. It can also be measured by the percent reduction in area

$$\text{Ductility (\%)} = 100\% \times (L_f - L_o)/L_o \quad \text{(Unit: length per length)}$$
$$= 100\% \times (A_f - A_o)/A_o \quad \text{(Unit: area per area)}$$

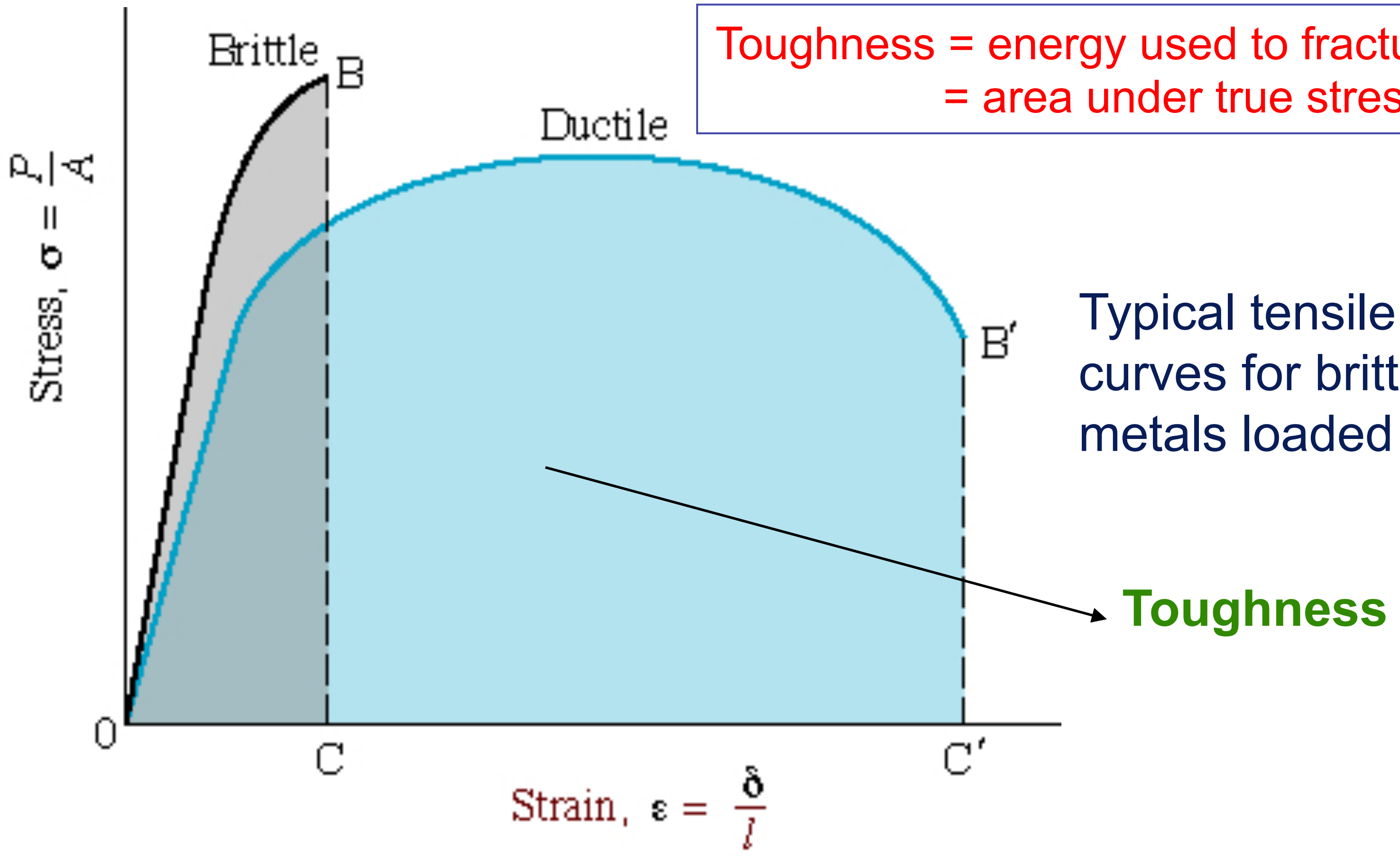
- Ductility measures how much the material can be stretched before fracture.
  - High ductility: platinum, steel, copper
  - Good ductility: aluminum
  - Low ductility (brittle): chalk, glass, graphite

- In structural design, displacement ductility factor ($\mu = u_f / u_y$) is usually used.

Definition

- **Toughness** (energy) – The total area under the curve, which measures the energy absorbed by the specimen in the process of breaking. (Unit: stress; inch-pound-force per cubic inch or (Joule per cubic metre)

Toughness = energy used to fracture
= area under true stress-strain curve



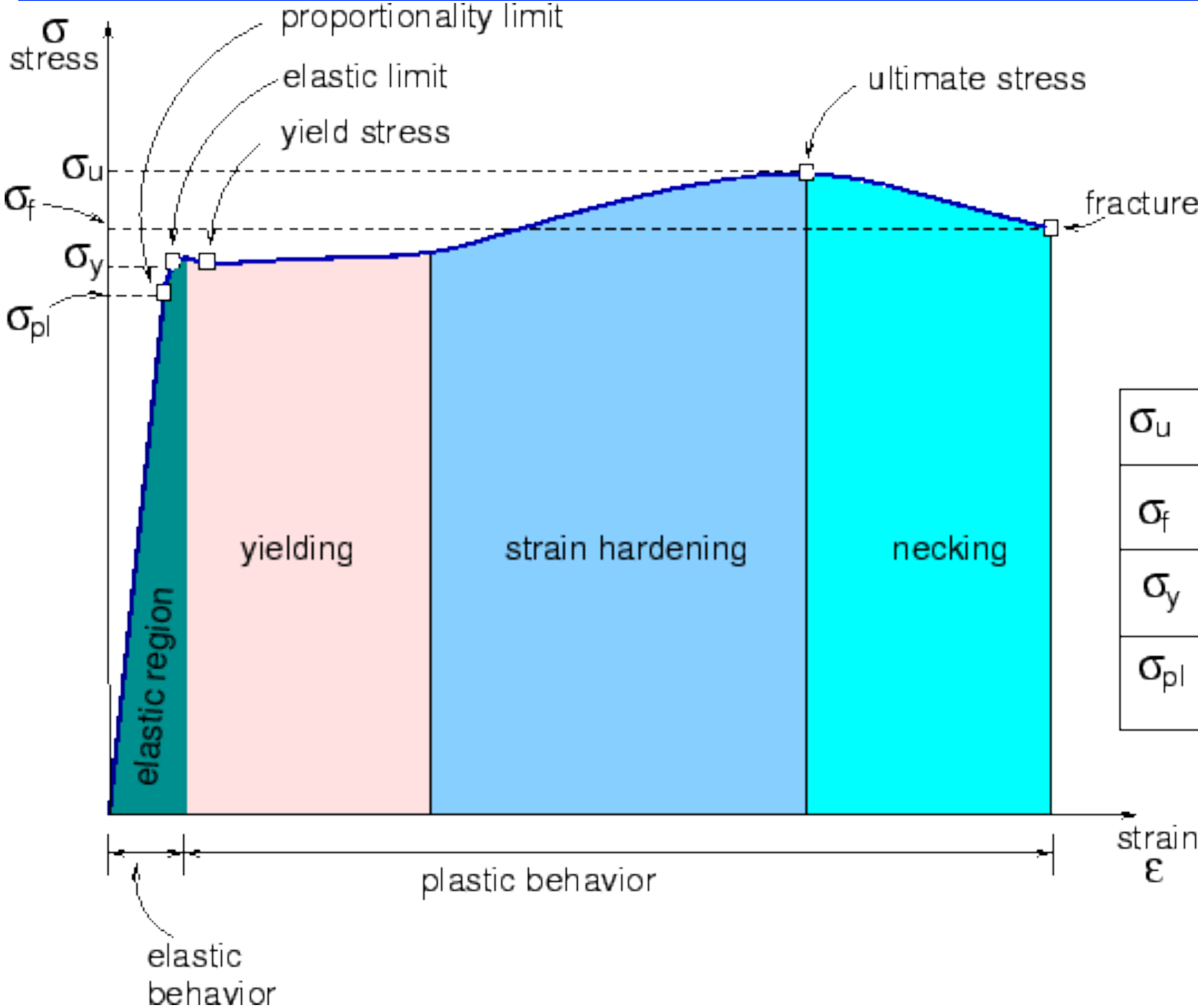
Typical tensile stress-strain curves for brittle and ductile metals loaded to fracture.

Definition

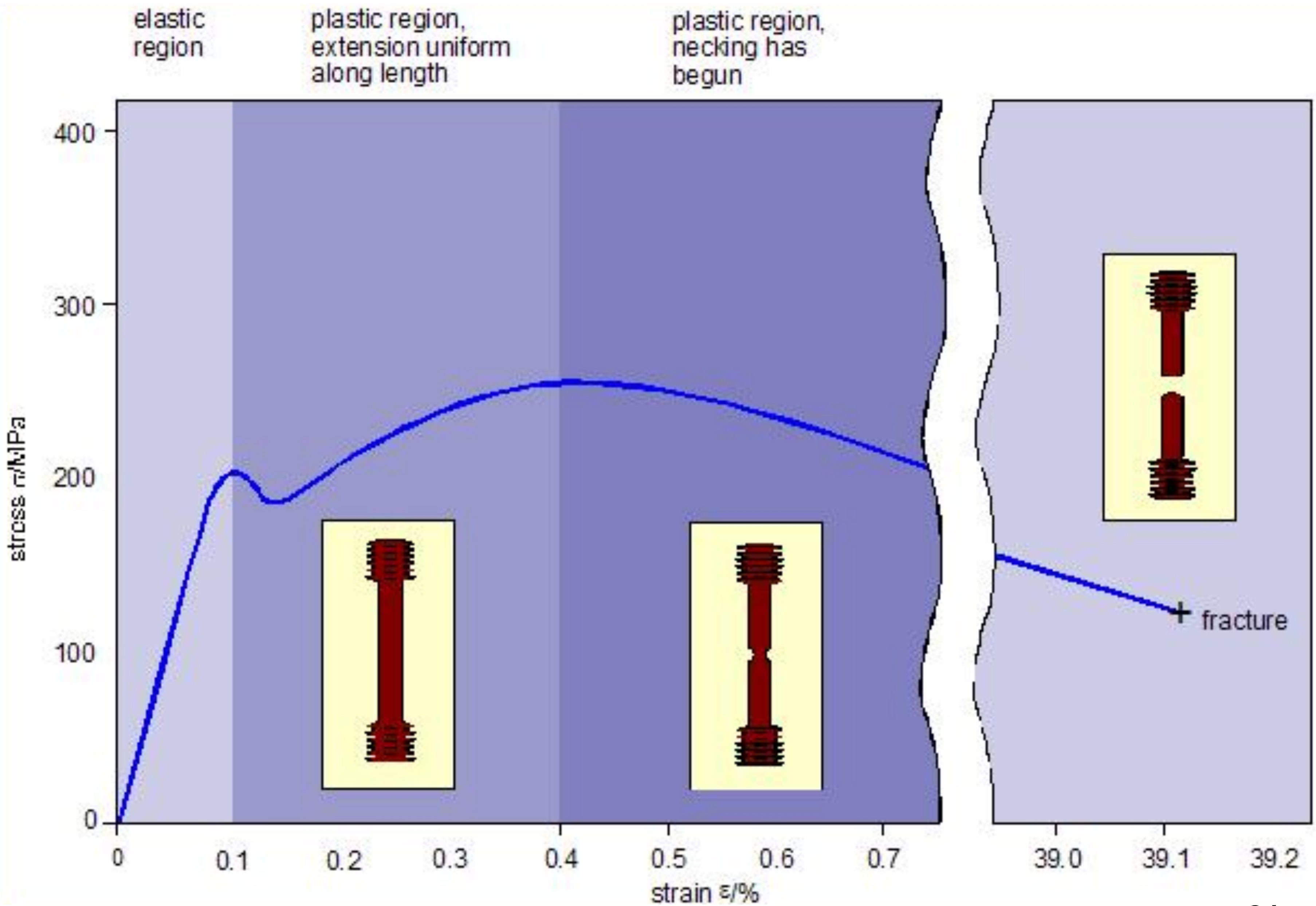
- **Proportional Limit** (σ_{pl}) - The greatest stress a material can develop without deviating from linearity between stress and strain. Otherwise stated, the greatest stress developed in a material within its elastic range.
- **Elastic Limit/Yield Point** (σ_{el}) – The greatest amount of tensile stress a material can develop without taking a permanent set.
- **Yield Strength** (S_y,σ_y) – The stress at which a material exhibits a specified limiting permanent set (typically 0.2% offset = 0.002 in/in).
- **Fracture/Breaking Strength** (S_f, σ_f) – The stress at which a material fails or factures, usually less than the maximum tensile strength because necking reduces the cross-sectional area..
- **Ultimate Strength** (S_u, σ_u) – The maximum tensile stress that a material is capable of developing during a test.

(Note the difference between strength and stress!)

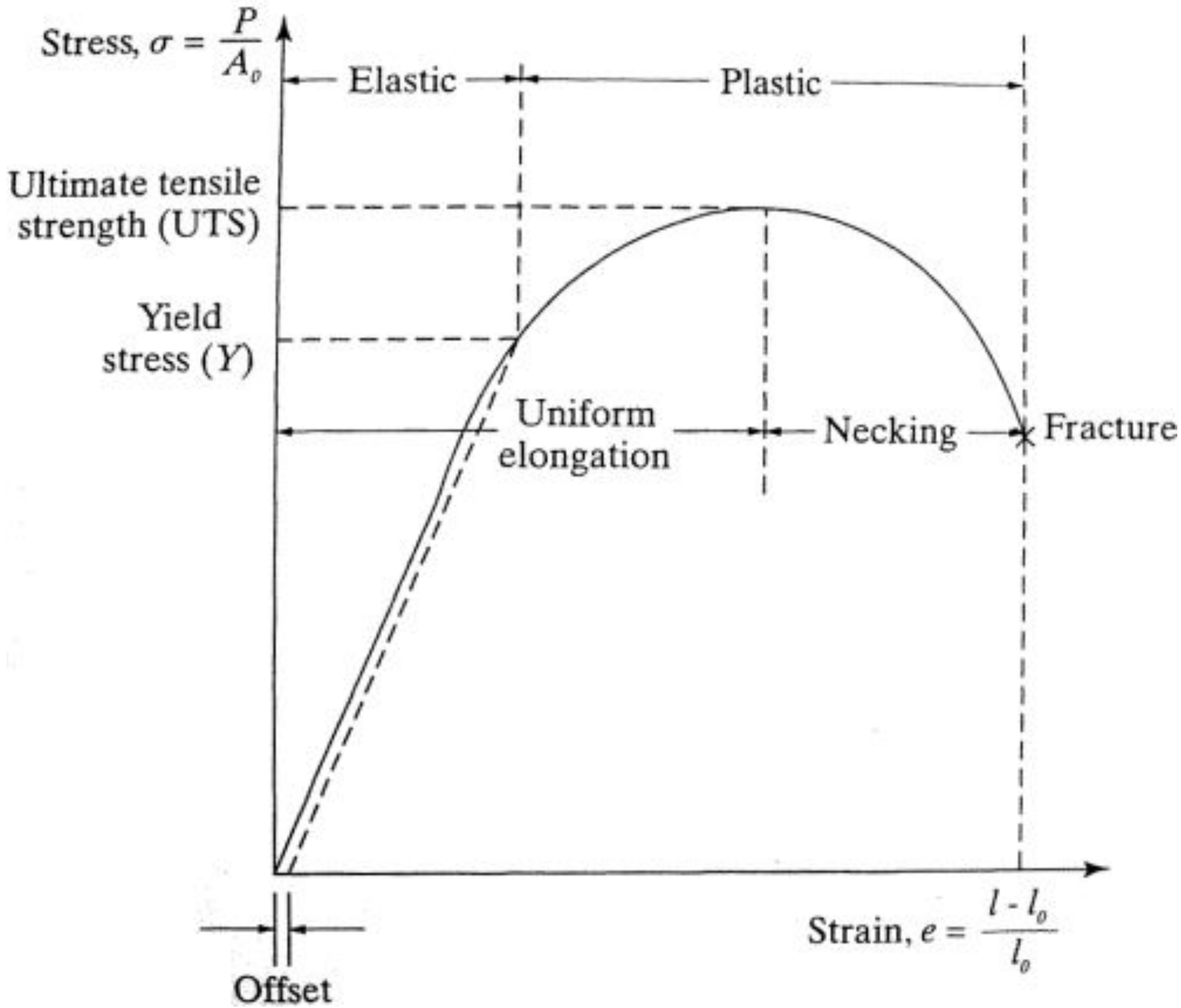
Definition



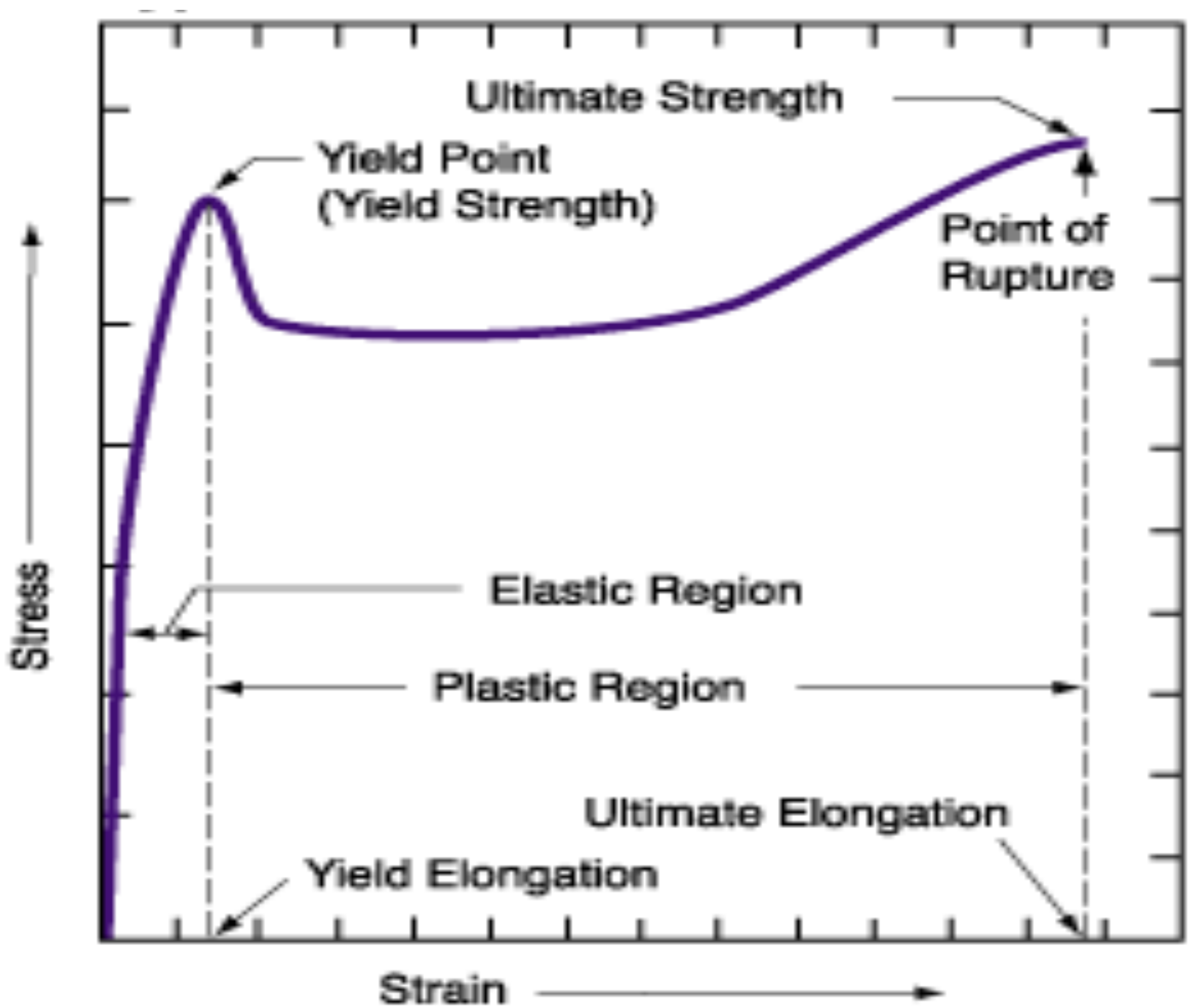
σ_u	Ultimate stress
σ_f	Fracture stress
σ_y	Yield stress
σ_{pl}	Proportionality limit


elastic region
plastic region, extension uniform along length
plastic region, necking has begun
fracture
stress σ/MPa
strain ε/%
0
100
200
300
400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
39.0
39.1
39.2

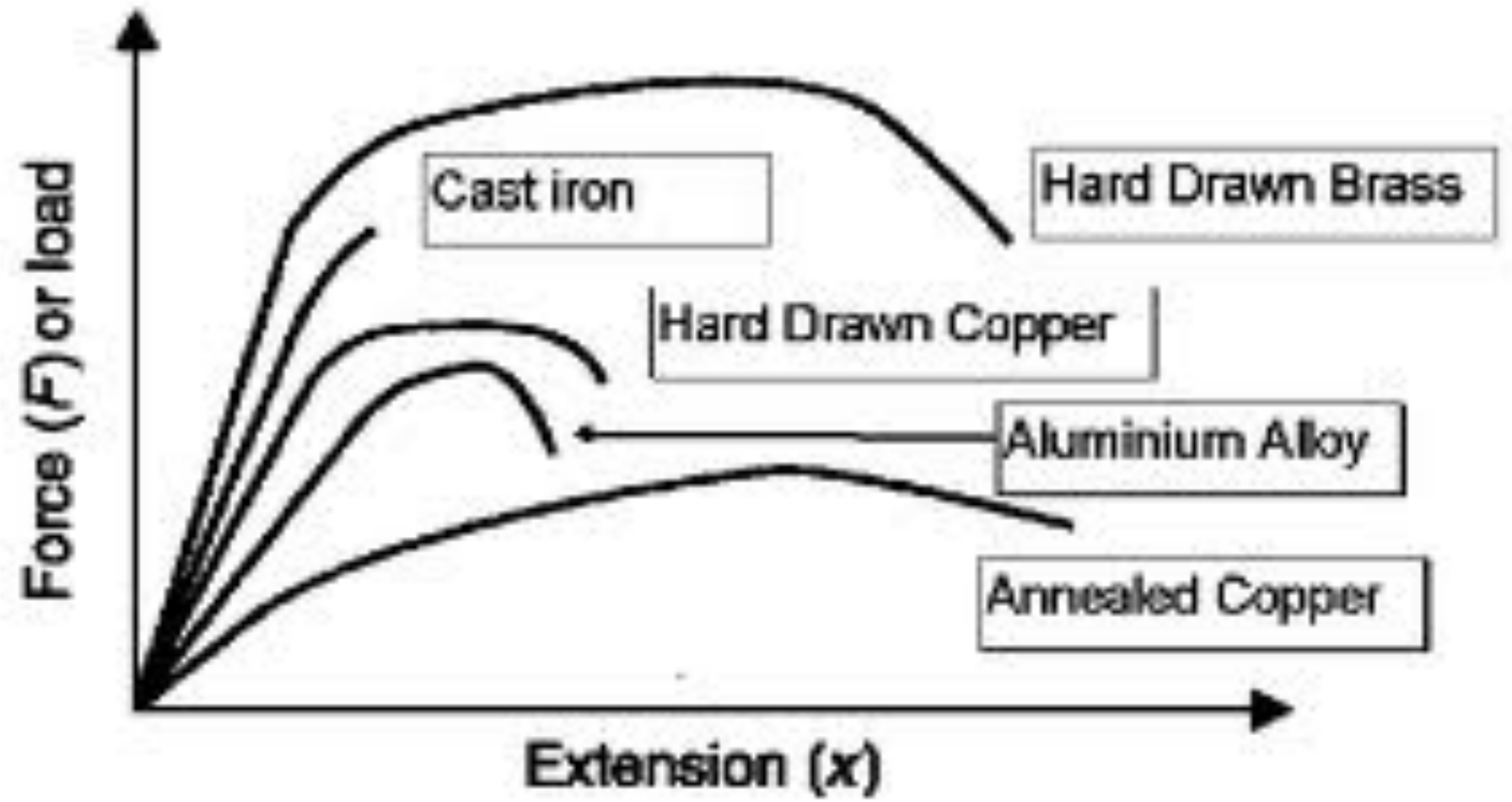
Stress-Strain Curve



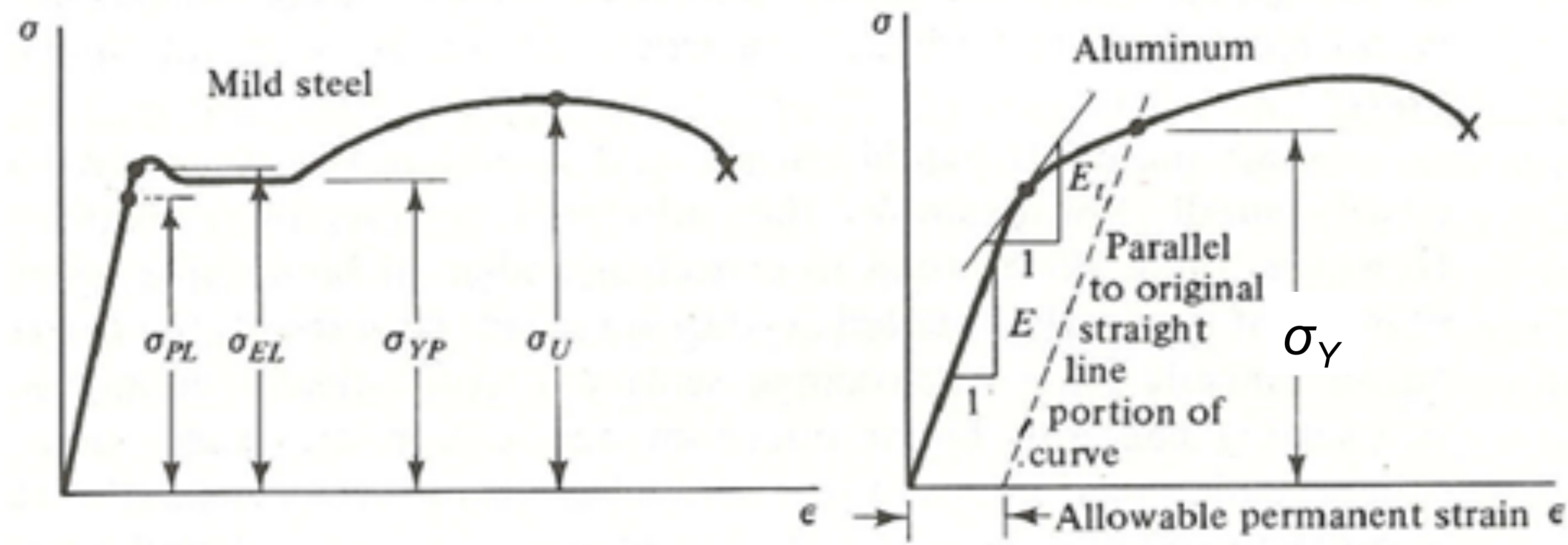
Stress-Strain Curve



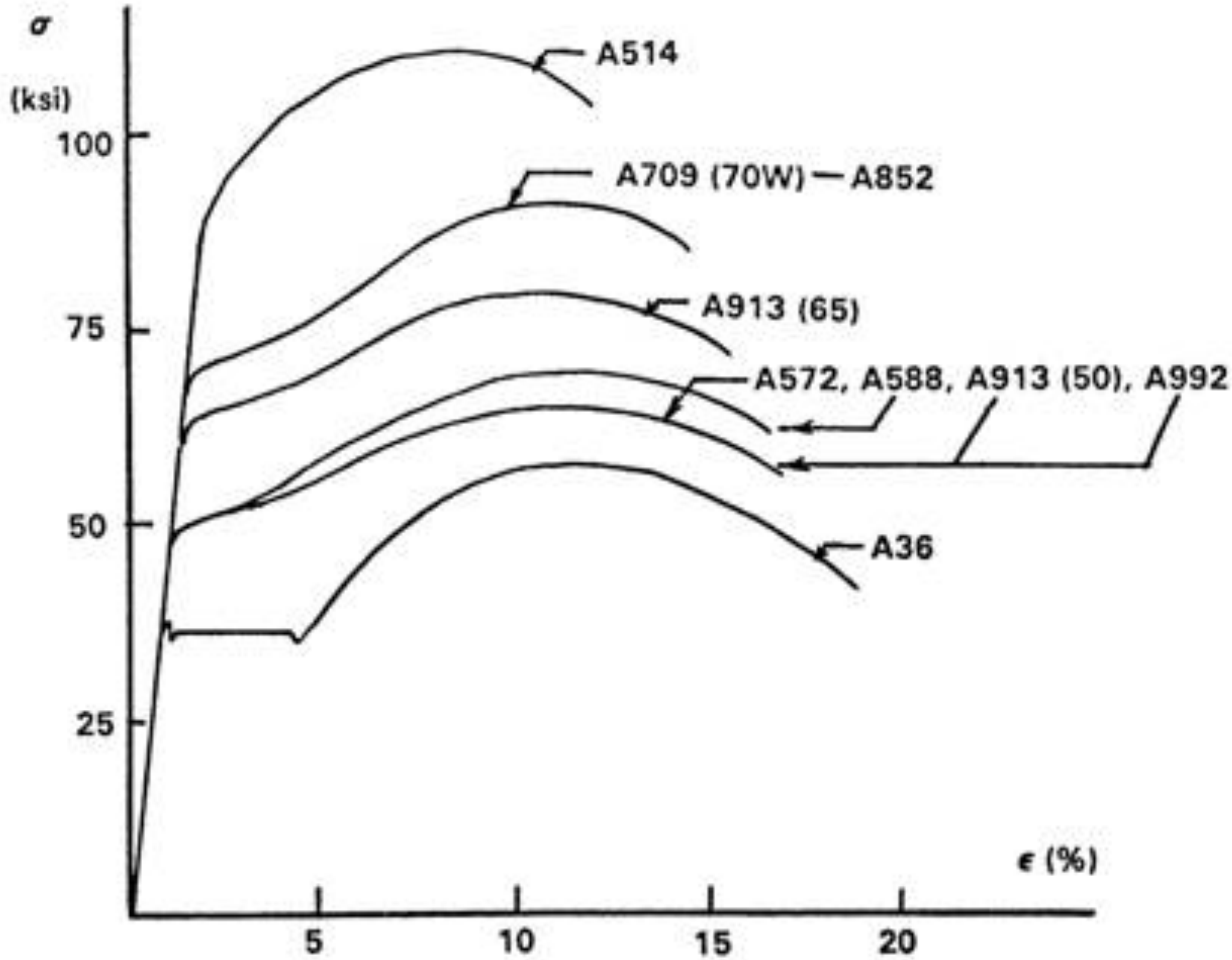
Stress-Strain Curve



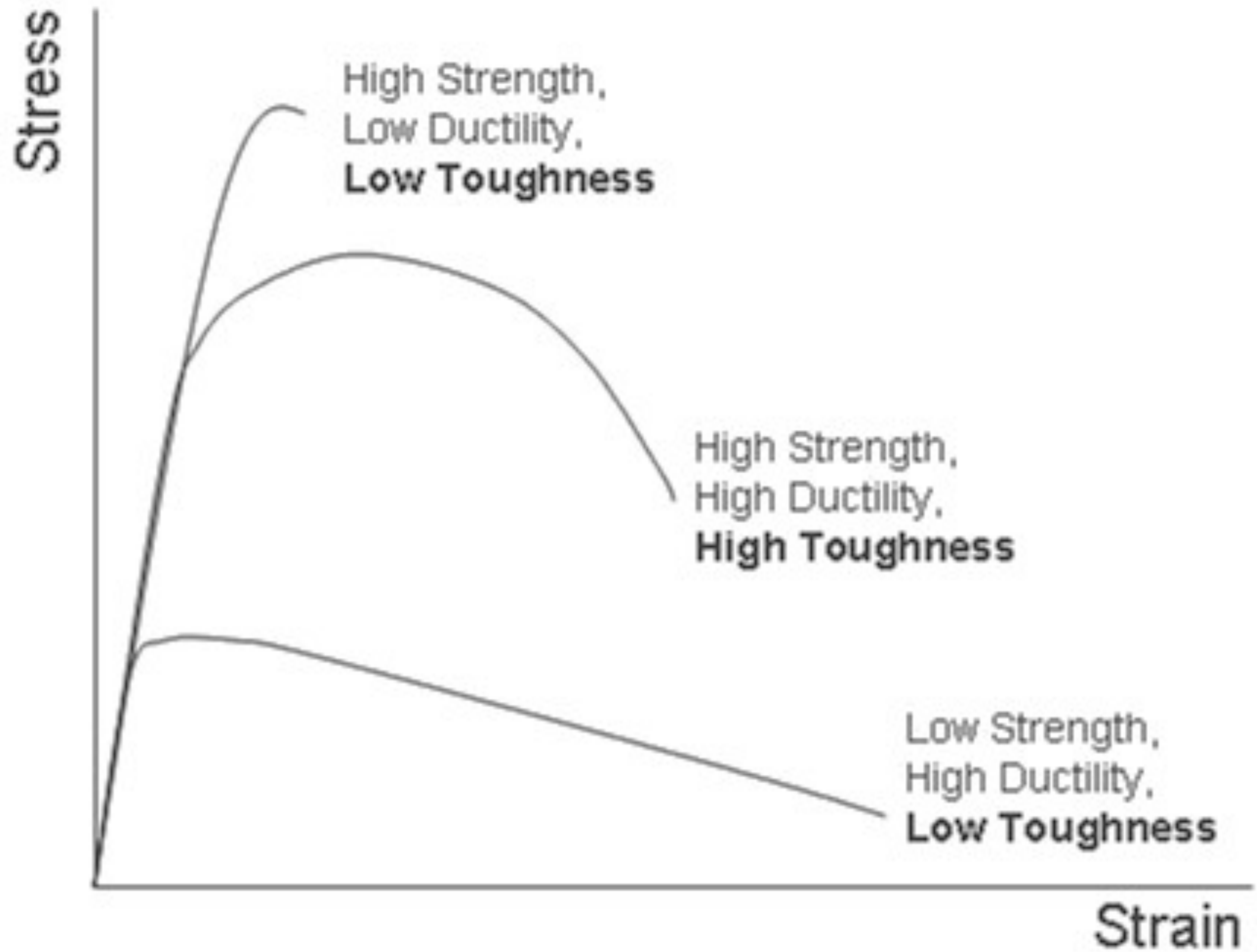
Stress-Strain Curve



Stress-Strain Curve



Stress-Strain Curve



Experimentation

- Objectives:
  - Develop an understanding of the basic material properties from the perspective of manufacturing and metal forming.
  - Determine the material properties by conducting a uniaxial tensile test under **ASTM (American Society for Testing and Materials)** specifications.
- Standards: ASTM **E8** "*Standard Test Methods for Tension Testing of Metallic Materials*" and **B557** "*Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*" (See attachments)
- Specimens: Threaded-end specimens
- Equipment: IN*S*TRON Material Testing Machine Model 1332 (Southwick 122)

Experimentation

- **Extensometer** – The change in gage length is determined using an extensometer. An extensometer is firmly fixed to the machine or specimen and relates the amount of deformation or deflection over the gage length during a test.

- **Yielding** – While paying close attention to the readings, data points are collected until the material starts to yield significantly. This can be seen when deformation continues without having to increase the applied load. Once this begins, the extensometer is removed and loading continued until failure. Ultimate tensile strength and rupture strength can be calculated from this latter loading.

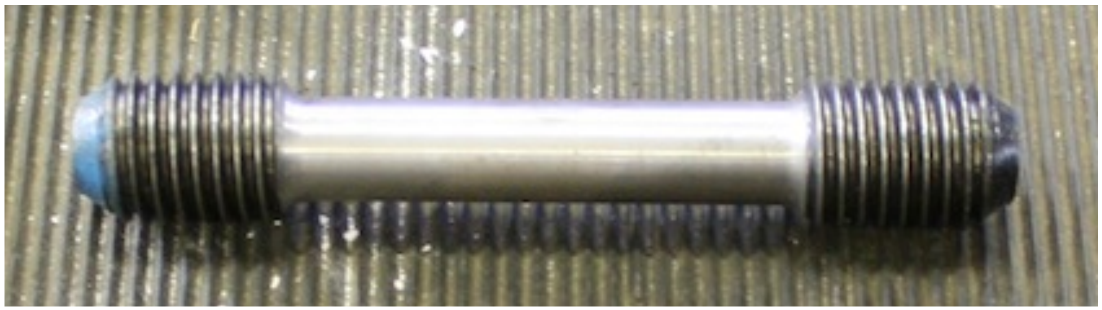
- **Stress-strain curve** – Once data have been collected, the tensile stress developed and the resultant strain can be calculated. Stress is calculated based on the applied load and cross-sectional area. Strain is the change in length divided by the original length.

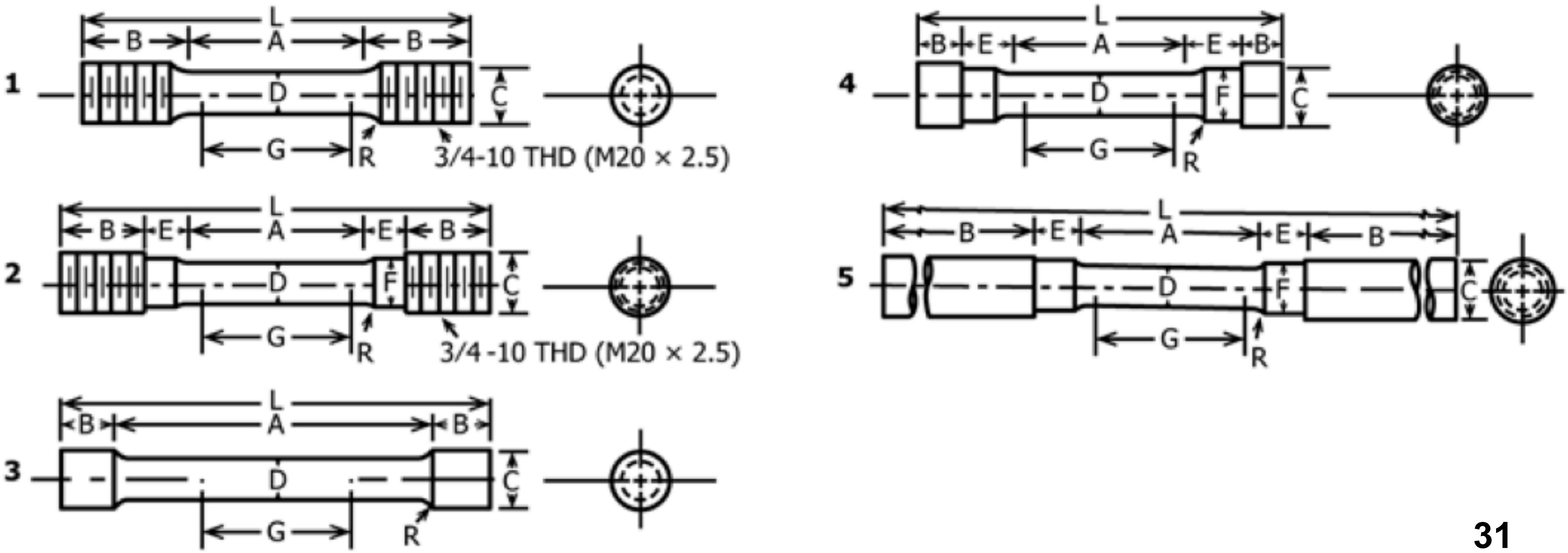
Standards

- ASTM standards for common tensile –
  - **E8** (metals) "*Standard Test Methods for Tension Testing of Metallic Materials*"
  - **B557** (metals/alloys) "*Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*"
  - **C496** (concrete) "*Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*"
  - C1006 (masonry) *"Standard Test Method for Splitting Tensile Strength of Masonry Units"*
  - D638 (plastics) "*Standard Test Method for Tensile Properties of Plastics*"
  - D2343 (fibers) "*Standard Test Method for Tensile Properties of Glass Fiber Strands, Yarns, and Rovings Used in Reinforced Plastics"*
  - D897 (adhesives) "*Standard Test Method for Tensile Properties of Adhesive Bonds*"
  - D412 (rubber) *"Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers— Tension"*

Specimens

- Specimen/test coupon (ASTM B8) –





Specimens

- Specimen/test coupon (ASTM B8) –

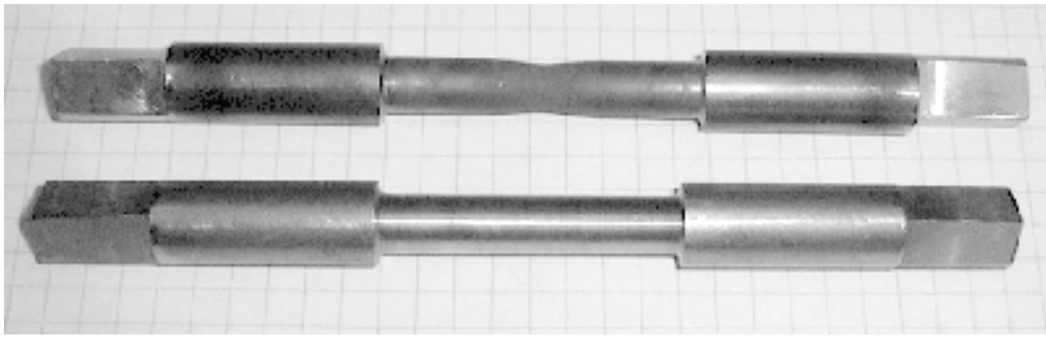
	Dimensions, in.				
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
G—Gage length	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005
D—Diameter (Note 1)	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010
R—Radius of fillet, min	3⁄8	3⁄8	1⁄16	3⁄8	3⁄8
A—Length of reduced section	2 1⁄4 , min	2 1⁄4 , min	4, approximately	2 1⁄4 , min	2 1⁄4 , min
L—Overall length, approximate	5	5 1⁄2	5 1⁄2	4 3⁄4	9 1⁄2
B—Length of end section (Note 2)	1 3⁄8 , approximately	1, approximately	3⁄4 approximately	1⁄2, approximately	3, min
C—Diameter of end section	3⁄4	3⁄4	23⁄32	7⁄8	3⁄4
E—Length of shoulder and fillet section, approximate	...	5⁄8	...	3⁄4	5⁄8
F—Diameter of shoulder	...	5⁄8	...	5⁄8	19⁄32

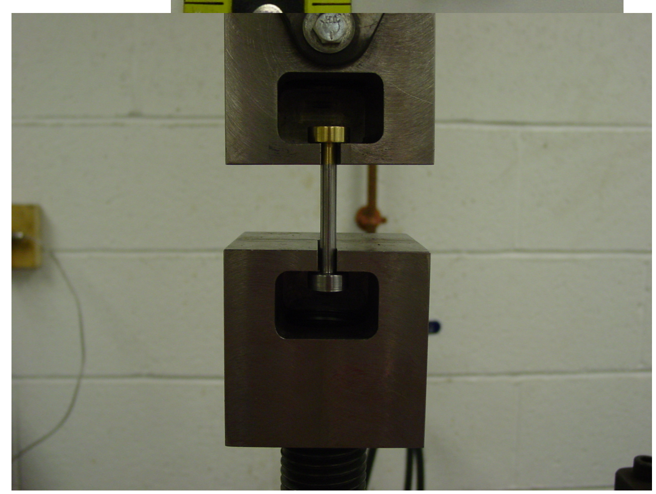
NOTE 1—The reduced section may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. larger in diameter than the center.

NOTE 2—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

FIG. 10 Various Types of Ends for Standard Round Tension Test Specimen

Specimens

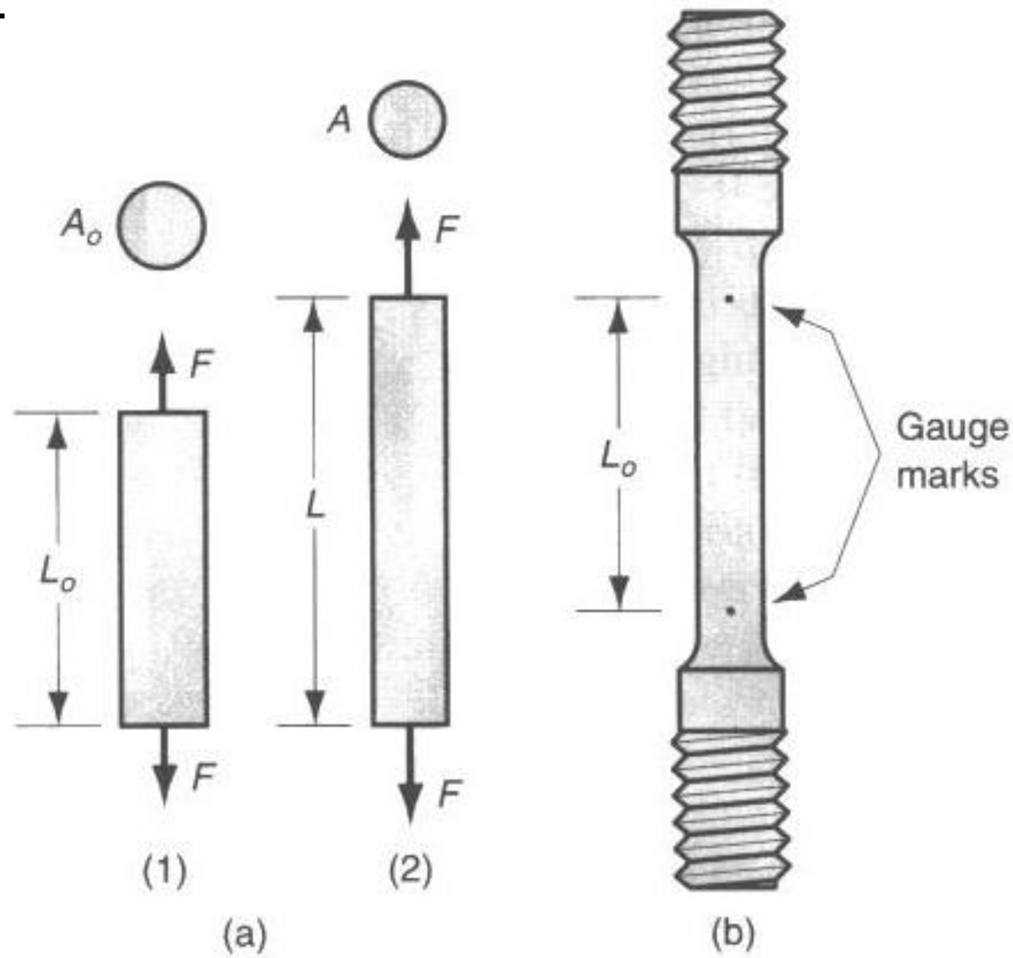




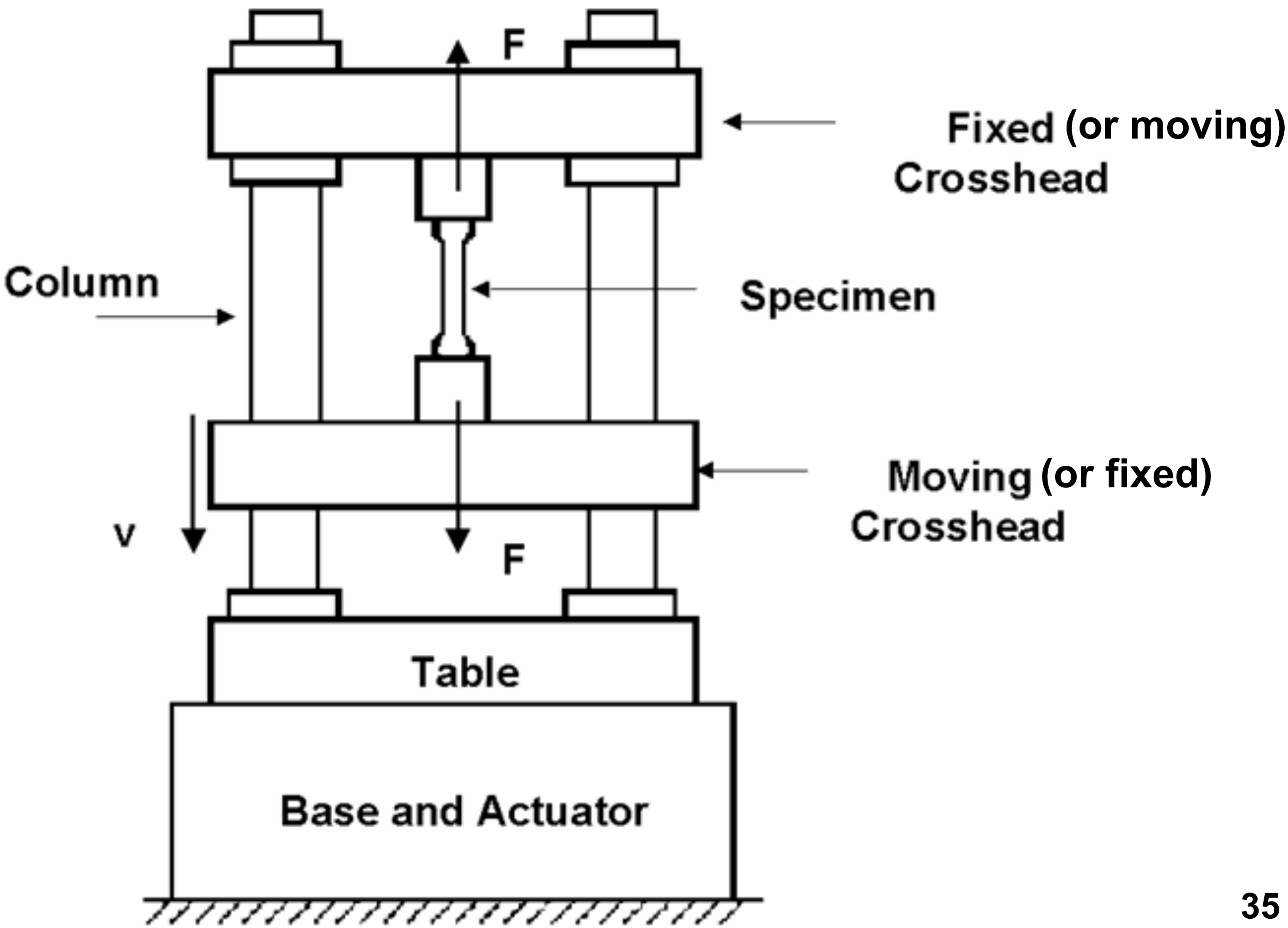
Necking in a tensile specimen

Specimens

- Specimen/test coupon –
- An axial force applied to a specimen of original length (lo) elongates it, resulting in a reduction in the cross-sectional area from A_o to A until fracture occurs.
- The load and change in length between two fixed points (gauge length) is recorded and used to determine the stress-strain relationship.
- A similar procedure can be adopted with a sheet specimen.



Equipment


F
Fixed (or moving)
Crosshead
Column
Specimen
Moving (or fixed)
Crosshead
V
F
Table
Base and Actuator

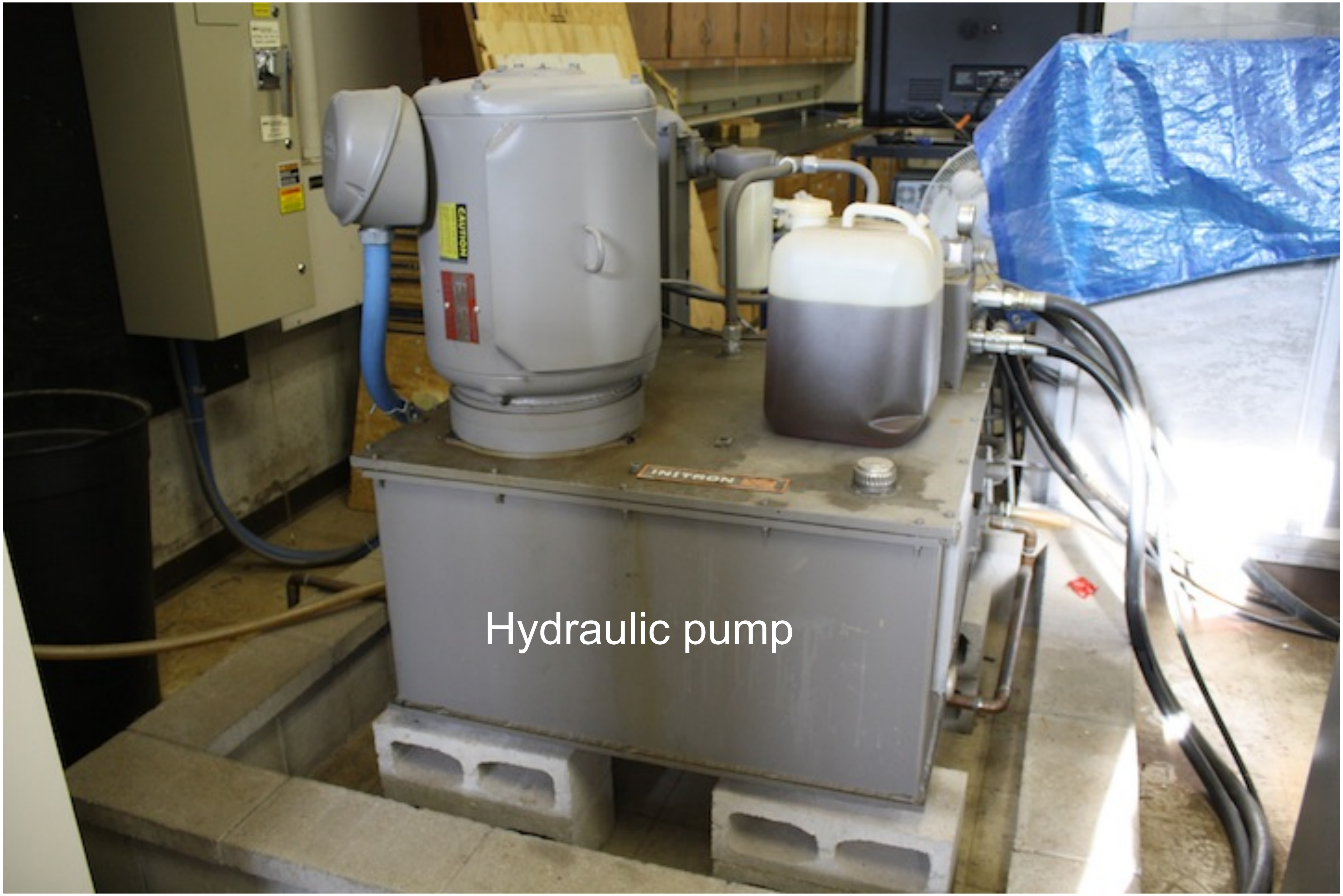
Equipment

- The tensile test machine:
  - **INSTRON Model 1332**
    Servohydraulic Testing Machine
  - Located in Southwick 122
  - Capacity: 100 kiloNewton (kN)

INSTRON
The difference is measurable

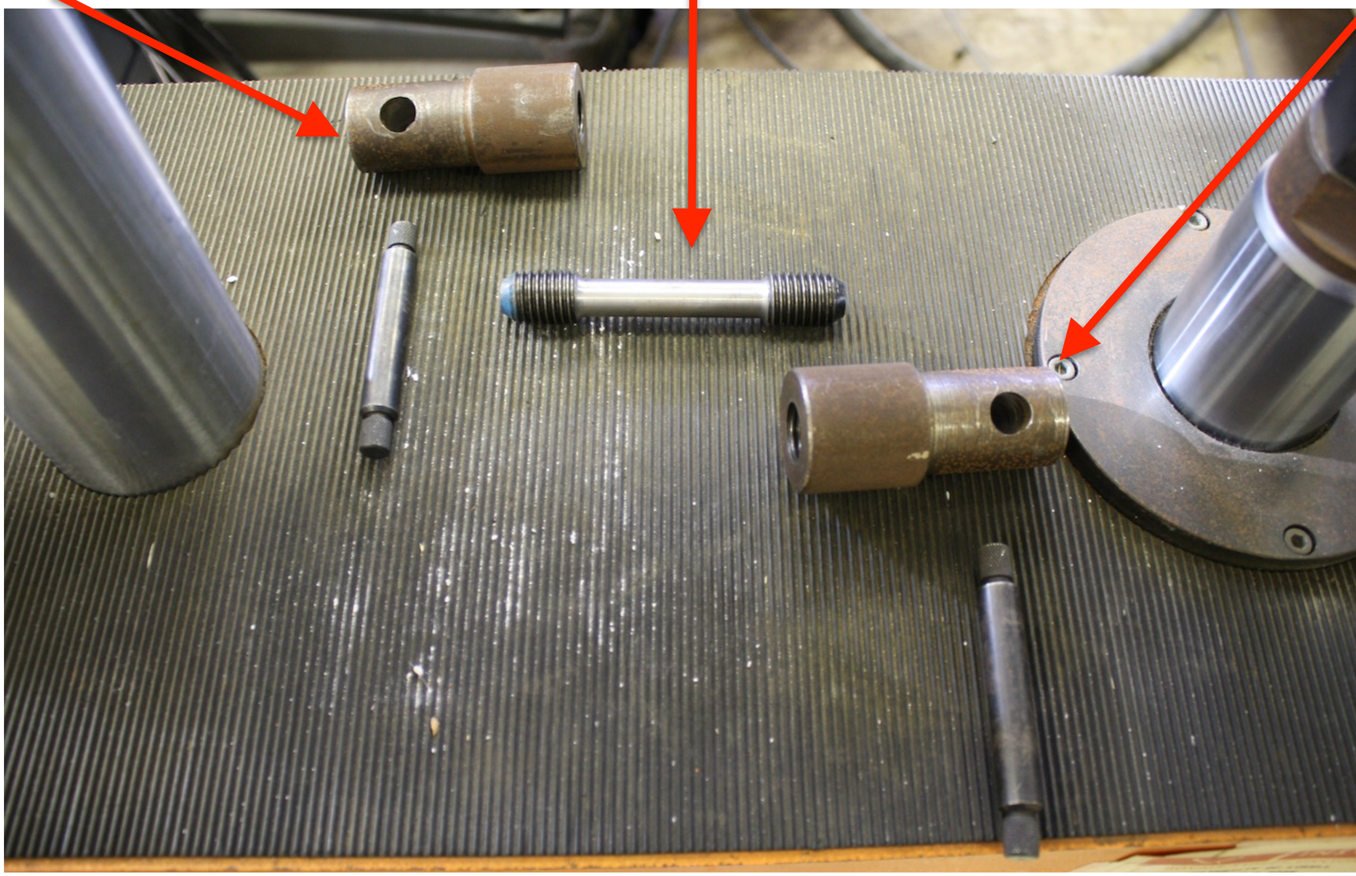

INSTRON
MODEL 1332

INSTRON
MODEL 1332
UP
HANDLE WITH CARE
FRAGILE

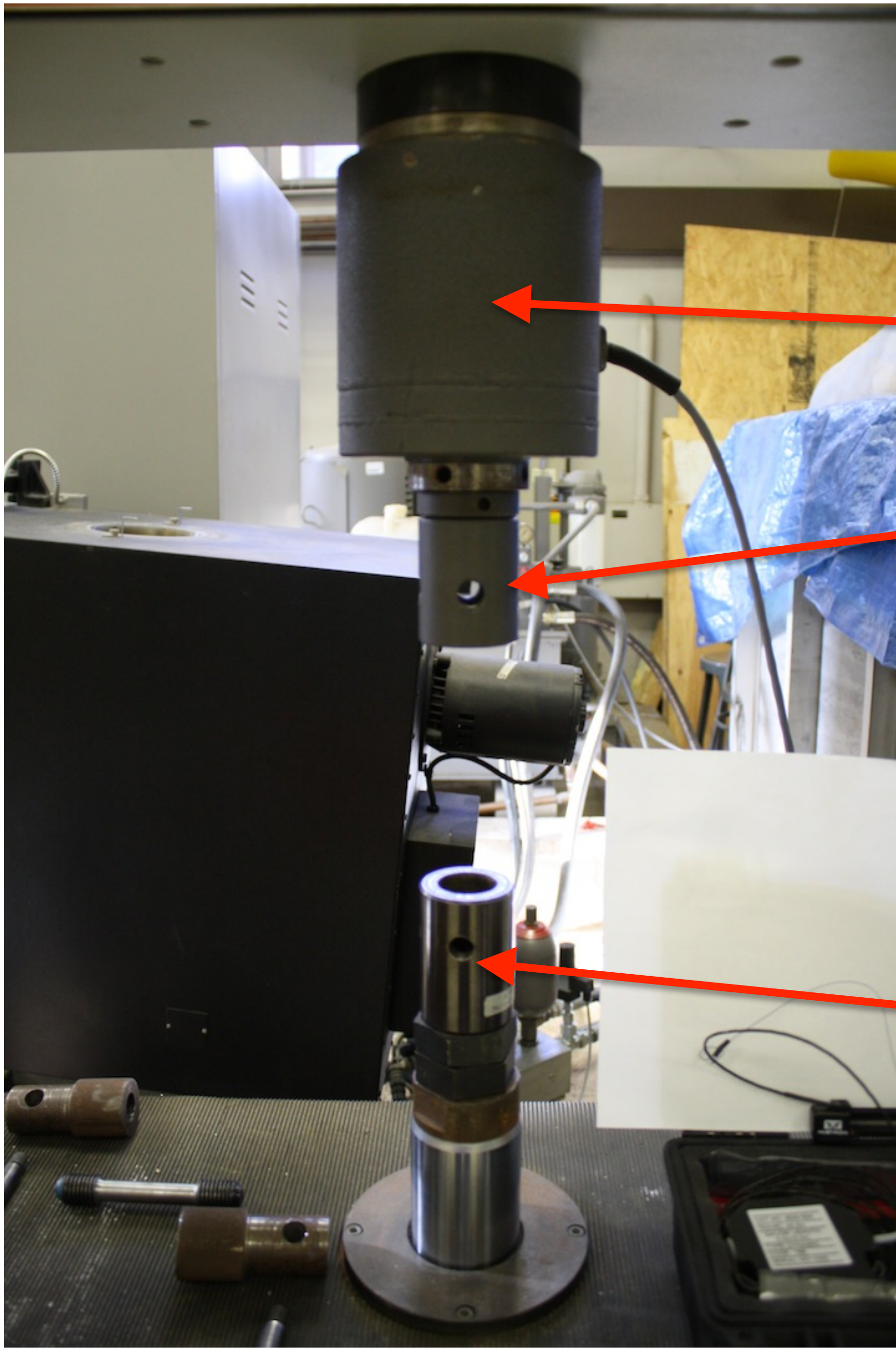

Hydraulic pump

Equipment

- The specimen:



Equipment



The load cell

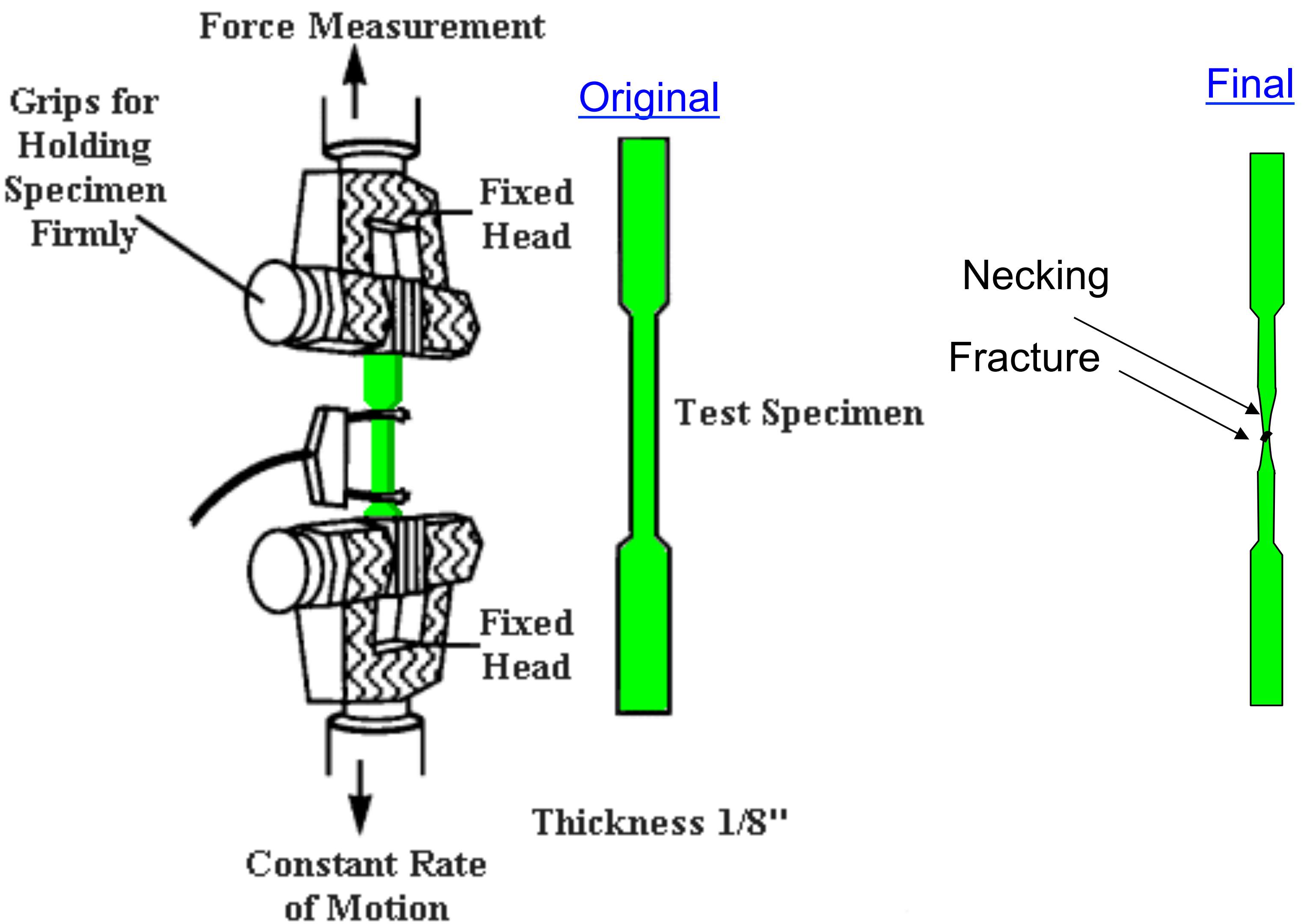
Specimen holder

Specimen holder

Equipment

- The sensor:
  - Extensometer

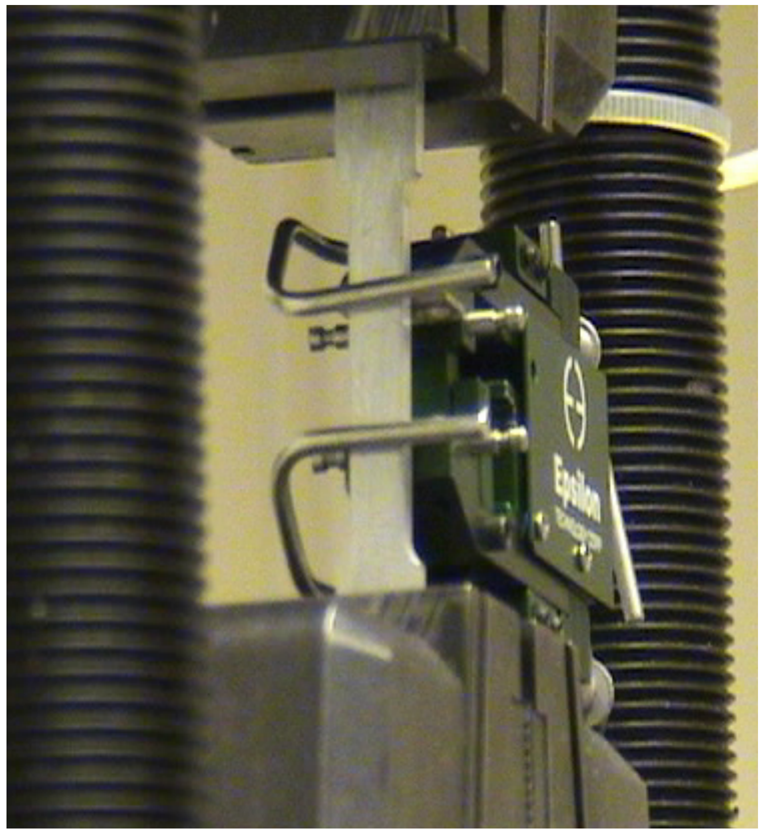
Experimentation



Experimentation

- Extensometer:

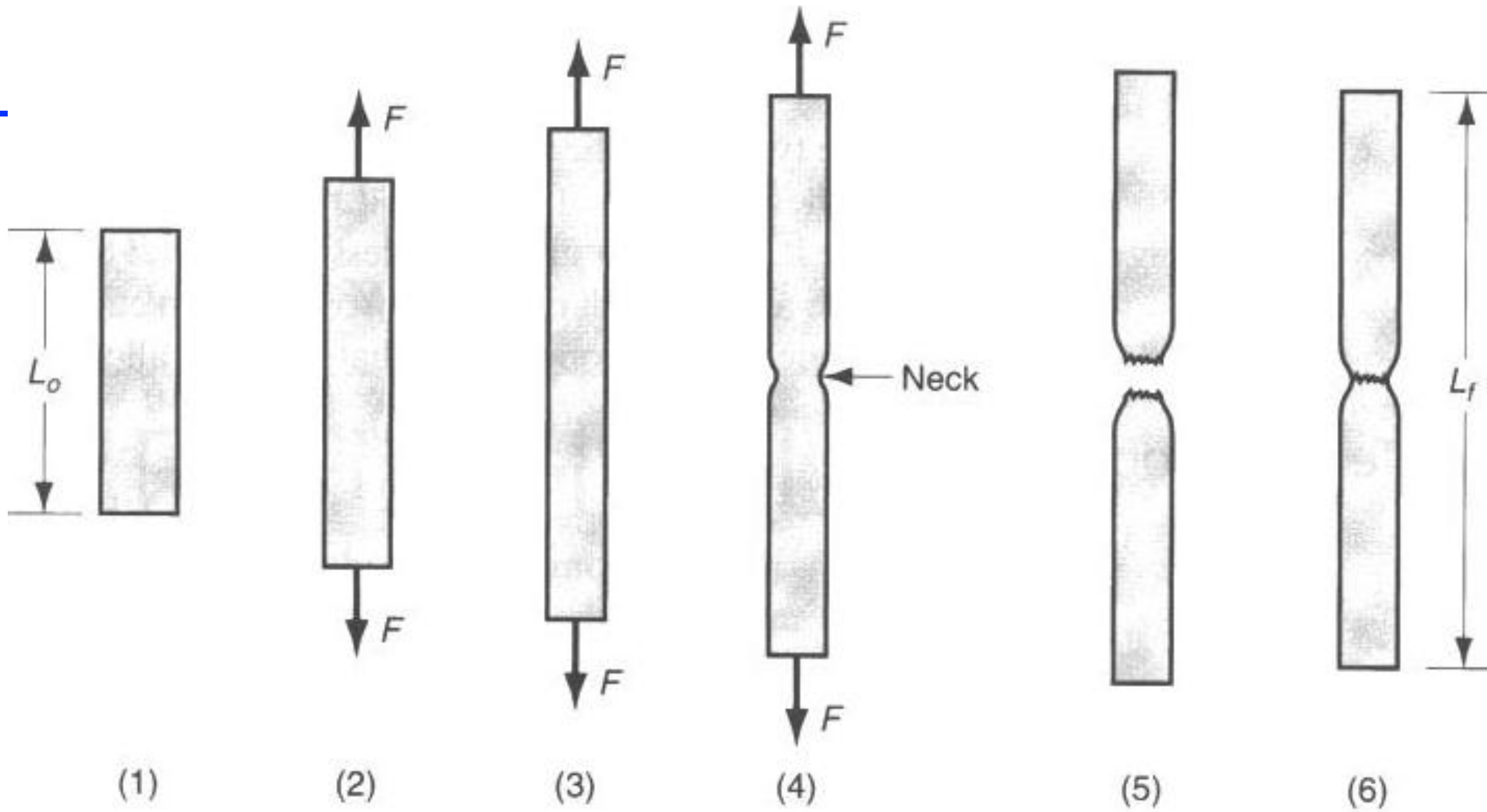
Analog



Digital

- The elongation during testing is measured with respect to the gauge length using an extensometer.
- As the specimen elongates, the extensometer reading (elongation of the specimen) is recorded, either real-time or at discrete time intervals.
- For the current test, a digital extensometer will be used.

Procedure



- Step 1: Original shape and size of the specimen with no load.
- Step 2: Specimen undergoing uniform elongation.
- Step 3: Point of maximum load and ultimate tensile strength.
- Step 4: The onset of necking (plastic instability).
- Step 5: Specimen fractures.
- Step 6: Final length.

Tasks

1) Collect load-elongation data.
2) Plot engineering stress-strain curve.
3) Determine the following:
   ① modulus of elasticity (E),
   ② proportional limit (σ_{pl}),
   ③ ASTM 0.2% offset yield strength (σ_y),
   ④ ultimate tensile strength (σ_u),
   ⑤ fracture strength (σ_f),
   ⑥ toughness, and
   ⑦ ductility
4) Submit your homework on time.

In the Laboratory

- Staff:
  - Laboratory Director: **Gary Howe**
- Guidelines in the lab:
  - *Don't touch it if you don't know what it is.*
  - *If you don't know what it is, ask.*
  - *Pay attention to the detail in the experiment.*
  - *Learn to describe the experiment as an engineer.*