Material Characteristics

Bachelor of Industrial Technology Management with Honours
Semester I Session 2013/2014

Why Materials are Important in Manufacturing?

- Manufacturing is a transformation process
  - It is the material that is transformed
  - And it is the behavior of the material when subjected to the forces, temperatures, and other parameters of the process that determines the success of the operation

Selection of Materials

Considerations in selecting materials :

- Properties of material – mechanical & physical
- Availability
- Cost
- Appearance
- Recycling

Selection of Manufacturing Processes

- Can the material undergo forming without cracking or breaking in your manufacturing process?
- How much will the investment cost?
- Safety Issue? Will the process leave sharp edges, burrs? How do you clean up the sharp edges?

Selection of Manufacturing Processes

Depends on :

- ➲ Shape of product
- ➲ Type of material and its properties
- ➲ Dimensional & surface finish considerations
- ➲ Operational / manufacturing cost involved

Basic Mechanical Properties

1. Strength : Ability to support load, tension, compression, shear
2. Hardness : Resistance to penetration
3. Ductility : Ability to change shape, opposite of brittleness
4. Stiffness : Ratio of load to elastic deformation (σ / ε = stress/strain)
5. Toughness : Ability to resist impact (energy absorption before fracture)

Physical Properties of Materials

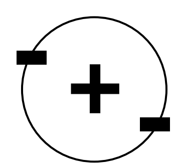
1. Density and melting properties
2. Thermal properties (thermal expansion & thermal conductivity) → heat dissipation/transfer;
3. Mass diffusion → movement of atoms/molecules within/across materials; eg. Carburizing, spot welding;
4. Electrical properties (conductivity or resistivity)
5. Electrochemical processes → eg. plating

Physical Properties in Manufacturing

- Important in manufacturing because they often influence process performance
- Examples:
  - In machining, thermal properties of the work material determine the cutting temperature, which affects tool life
  - In microelectronics, electrical properties of silicon and how these properties can be altered by chemical and physical processes is the basis of semiconductor manufacturing

Atomic Structure and The Elements

- The basic structural unit of matter is the atom
- Each atom is composed of a positively charged nucleus, surrounded by a sufficient number of negatively charged electrons so the charges are balanced



- More than 100 elements and they are the chemical building blocks of all matter

Element Groupings

- The elements can be grouped into families and relationships established between and within the families by means of the Periodic Table
  - Metals occupy the left and center portions of the table
  - Nonmetals are on right
  - Between them is a transition zone containing *metalloids* or *semi-metals*

Periodic Table of Elements

Metals — Transition Zone — Nonmetals

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H																1 H	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac															

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

The atomic number and symbol are listed for the 103 elements

Materials, Manufacturing & Parts

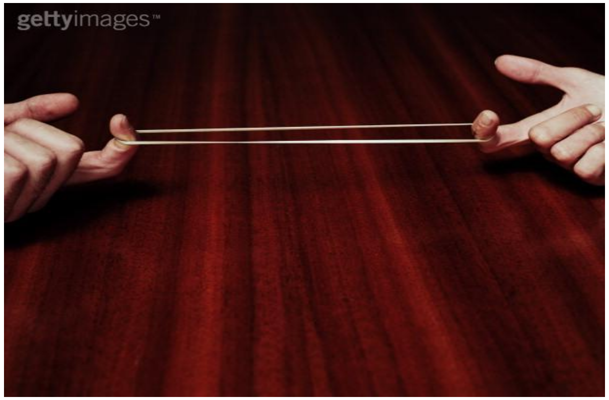
- Many manufactured parts are created by mechanical means:
  - Solidification
  - Deformation
  - Material Removal
- The response to external applied forces is extremely important (during manufacturing & service stages)
- The behavior of different materials need to be considered
  - Wings on an aircraft
  - Crankshaft of an automobile
  - Gear teeth in a transmission

Stress-Strain Relationships

- 3 types of static stresses to which materials can be subjected:
  1. Tensile – tend to stretch the material
  2. Compressive – tend to squeeze it
  3. Shear – tend to cause adjacent portions of material to slide against each other
- Stress-strain curve – basic relationship that describes mechanical properties for all three types of static stresses
- Material response to external applied forces

Definitions

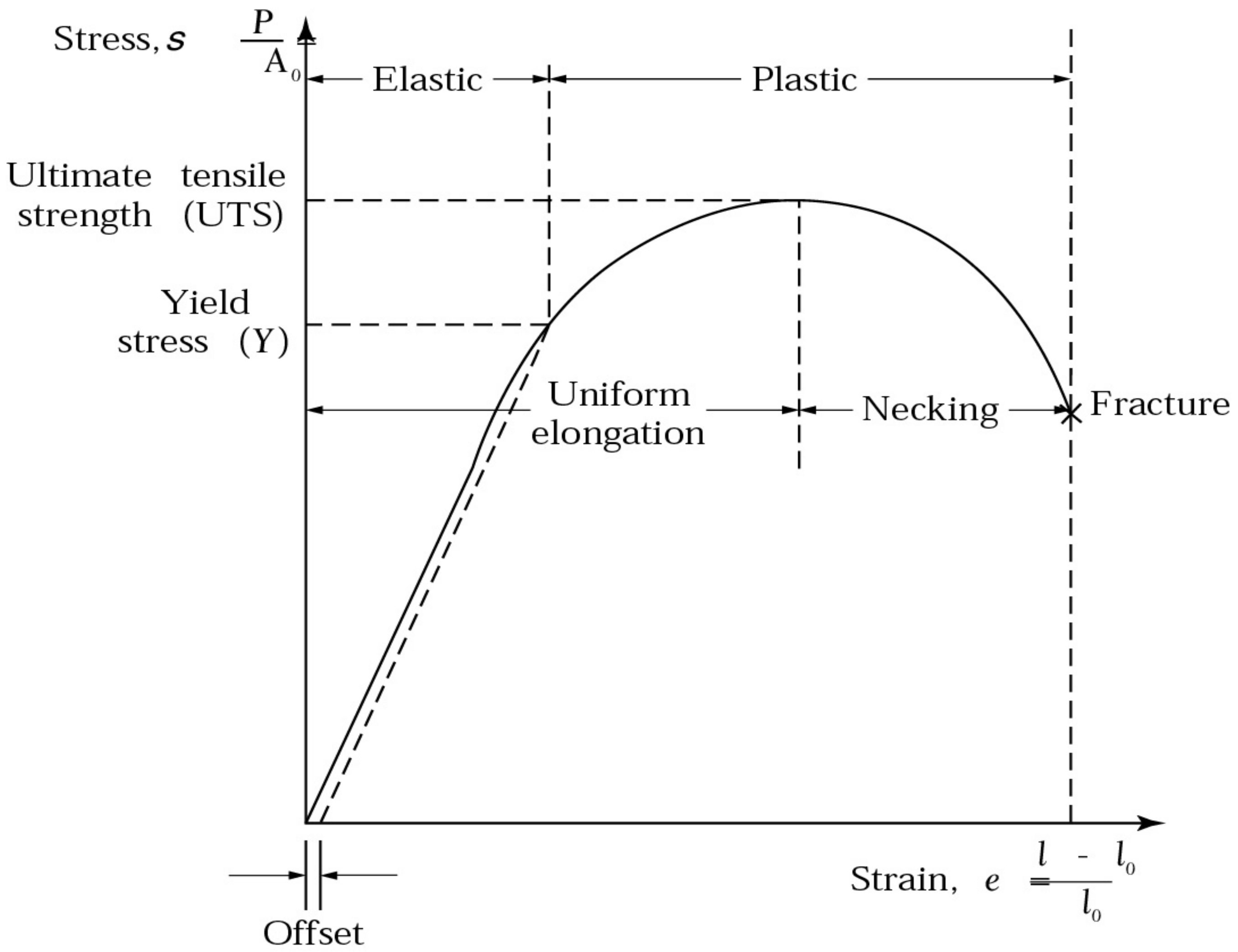
- Stress = σ = Force applied / Area
- Strain = ε = Δ length / original length
- Plastic elongation vs. elastic elongation



Temporary Deformation
(elastic elongation)

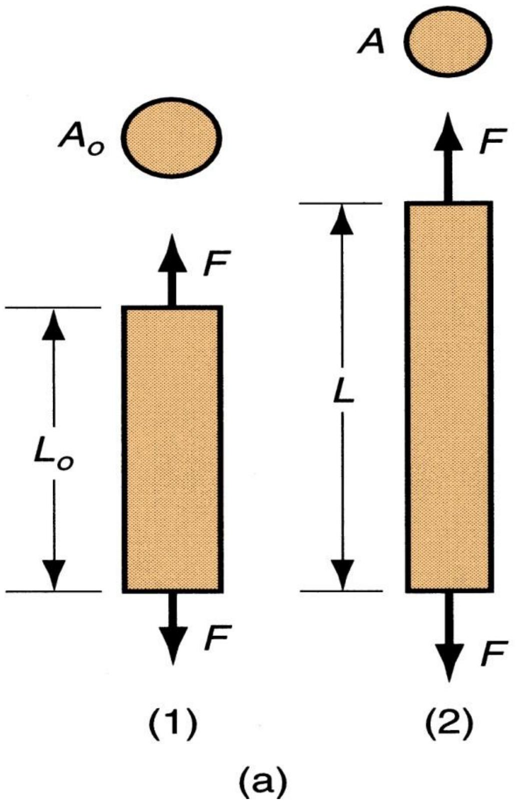
Permanent Deformation
(plastic elongation)

Stress-Strain Curve



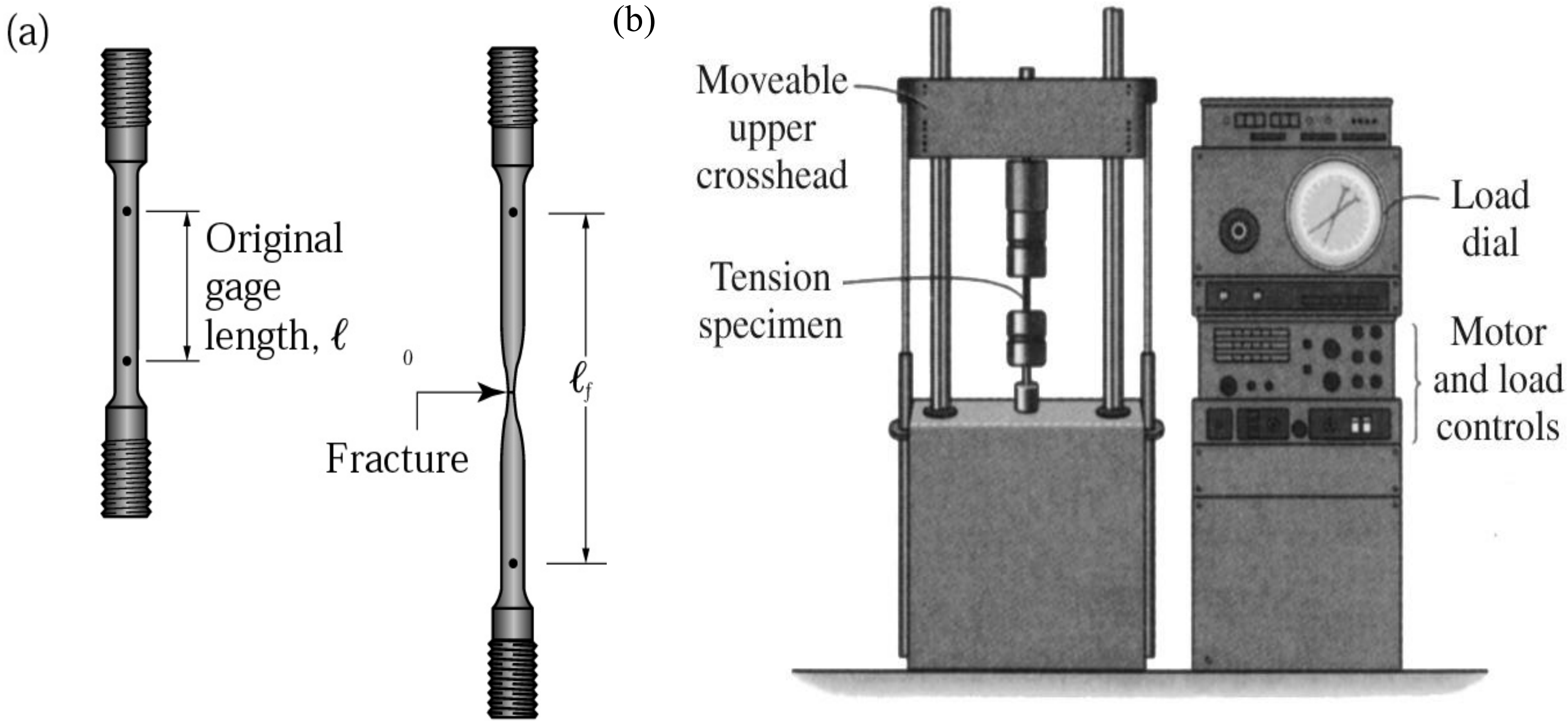
Tensile Test

- Most common test for studying stress-strain relationship, especially metals
- In the test, a force pulls the material, elongating it and reducing its diameter



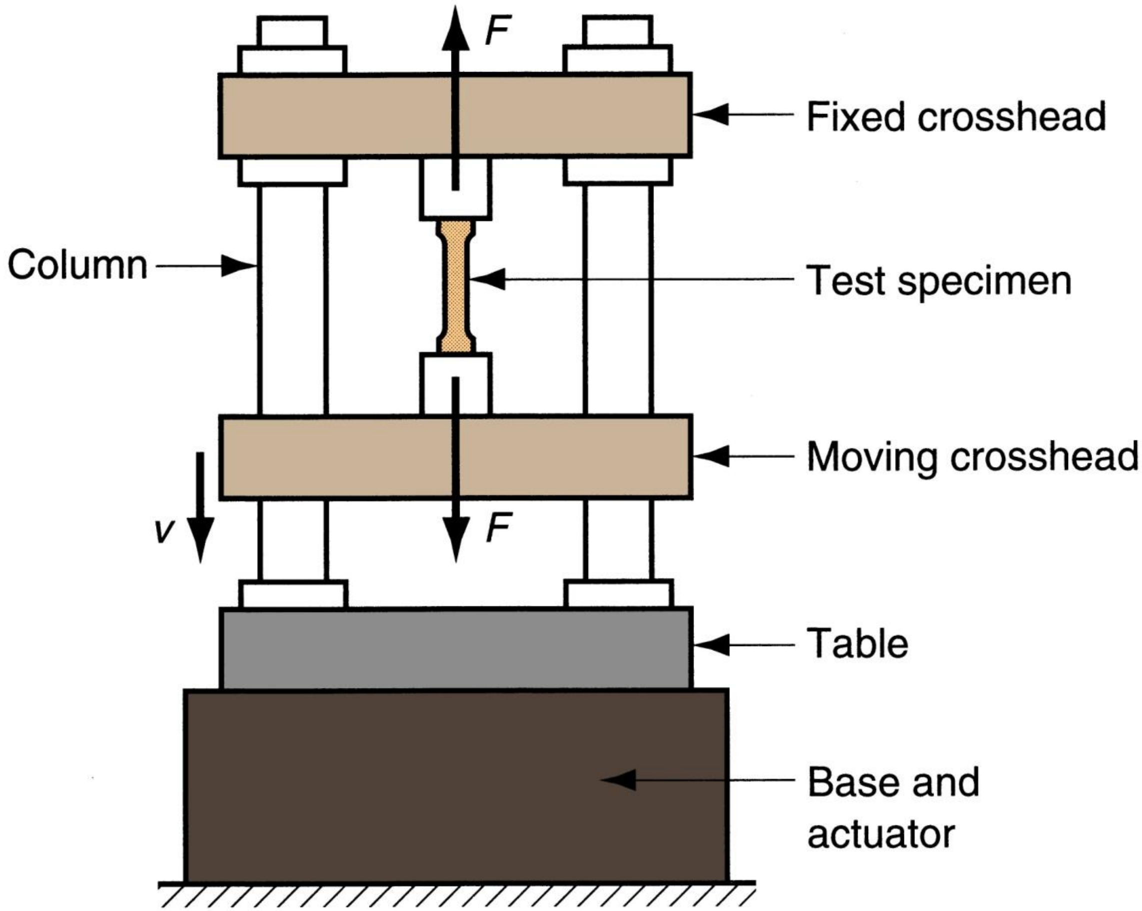
Tensile test: (a) tensile force applied in (1) and (2) resulting elongation of material

Tensile Test Specimen & Machine



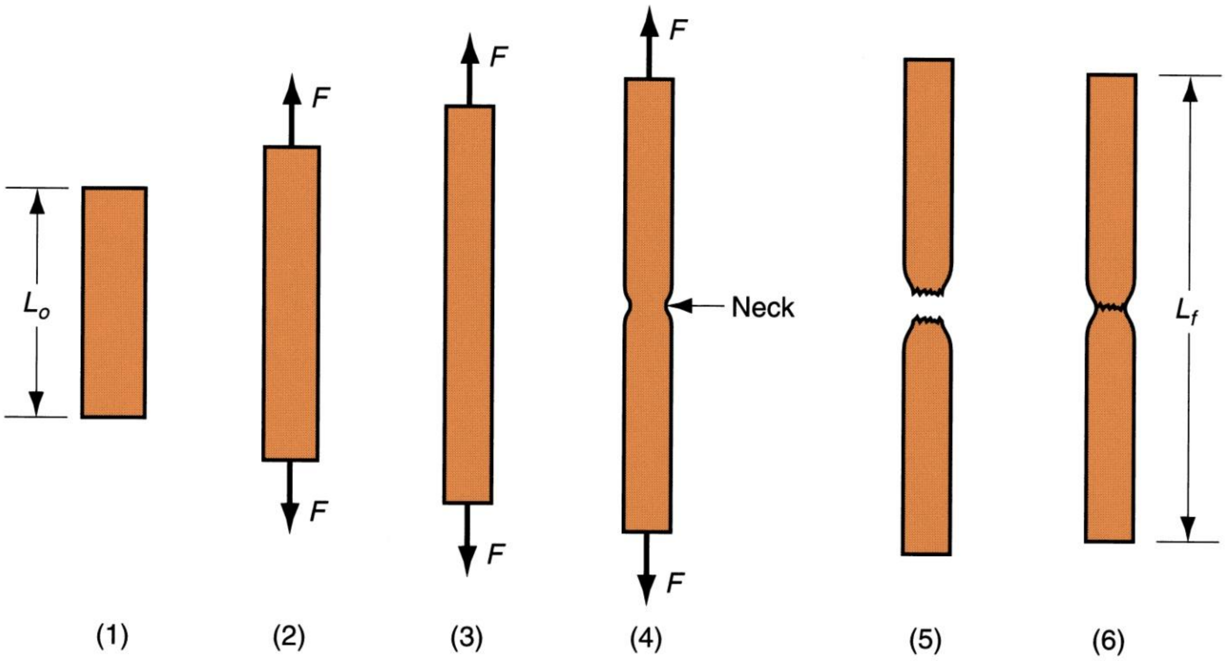
(a) A standard tensile-test specimen before and after pulling, showing original and final gage lengths. (b) A typical tensile-testing machine.

Tensile Test Setup



(c)

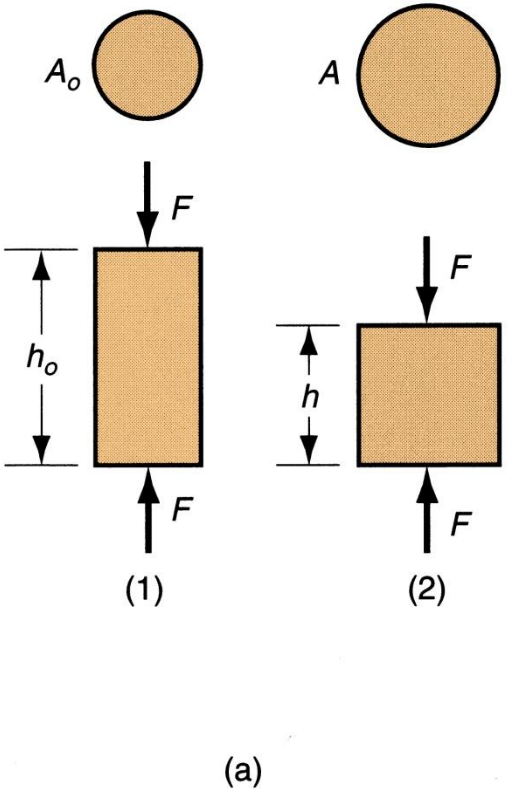
Tensile Test



Typical progress of a tensile test: (1) beginning of test, no load; (2) uniform elongation and reduction of cross-sectional area; (3) continued elongation, maximum load reached; (4) necking begins, load begins to decrease; and (5) fracture. If pieces are put back together as in (6), final length can be measured

Compression Test

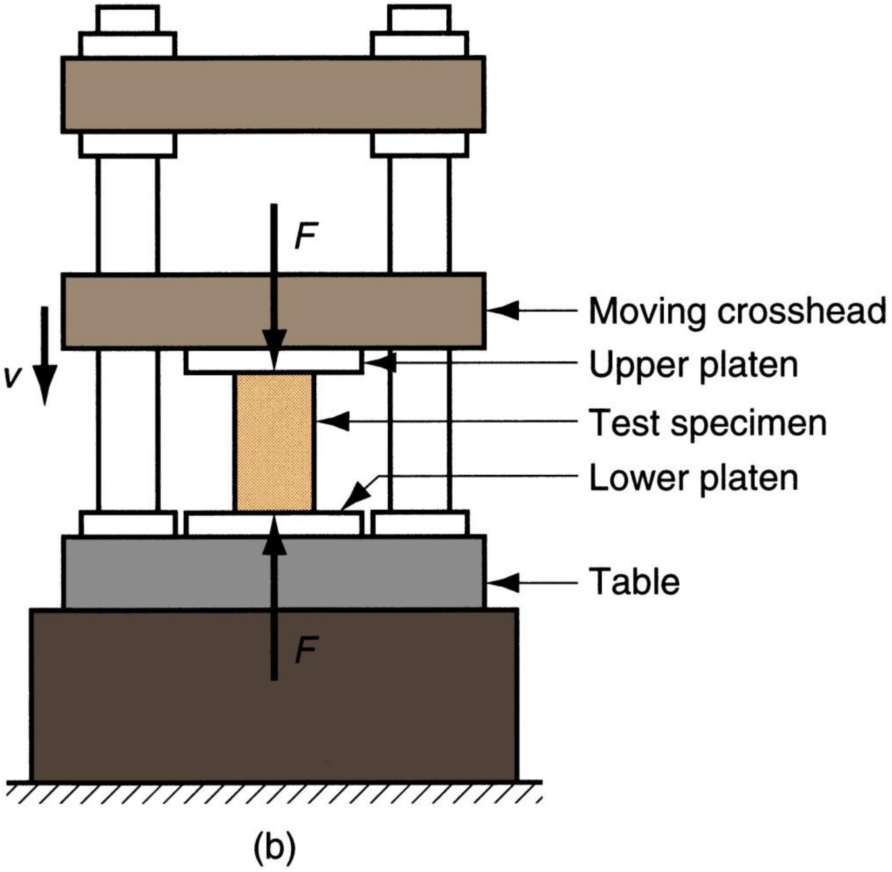
➲ Applies a load that squeezes the ends of a cylindrical specimen between two platens



Compression test:

(a) compression force applied to test piece in (1) and (2) resulting change in height

Compression Test

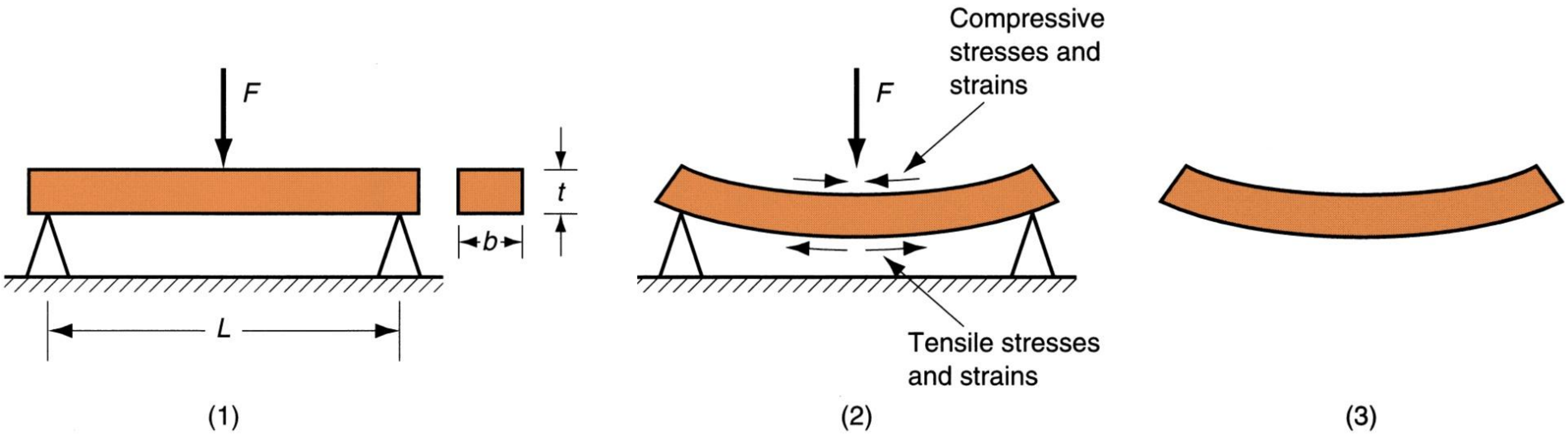


Compression test: (b) setup for the test with size of test specimen exaggerated

Testing of Brittle Materials

- Hard brittle materials (e.g., ceramics) possess elasticity but little or no plasticity
- Often tested by a *bending test* (also called *flexure test*)
  - Specimen of rectangular cross-section is positioned between two supports, and a load is applied at its center

Testing of Brittle Materials

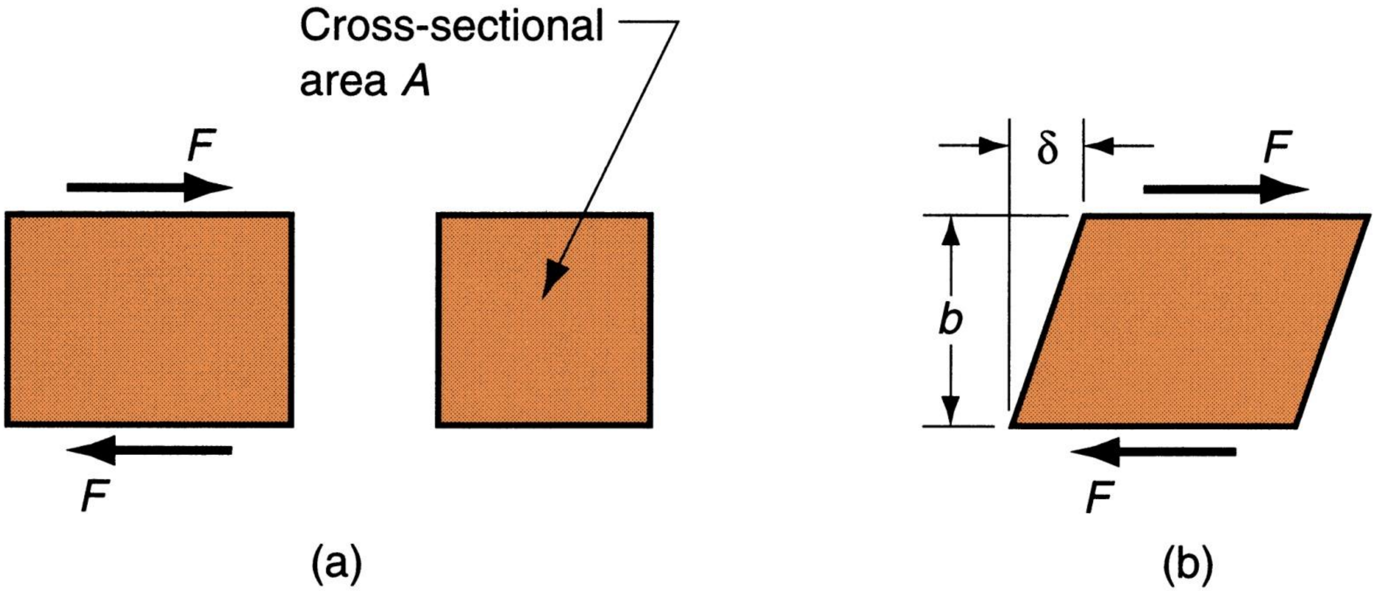


Bending of a rectangular cross-section results in both tensile and compressive stresses in the material: (1) initial loading; (2) highly stressed and strained specimen; and (3) bent part

- Brittle materials do not flex
- They deform elastically until fracture

Shear Stress and Strain

Application of stresses in opposite directions on either side of a thin element



Shear (a) stress and (b) strain

Hardness

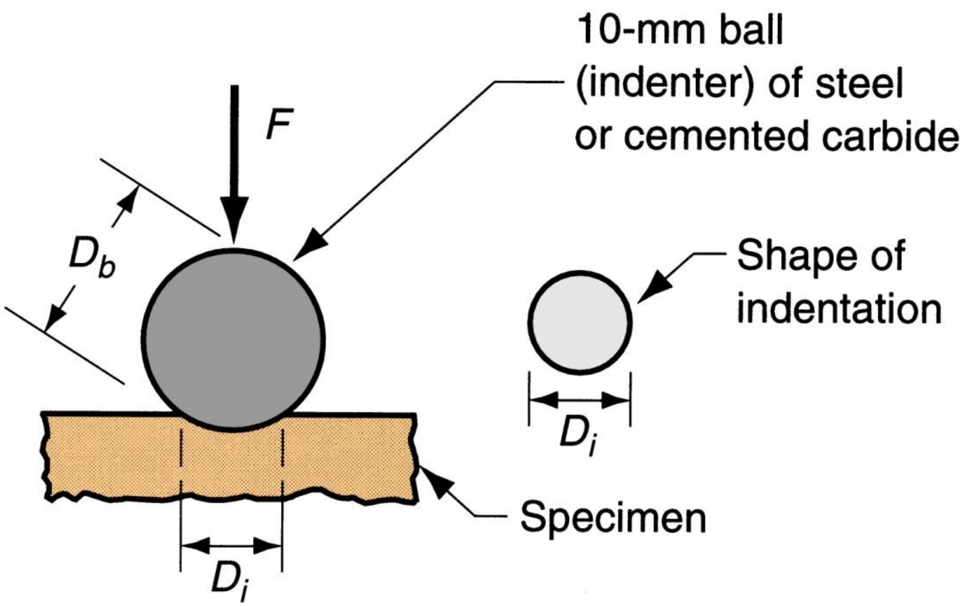
- Resistance to permanent indentation
- Good hardness generally means material is <u>resistant to scratching and wear</u>
- Most tooling used in manufacturing must be hard for scratch and wear resistance

Hardness Tests

- <u>Commonly used</u> for assessing material properties because they are <u>quick and convenient</u>
- <u>Variety of testing methods</u> are appropriate due to differences in hardness among different materials
- <u>Most well-known</u> hardness tests are *Brinell* and *Rockwell*
- Other test methods are also available, such as Vickers, Knoop, Scleroscope, and durometer

Brinell Hardness

- Widely used for testing metals and nonmetals of <u>low to medium hardness</u>
- <u>A hard ball</u> is pressed into specimen surface with a load of 500, 1500, or 3000 kg



(a) Brinell

Hardness testing methods

Rockwell Hardness Test

- Another widely used test
- A <u>cone shaped indenter</u> is pressed into specimen using a minor load of 10 kg, thus seating indenter in material
- Then, a major load of 150 kg is applied, causing indenter to penetrate beyond its initial position
- Additional penetration distance *d* is converted into a Rockwell hardness reading by the testing machine

Rockwell Hardness Test

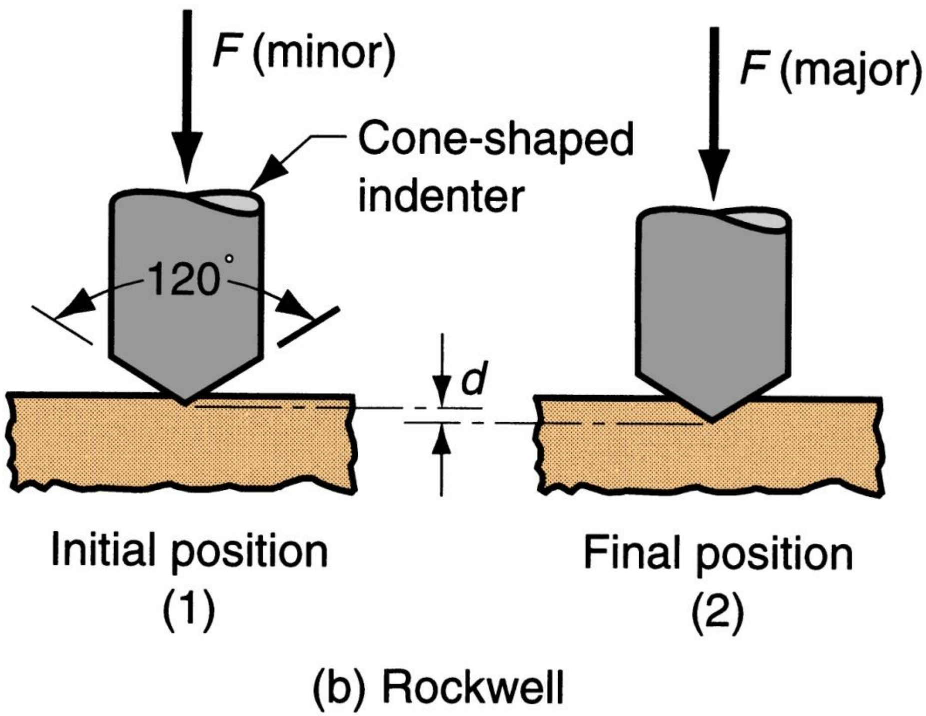
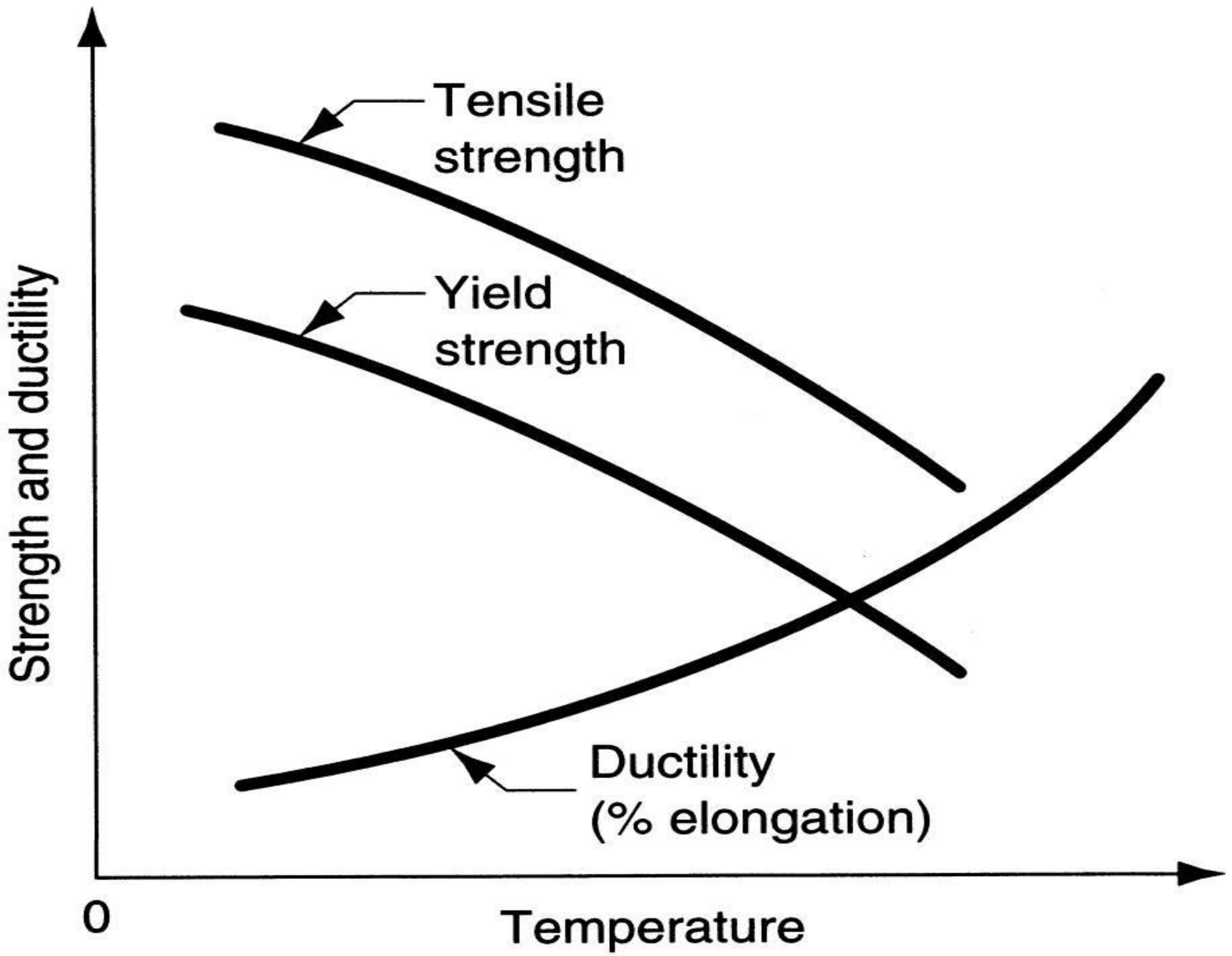


Figure 3.14 – Hardness testing methods: (b) Rockwell: (1) initial minor load and (2) major load

Effect of Temperature on Properties



Fluid Properties and Manufacturing

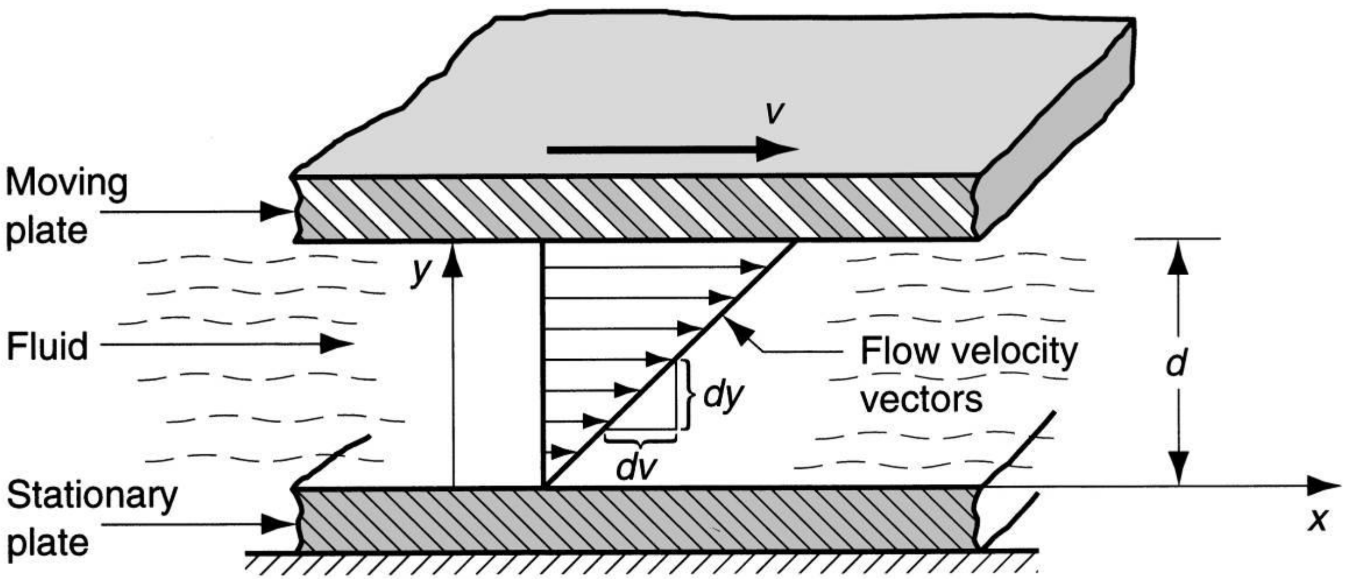
- Fluids flow – They take the shape of the container that holds them
- Many manufacturing processes are accomplished on materials converted from solid to liquid by heating
  - Called *solidification processes*
- Examples:
  - Metals are cast in molten state
  - Glass is formed in a heated and fluid state
  - Polymers are almost always shaped as fluids

Viscosity in Fluids

- Viscosity is the resistance to flow that is characteristic of a given fluid
- Viscosity is a measure of the internal friction when velocity gradients are present in the fluid
  - The more viscous the fluid, the higher the internal friction and the greater the resistance to flow
  - Reciprocal of viscosity is *fluidity* – the ease with which a fluid flows

Viscosity in Fluids

Viscosity can be defined using two parallel plates separated by a distance *d* and a fluid fills the space between the two plates

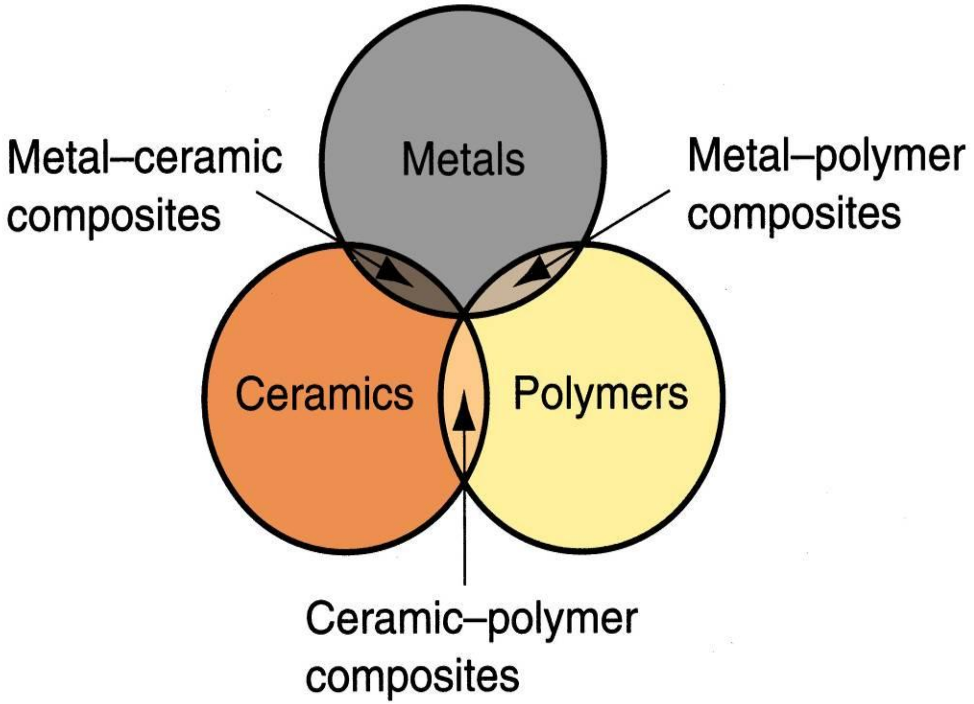


How Do We Choose the Right Material?

- Yield Strength (Y): The point at which permanent elongation occurs
- Ductility: The extent of plastic deformation that occurs (width of stress-strain curve)
- Fatigue: A cyclic stress (baseball bat, gear teeth)
- Creep: Permanent elongation of a work piece under a static load maintained for a period of time

Four Types of Engineering Material

1. Metals
2. Polymers
3. Ceramics
4. Composites



Basic Properties of Material

- **Metal:** high strength and hardness, high electrical and thermal conductivity
- **Ceramic:** high hardness and stiffness, electrically insulating and chemically inert
- **Polymer:** low density, high electrical resistivity, low thermal conductivity and strength and stiffness vary widely

Metals : The Most Important Engineering Materials Today

- They have properties that satisfy a wide variety of design requirements
- The manufacturing processes by which they are shaped into products have been developed and refined over many years
- Engineers understand metals

Metals and Alloys

- Some metals are important as pure elements (e.g., gold, silver, copper)
- Most engineering applications require the enhanced properties obtained by alloying
- Through alloying, it is possible to increase strength, hardness, and other properties compared to pure metals

Classification of Metals

- *Ferrous* – those based on iron
  - *Steels*
  - *Cast irons*
- *Nonferrous* – all other metals
  - Aluminum, magnesium, copper, nickel, titanium, zinc, lead, tin, molybdenum, tungsten, gold, silver, platinum, and others
- Super alloys

Ferrous Metals

- Based on iron, one of the oldest metals known to man
- Ferrous metals of engineering importance are alloys of iron and carbon
- These alloys divide into two major groups:
  - Steel
  - Cast iron
- Together, they constitute approximately 85% of the metal tonnage in the US

Nonferrous Metals

- Metal elements and alloys not based on iron
- Most important engineering metals in nonferrous group are aluminum, copper, magnesium, nickel, titanium, and zinc, and their alloys
- Although not as strong as steels, certain nonferrous alloys have corrosion resistance and/or strength-to-weight ratios that make them competitive with steels in moderate-to-high stress applications
- Many nonferrous metals have properties other than mechanical that make them ideal for applications in which steel would not be suitable

Why Metals are Important

- *High stiffness and strength* – can be alloyed for higher rigidity, strength, and hardness
- *Toughness* – capacity to absorb energy better than other classes of materials
- *Good electrical conductivity* – Metals are conductors
- *Good thermal conductivity* – conduct heat better than ceramics or polymers
- *Cost* – the price of steel is very competitive with other engineering materials

Why Super alloys are Important

- High temperature performance is excellent – tensile strength, hot hardness, creep resistance, and corrosion resistance at very elevated temperatures
- Operating temperatures often in the vicinity of 1100°C (2000°F)
- Applications: gas turbines, jet and rocket engines, steam turbines, and nuclear power plants – systems in which operating efficiency increases with higher temperatures

Polymer

- A compound consisting of long-chain molecules, each molecule (e.g. ethylene C_2H_4) made up of repeating units connected together
- The word *polymer* is derived from the Greek words *poly*, meaning many, and *meros* (reduced to *mer*), meaning part
- Most polymers are based on carbon and are therefore considered organic chemicals

Types of Polymer

- Polymers can be separated into *plastics* and *rubbers*

- As engineering materials, it is appropriate to divide them into the following three categories:

  1. *Thermoplastic* polymers
  2. *Thermosetting* polymers
  3. *Elastomers*

  ✓ where (1) and (2) are plastics & (3) are rubbers

Examples of Polymers

- Thermoplastics:
  - Polyethylene, polyvinylchloride (PVC), polypropylene, polystyrene, and nylon
- Thermosets:
  - Phenolics, epoxies, and certain polyesters
- Elastomers:
  - Natural rubber
  - Synthetic rubbers

Thermoplastics (TP)

- Solid materials at room temperature but viscous liquids when heated to temperatures of only a few hundred degrees
- This characteristic allows them to be easily and economically shaped into products
- They can be subjected to heating and cooling cycles repeatedly without significant degradation

Commercial Thermoplastic Products and Raw Materials

- Thermoplastic products include molded and extruded items, fibers, films and sheets, packaging materials, and paints and varnishes
- The starting plastic materials are normally supplied to the fabricator in the form of powders or pellets in bags, drums, or larger loads by truck or rail car

Thermosets (TS)

- Cannot tolerate repeated heating cycles as thermoplastics can
  - When initially heated, they soften and flow for molding
  - But elevated temperatures also produce a chemical reaction that hardens the material into an infusible solid
  - If reheated, thermosets degrade rather than soften

Commercial Thermoset Products

- TS plastics are not as widely used as the TP
- TS Products: countertops, plywood adhesives, paints, molded parts, printed circuit boards and other fiber reinforced plastics

Elastomers

- Polymers that exhibit extreme elastic extensibility when subjected to relatively low mechanical stress
- Also known as rubber
- Some elastomers can be stretched by a factor of 10 and yet completely recover to their original shape
- Two categories:
  1. *Natural rubber* :

     derived from biological plants

     rubber is extracted from latex by various methods that remove the water
  2. *Synthetic polymers :*

     produced by polymerization (synthesis) processes

     the main raw material for synthetic rubbers is petroleum

Reasons Why Polymers are Important

- Plastics can be formed by molding into intricate part shapes, usually with no further processing required
  - Very compatible with *net shape* processing
- On a volumetric basis, polymers:
  - Cost competitive with metals
  - Generally require less energy to produce than metals
- Certain plastics are translucent and/or transparent, which makes them competitive with glass in some applications

Ceramics

- ➲ Compounds containing metallic (or semi-metallic) and nonmetallic elements.
- ➲ Typical nonmetallic elements are oxygen, nitrogen, and carbon
- ➲ For processing, ceramics divide into:
  1. Crystalline ceramics – includes:
     - Traditional ceramics, such as clay (hydrous aluminum silicates)
     - Modern ceramics, such as alumina (Al_2O_3)
  2. Glasses – mostly based on silica (SiO_2)

Composites

- Material consisting of two or more phases that are processed separately and then bonded together to achieve properties superior to its constituents
- Examples:

  Cemented carbides (tungsten carbide with cobalt binder)

  Plastic molding compounds with fillers, e.g. glass fiber

  Rubber with carbon black


Q
A