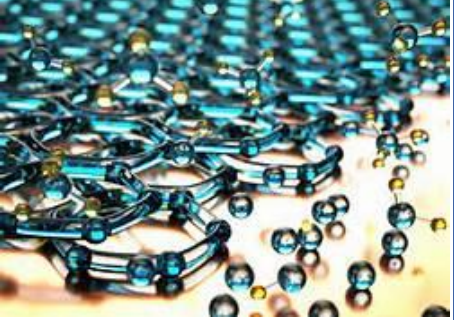


Materials Science

Lecture 11

Lebanese University - Faculty of Engineering – Branch 3

Fall 2022

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Chap 4: Imperfections in Solids

Exercises

Exercise 1

Calculate the fraction of atom sites that are vacant for lead at its melting temperature of 327°C (600 K). Assume an energy for vacancy formation of 0.55 eV/atom.

Exercise 2

Atomic radius, crystal structure, electronegativity, and the most common valence are tabulated in the following table for several elements; for those that are nonmetals, only atomic radii are indicated.

Element	*Atomic Radius (nm)*	*Crystal Structure*	*Electro-negativity*	*Valence*
Cu	0.1278	FCC	1.9	+2
C	0.071			
H	0.046			
O	0.060			
Ag	0.1445	FCC	1.9	+1
Al	0.1431	FCC	1.5	+3
Co	0.1253	HCP	1.8	+2
Cr	0.1249	BCC	1.6	+3
Fe	0.1241	BCC	1.8	+2
Ni	0.1246	FCC	1.8	+2
Pd	0.1376	FCC	2.2	+2
Pt	0.1387	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Exercise 2

Which of these elements would you expect to form the following with **copper:**

(a) A substitutional solid solution having complete solubility

(b) A substitutional solid solution of incomplete solubility

(c) An interstitial solid solution

Exercise 3

For both FCC and BCC crystal structures, there are two different types of interstitial sites. In each case, one site is larger than the other and is normally occupied by impurity atoms.

For FCC, this larger one is located at the center of each edge of the unit cell; it is termed an ***octahedral interstitial*** *site*.

On the other hand, with BCC the larger site type is found at 0 ½ ¼ positions—that is, lying on {100} faces and situated midway between two unit cell edges on this face and one-quarter of the distance between the other two unit cell edges; it is termed a ***tetrahedral interstitial site***.

For both FCC and BCC crystal structures, compute the radius *r* of an impurity atom that will just fit into one of these sites in terms of the atomic radius *R* of the host atom.

Exercise 4

Calculate the composition, in weight percent, of an alloy that contains 218.0 kg titanium, 14.6 kg aluminum, and 9.7 kg vanadium.

Exercise 5

Determine the approximate density of a high-leaded brass that has a composition of 64.5 wt% Cu, 33.5 wt% Zn, and 2 wt% Pb.

Exercise 6

For an FCC single crystal, would you expect the surface energy for a (100) plane to be greater or less than that for a (111) plane?   Why?

(*Note: Use the results of the following exercise of chapter 3)*

Derive planar density expressions for FCC (100) and (111) planes in terms of the atomic radius *R*.

Exercise 7

(a) For a given material, would you expect the surface energy to be greater than, the same as, or less than the grain boundary energy? Why?

(b) The grain boundary energy of a small-angle grain boundary is less than for a high-angle one. Why is this so?

Exercise 8

For each of the following stacking sequences found in FCC metals, cite the type of planar defect that exists:

(a) . . . *A B C A B C B A C B A* . . .

(b) . . . *A B C A B C B C A B C* . . .

Now, copy the stacking sequences and indicate the position(s) of planar defect(s) with a vertical dashed line.

Contents

Lecture 11:

⦿ Chap 5: Mechanical Behavior

5.1. Introduction

Why study the mechanical properties of metals?

- It is incumbent on engineers to **understand** how the various **mechanical properties** are **measured** and what these **properties represent.**

- They may be called upon to **design structures**/**components** using predetermined materials such that unacceptable levels of **deformation** and/or **failure** will **not occur**.

- Many materials are subjected to **forces** or **loads** when **in service**; **examples** include the **aluminum** alloy from which an **airplane wing** is constructed and the **steel** in an **automobile axle**.

- In such situations it is **necessary** to **know** the **characteristics** of the material and to **design** the member from which it is made such that any resulting **deformation** will **not be excessive**, and **fracture** will **not occur**.

- The **mechanical behavior** of a material reflects its **response or deformation** in relation to an **applied load** or **force**. Key mechanical design properties are **stiffness**, **strength**, **hardness**, **ductility**, and **toughness**.

5.1. Introduction

- The **mechanical properties** of materials are **ascertained** by performing carefully designed **laboratory experiments** that replicate as **nearly** as possible the **service conditions**.

- **Factors** to be considered include the **nature** of the **applied load** and its **duration**, as well as the **environmental conditions**.

- It is possible for the load to be **tensile**, **compressive**, or **shear**, and its magnitude may be **constant with time**, or it may **fluctuate continuously**.

- **Application time** may be only a **fraction** of a **second**, **or** it may extend over a period of **many years**.

- Service **temperature** may be an **important factor**.

5.1. Introduction

- **Mechanical properties** are of **concern** to a **variety of parties** (e.g., **producers** and **consumers** of materials, **research organizations**, **government agencies**) that have differing **interests**.

- Consequently, it is imperative that there be **some consistency** in the manner in which **tests are conducted** and in the **interpretation** of **their results**. This consistency is accomplished by using **standardized testing techniques**.

- **Establishment** and **publication** of these **standards** are often coordinated by **professional societies**. In the United States the **most active organization** is the **American Society for Testing and Materials (ASTM)**.

- Its **Annual Book** of **ASTM** Standards (**http://www.astm.org**) comprises numerous volumes that are issued and updated yearly; a large number of these standards relate to mechanical testing techniques.

5.1. Introduction

- The role of **structural engineers** is to **determine stresses** and stress **distributions** within members that are subjected to well-defined loads.

- This may be accomplished **by experimental testing techniques** and/or by **theoretical** and **mathematical** stress **analyses**. These topics are treated in traditional texts on stress analysis and strength of materials.

- **Materials** and **metallurgical engineers**, however, are concerned with **producing** and **fabricating materials** to meet service requirements as predicted by these stress analyses.

- This necessarily involves an **understanding** of the **relationships** between the **microstructure** (i.e., **internal features**) of materials and their **mechanical properties**.

Contents

Lecture 11:

⦿ Chap 5: Mechanical Behavior

5.2. Concepts of stress and strain

- Whenever a **force** is applied to a body, it will tend to **change** the **body's shape** and **size**.

- These changes are referred to as **deformation**, and they **may be highly visible** or practically **unnoticeable**.

- <u>**For example**</u>, a **rubber band** will undergo a **very large deformation** when stretched, whereas only **slight deformations** of structural members occur when a **building** is occupied.

- **Deformation** of a body can also **occur** when the **temperature** of the body is **changed**. A **typical example** is the **thermal expansion** or **contraction** of a roof caused by the weather.

5.2. Concepts of stress and strain

- In a general sense, the **deformation** will **not be uniform** throughout the body, and so the **change in geometry** of any line segment within the body may **vary substantially** along its **length**.

- Hence, to **study deformation**, we will **consider** line **segments** that are very **short** and **located** in the neighborhood of a **point**.

- Realize, however, that the **deformation** will also **depend** on the **orientation** of the **line segment** at the point.

5.2. Concepts of stress and strain

- **For example**, as shown in the adjacent photos, a **line segment** may elongate if it is **oriented** in **one direction**, whereas it may **contract** if it is oriented in **another direction**.

Note the before and after positions of three different line segments on this rubber membrane which is subjected to tension.

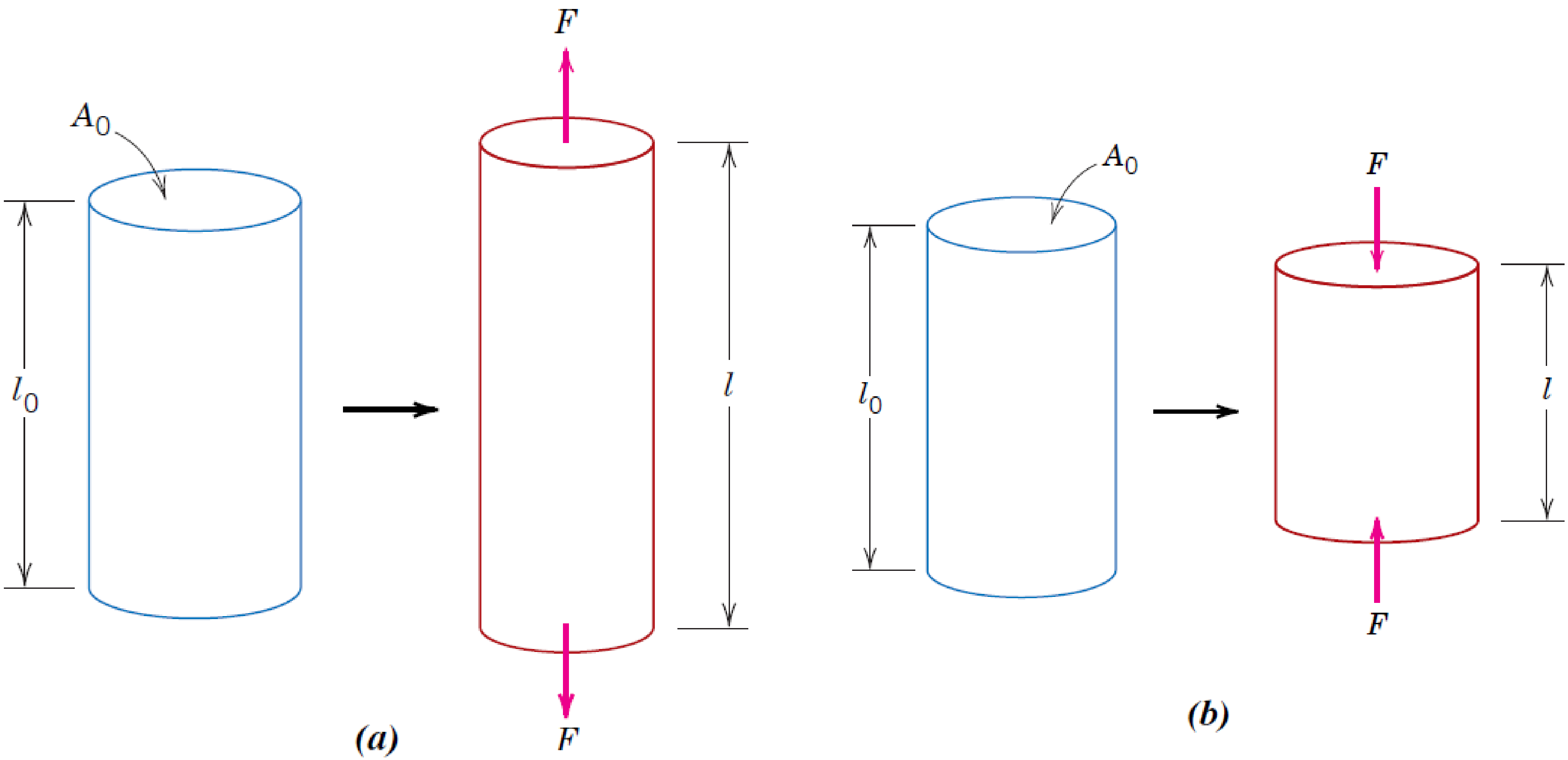
The **vertical** line is **lengthened**, the **horizontal** line is **shortened**, and the **inclined** line changes its **length** and **rotates**.

5.2. Concepts of stress and strain

- If a **load** is **static** or **changes** relatively **slowly** with **time** and is **applied uniformly** over a **cross section** or **surface** of a member, the mechanical behavior may be ascertained by a **simple stress–strain test**; these are **most commonly conducted** for **metals** at **room temperature**.

- There are **three principal ways** in which a load may be applied: **tension**, **compression**, and **shear**. In engineering practice many loads are **torsional** rather than pure shear.

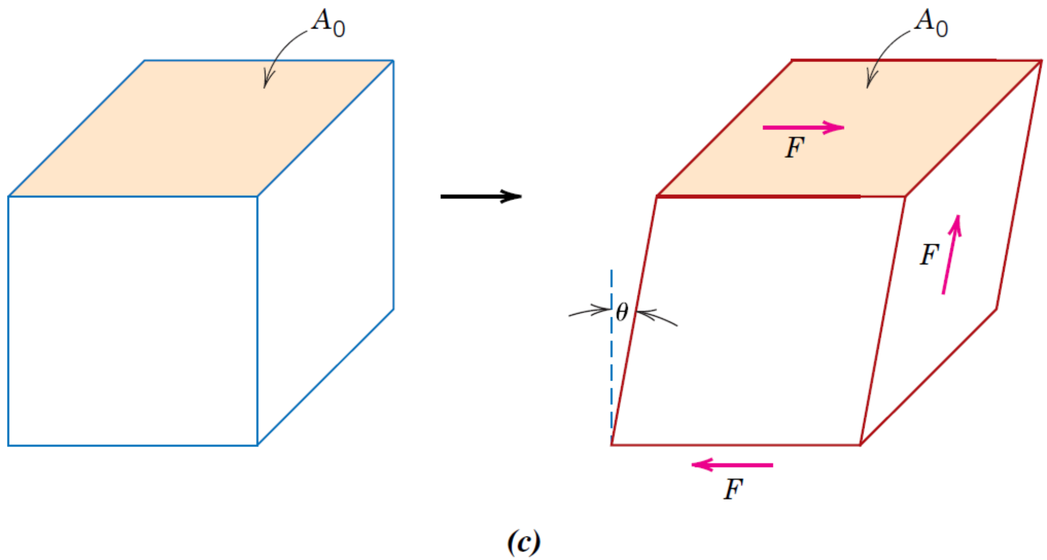
5.2. Concepts of stress and strain



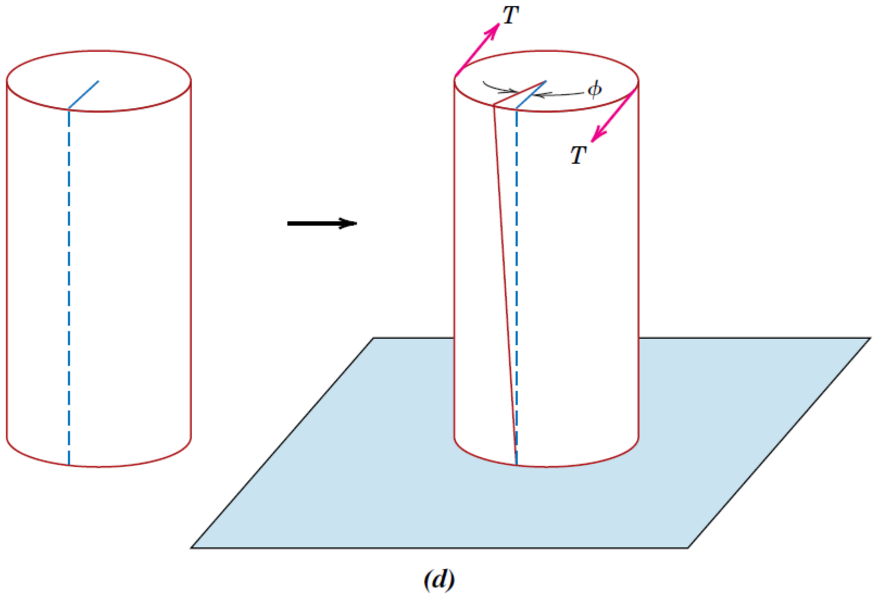
(a) Schematic illustration of how a tensile load produces an elongation and positive linear strain.

(b) Schematic illustration of how a compressive load produces contraction and a negative linear strain.

5.2. Concepts of stress and strain



(c) Schematic representation of shear strain γ, where γ=tan θ.



(d) Schematic representation of torsional deformation (i.e., angle of twist φ) produced by an applied torque T.

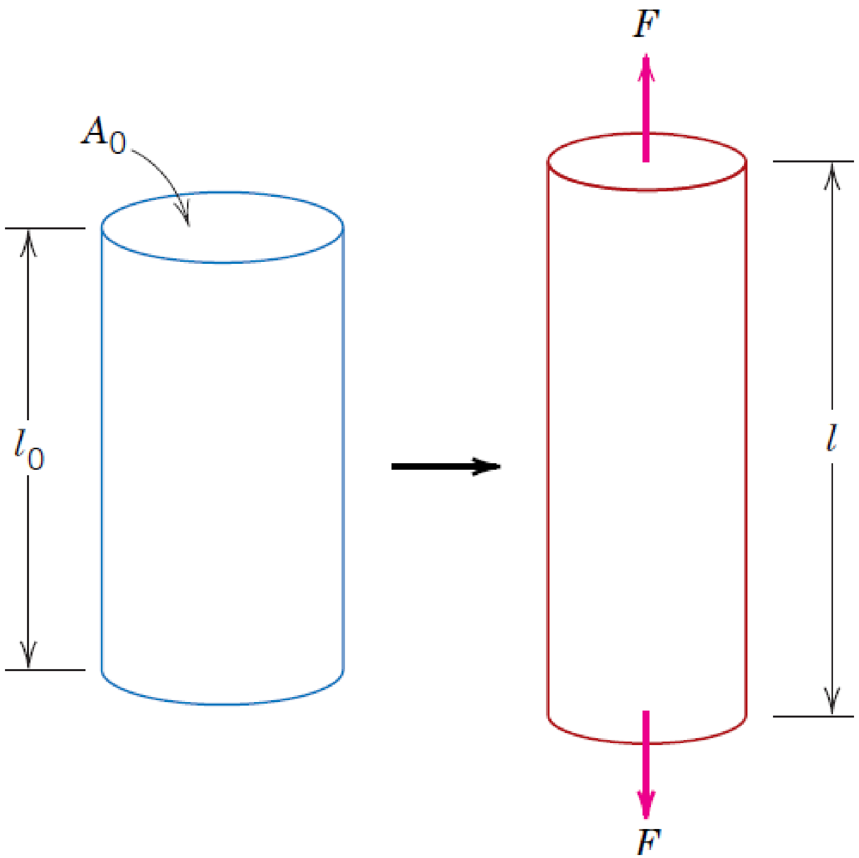
5.2. Concepts of stress and strain

Tension Tests

- One of the **most common** mechanical stress–strain tests is performed in tension.

- As will be seen, the tension test can be used to ascertain **several mechanical properties** of materials that are **important in design**.

- A **specimen** is **deformed**, usually to **fracture**, with a gradually increasing tensile load that is applied uniaxially along the long axis of a specimen.

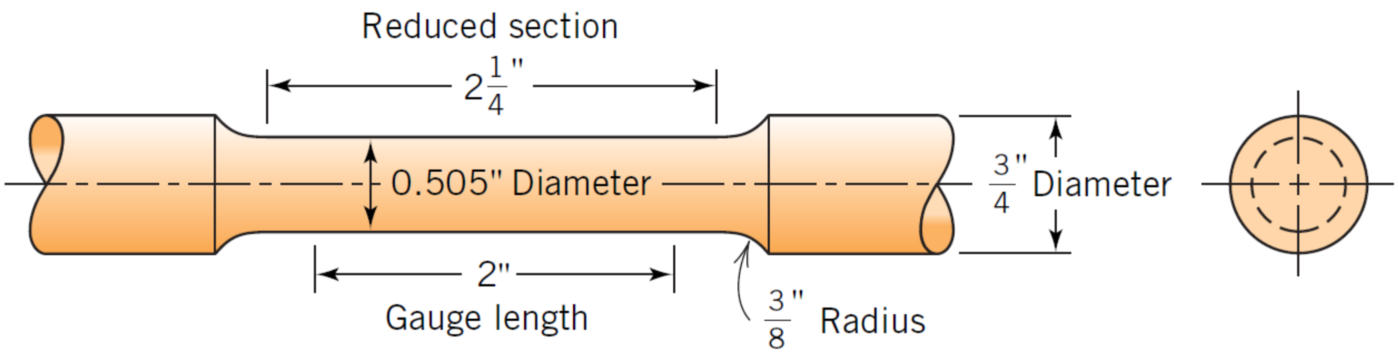


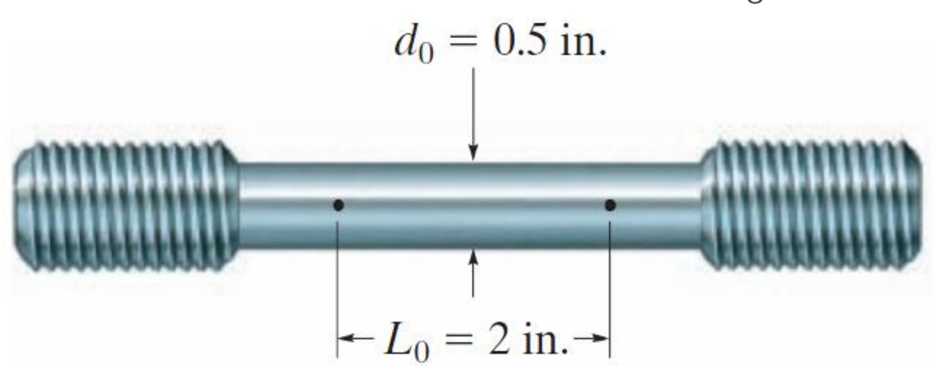
Schematic illustration of how a tensile load produces an elongation and positive linear strain.

5.2. Concepts of stress and strain

Tension Tests

- A **standard tensile specimen** is shown in the figure. Normally, the **cross section** is **circular**, but **rectangular** specimens are also used.
- This "**dogbone**" specimen configuration was chosen so that, during testing, deformation is confined to the **narrow center region** (which has a uniform cross section along its length) and also to **reduce** the **likelihood** of **fracture** at **the ends** of the specimen.





5.2. Concepts of stress and strain

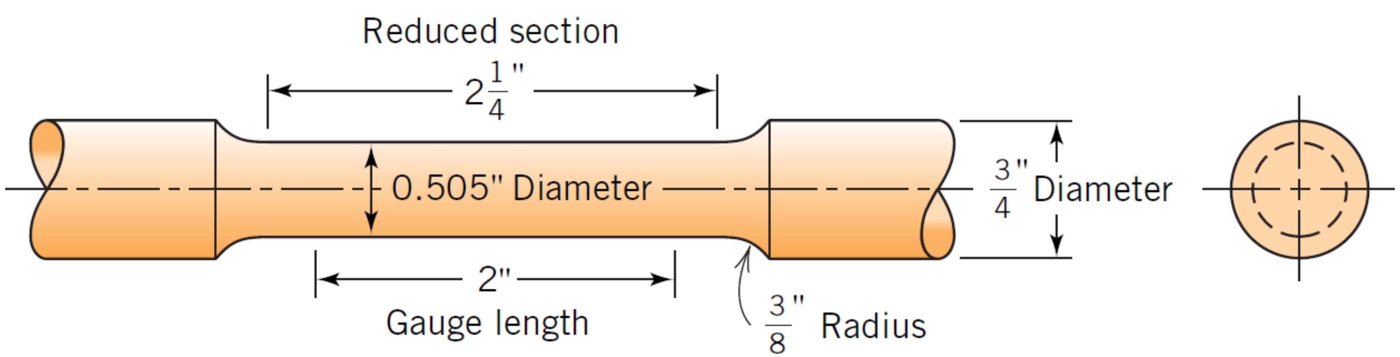
Tension Tests

- The **standard diameter** is approximately **12.8 mm** (0.5 in.), whereas the **reduced section length** should be **at least four times this diameter**; **60 mm** (2.25 in.) is common.

- Gauge length is used in ductility computations; the standard value is **50 mm** (2.0 in.).

- **Before testing**, two small **punch marks** are **sometimes** placed **along** the **specimen's uniform length**.

- The specimen is mounted by its **ends** into the **holding grips** of the testing **apparatus**.

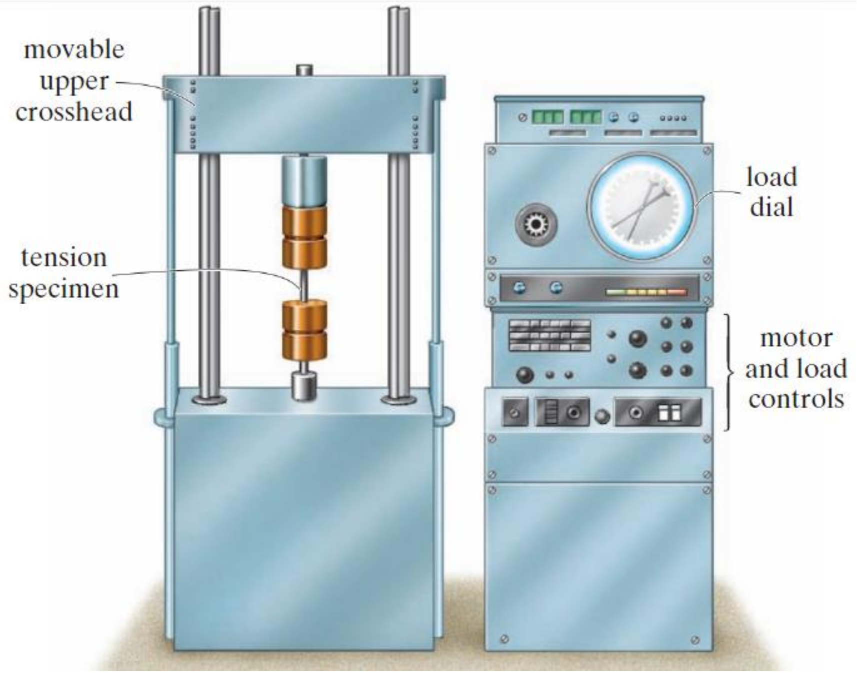


5.2. Concepts of stress and strain

Tension Tests

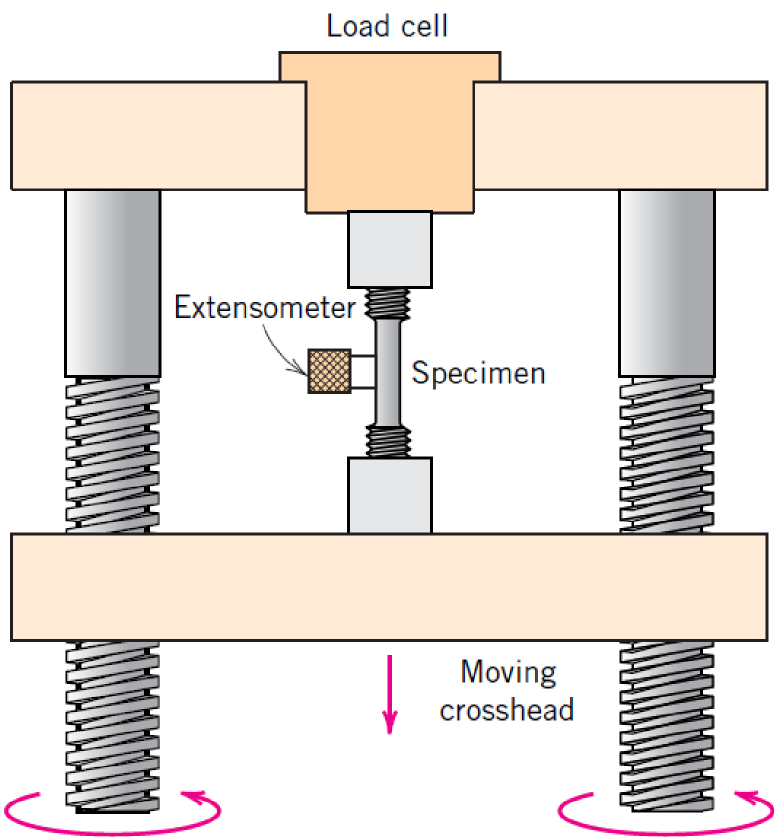
- The **tensile testing machine** is designed to **elongate** the **specimen** at a **constant rate**, and to **continuously** and **simultaneously measure** the **instantaneous applied load** (with a load cell) and the **resulting elongations**.

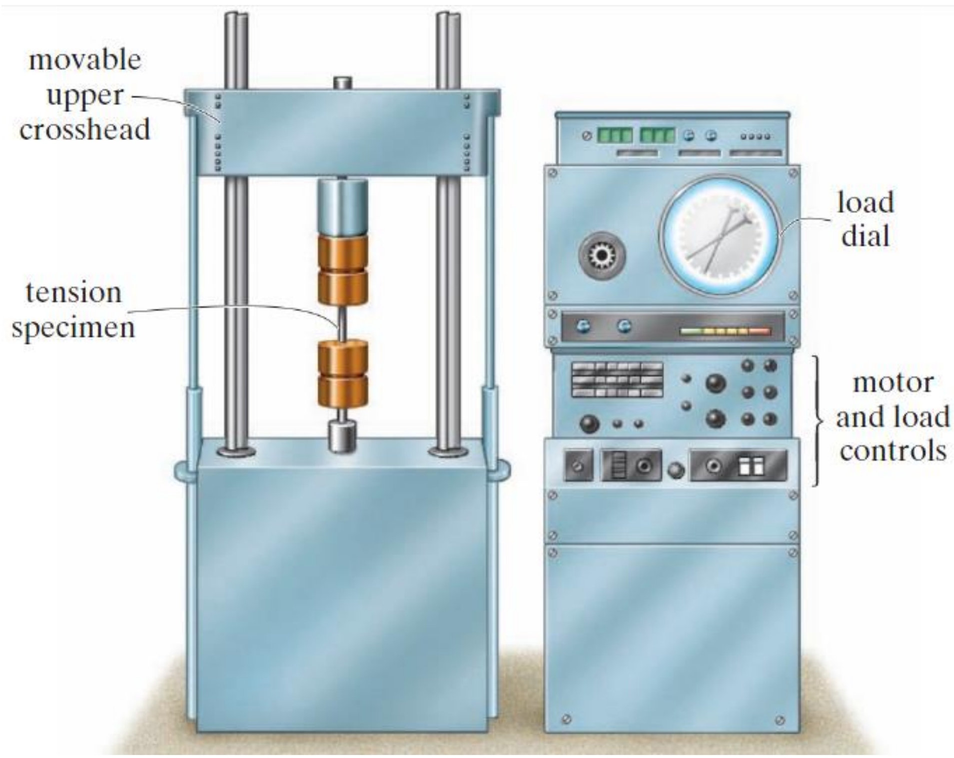
- A stress–strain test typically takes **several minutes** to perform and is **destructive**; that is, the test specimen is **permanently deformed** and **usually fractured**.



5.2. Concepts of stress and strain

Tension Tests





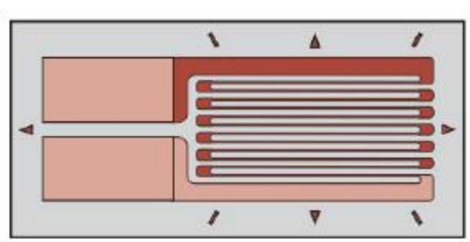
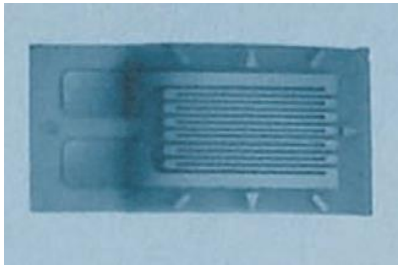
Schematic representation of the apparatus used to conduct tensile stress– strain tests. The specimen is elongated by the moving crosshead; load cell and extensometer measure, respectively, the magnitude of the applied load and the elongation.

Tension Tests

- At frequent intervals, data is **recorded** of the applied load.

- Also, the **elongation $\delta = L - L_0$** between the punch marks on the specimen may be measured, using either a **caliper** or a **mechanical** or **optical** device called an ***extensometer***.

- Rather than taking this measurement and then calculating the strain, it is also **possible** to **read** the normal **strain directly** on the specimen by using an ***electrical-resistance strain gage***, which looks like the one shown in the figure.

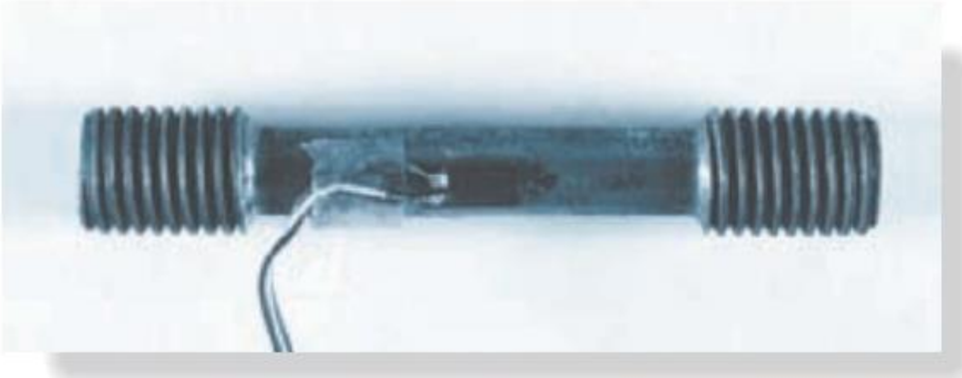
5.2. Concepts of stress and strain

Tension Tests

- As shown in the photo, the **gage is cemented to the specimen** along its **length**, so that it becomes an integral part of the specimen.

- When the **specimen** is **strained** in the direction of the gage, both the **wire and specimen will experience the same deformation** or **strain**.

- By **measuring** the **change** in the **electrical resistance of the wire**, the **gage** may then be **calibrated** to **directly read** the **normal strain** in the specimen.



Typical steel specimen with attached strain gage