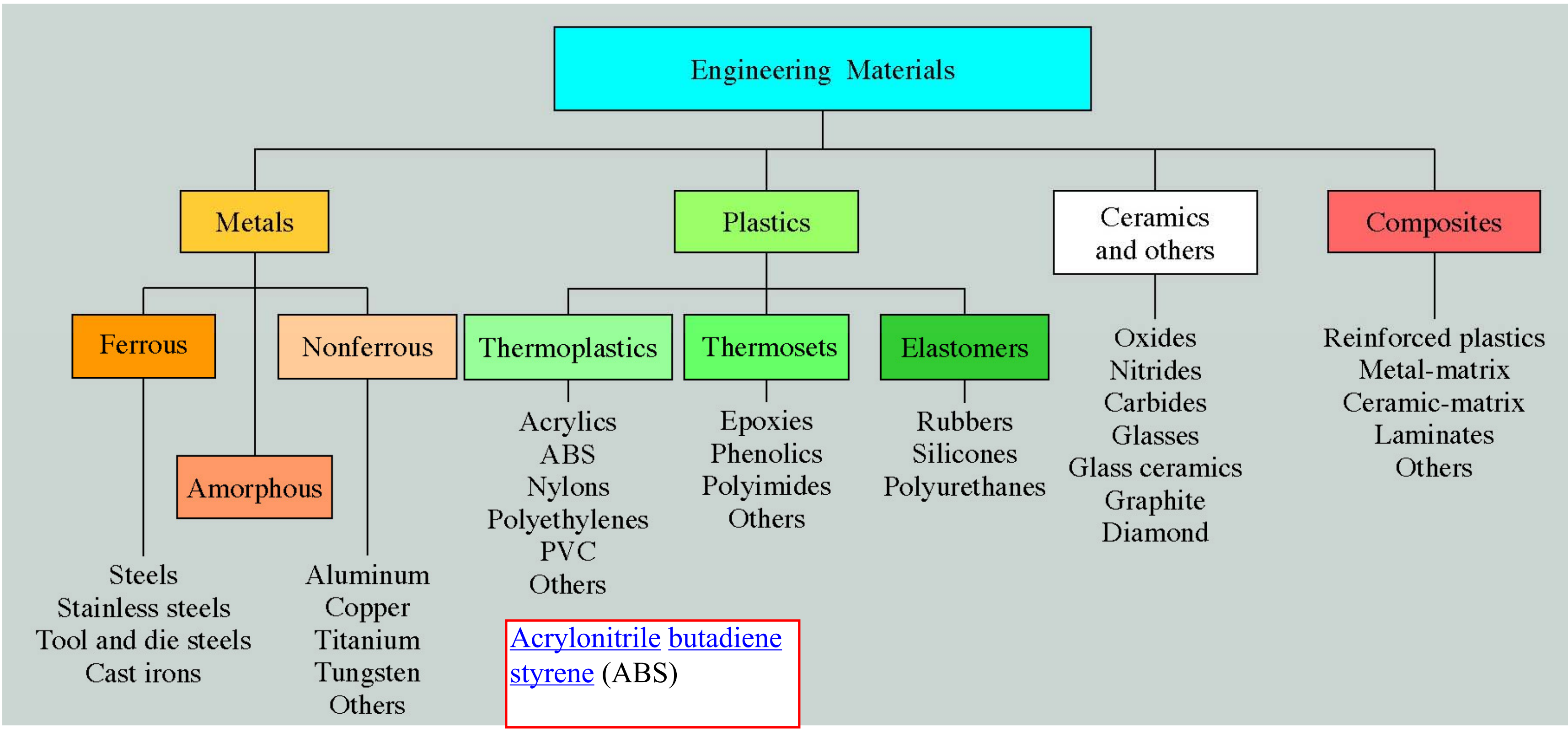
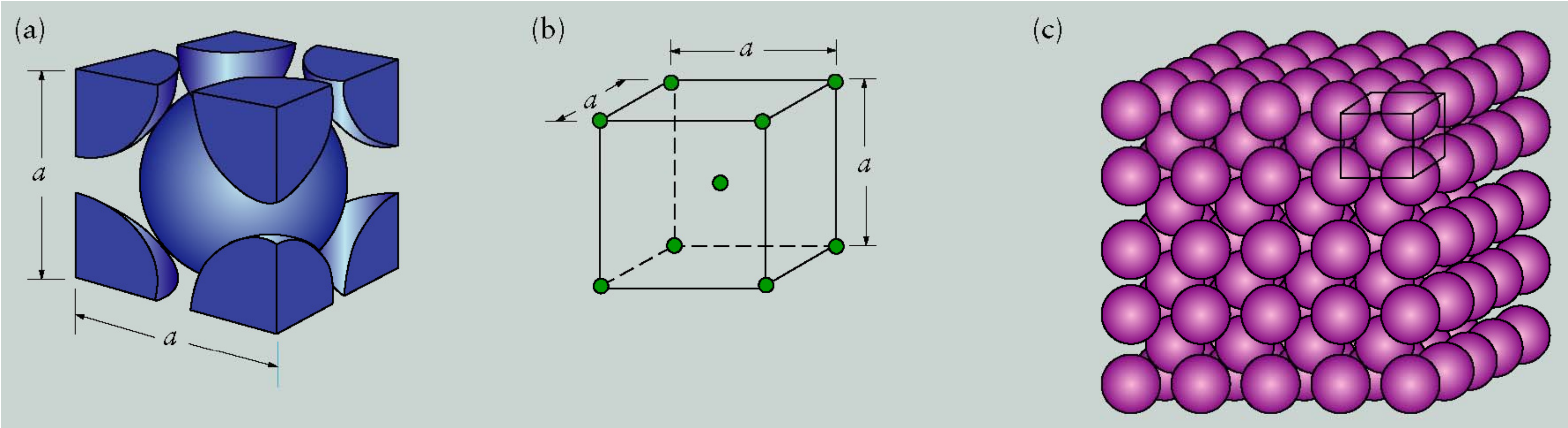


Manufacturing Processes for Engineering Materials, 4th ed.
Kalpakjian • Schmid
Prentice Hall, 2003

Manufacturing Materials

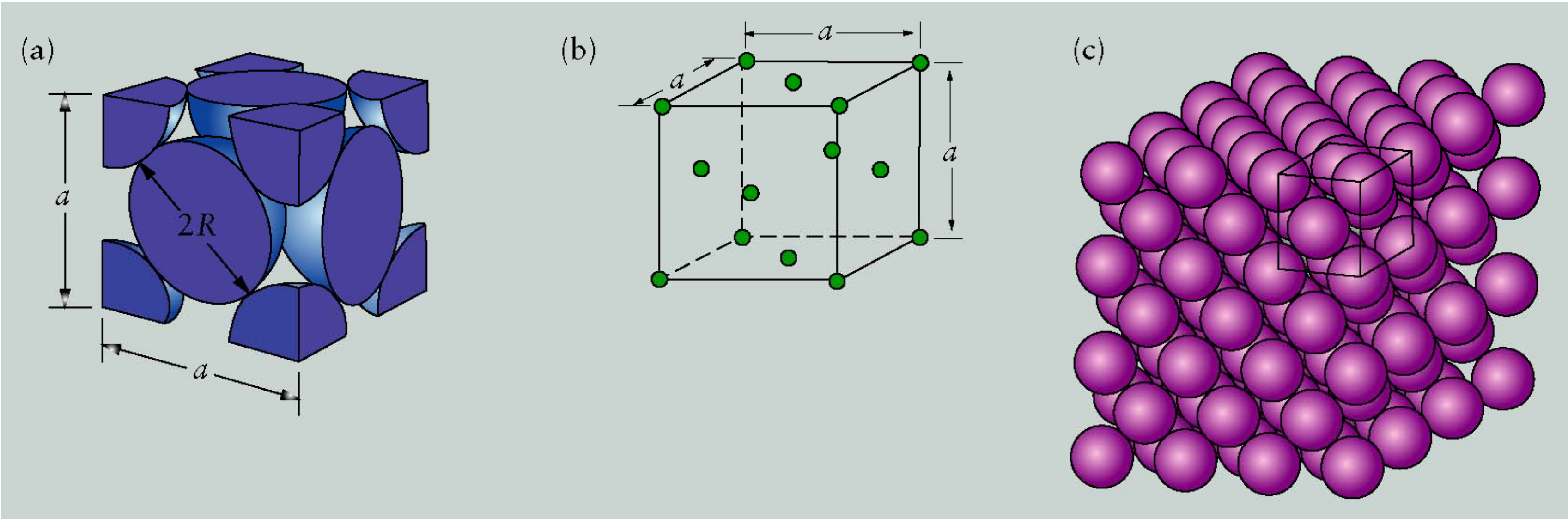
- Metals
  - Ferrous
    - Pure iron is rarely used as an engineering material
    - It is used in the form of alloys; composed of two or more elements
    - Generally these are classified on the basis of %C with Fe
    - %C >2.11: Cast Iron; %C<2.11: Steels
  - Non-ferrous
- Ceramics
- Polymers
- Composites

Body-Centered Cubic Crystal Structure



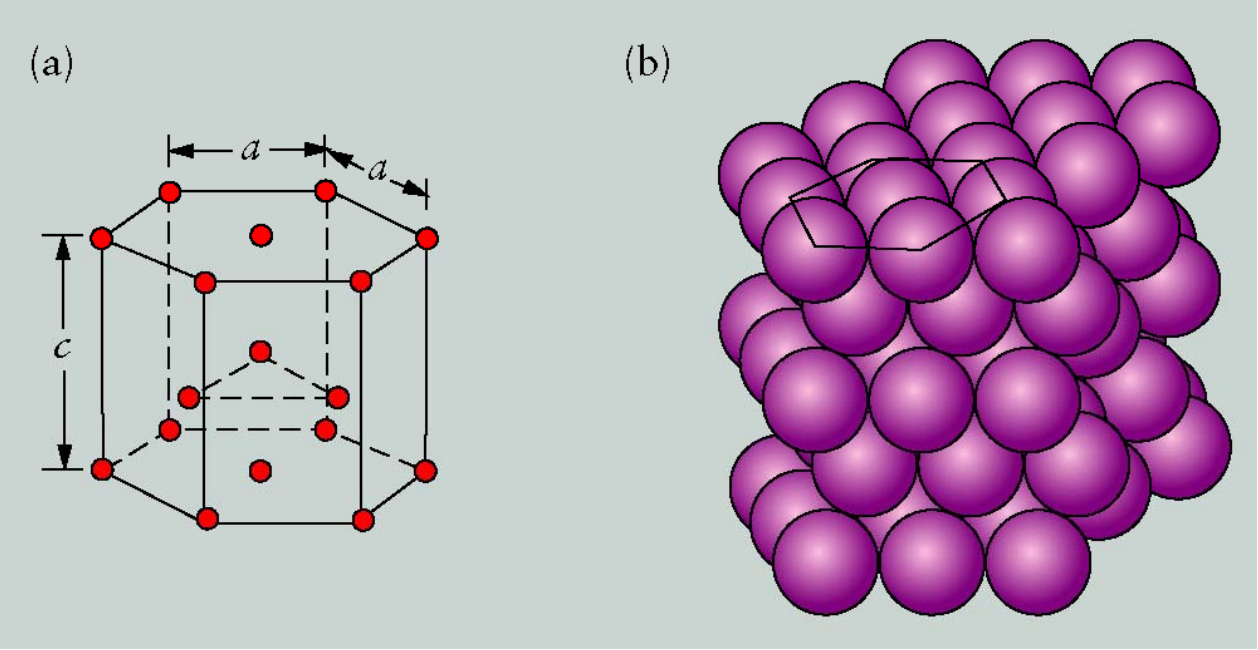
The body-centered cubic (bcc) crystal structure: (a) hard-ball model; (b) unit cell; and (c) single crystal with many unit cells. Source: W.G. Moffatt et al.

Face-Centered Cubic Crystal Structure



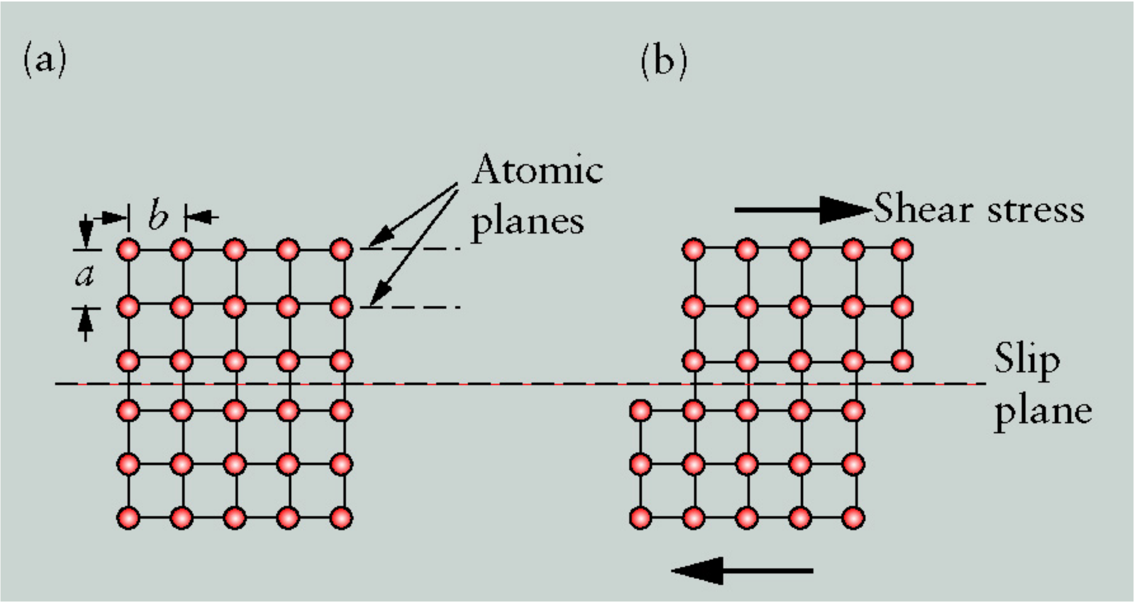
The face-centered cubic (fcc) crystal structure: (a) hard-ball model; (b) unit cell; and (c) single crystal with many unit cell. *Source*: W.G. Moffatt et al.

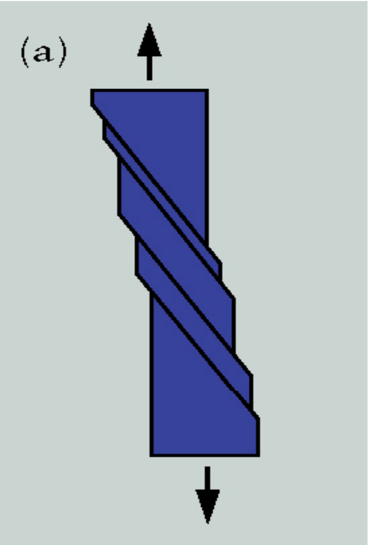
Hexagonal Close-Packed Crystal Structure



The hexagonal close-packed (hcp) crystal structure: (a) unit cell; and (b) single crystal with many unit cells. *Source*: W.G. Moffatt et al.

Plastic Deformation of a Single Crystal

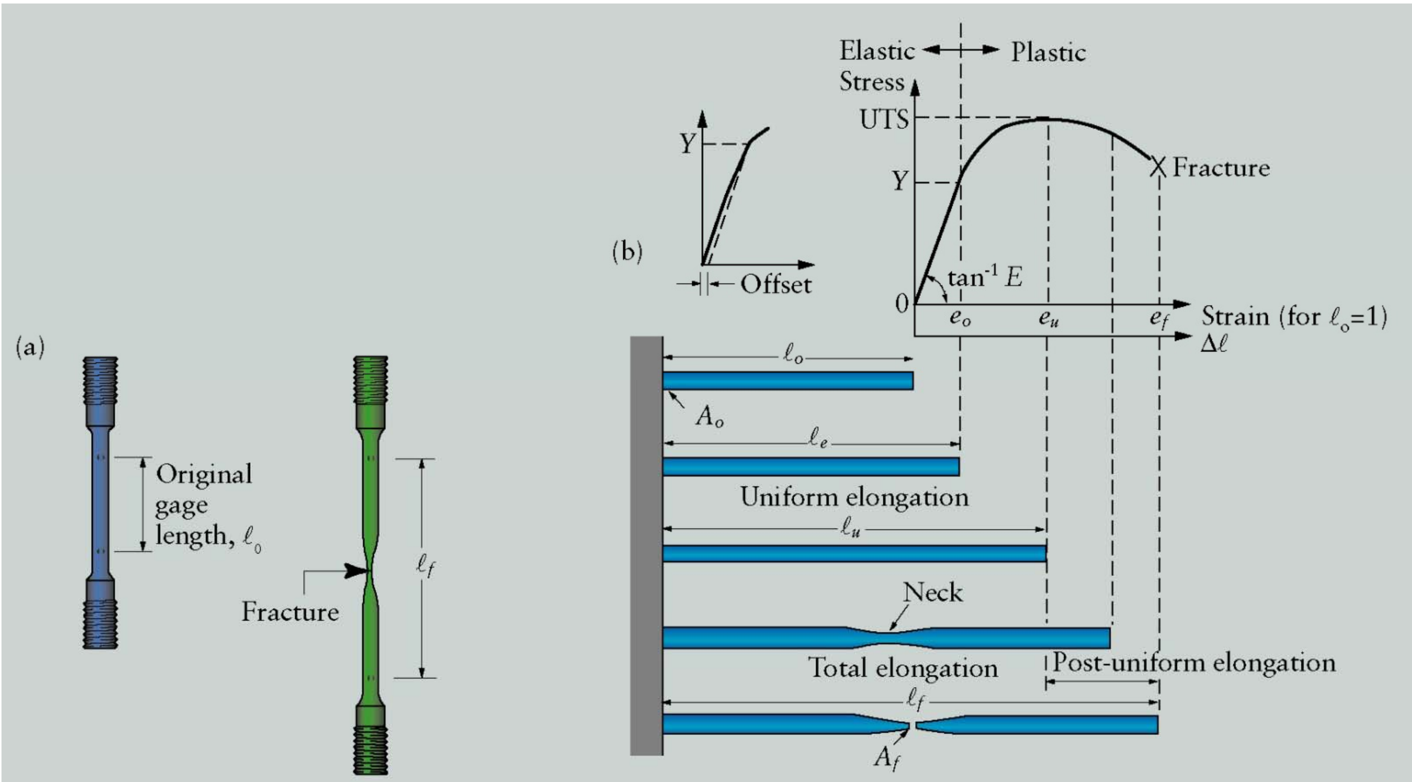


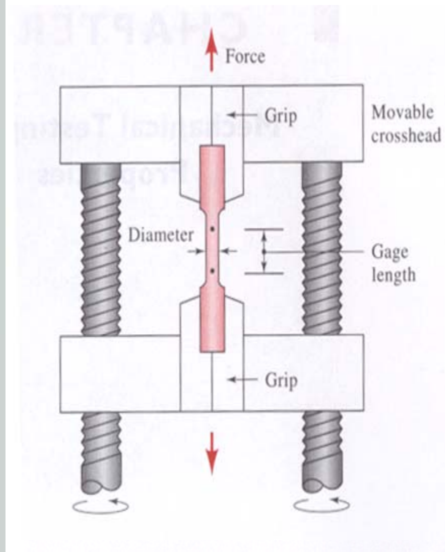


Tensile Loading

Permanent deformation, also called plastic deformation, of a single crystal subjected to a shear stress: (a) structure before deformation by slip. The *b/a* ratio influences the magnitude of the shear stress required to cause slip.

Tension Test





$$\text{Engineering stress} = \sigma = \frac{F}{A_0}$$

$$\text{Engineering strain} = \varepsilon = \frac{l - l_0}{l_0}$$

Tensile Test & the properties obtained from the Tensile Test

6-2 The Tensile Test: Use of the Stress-Strain Diagram

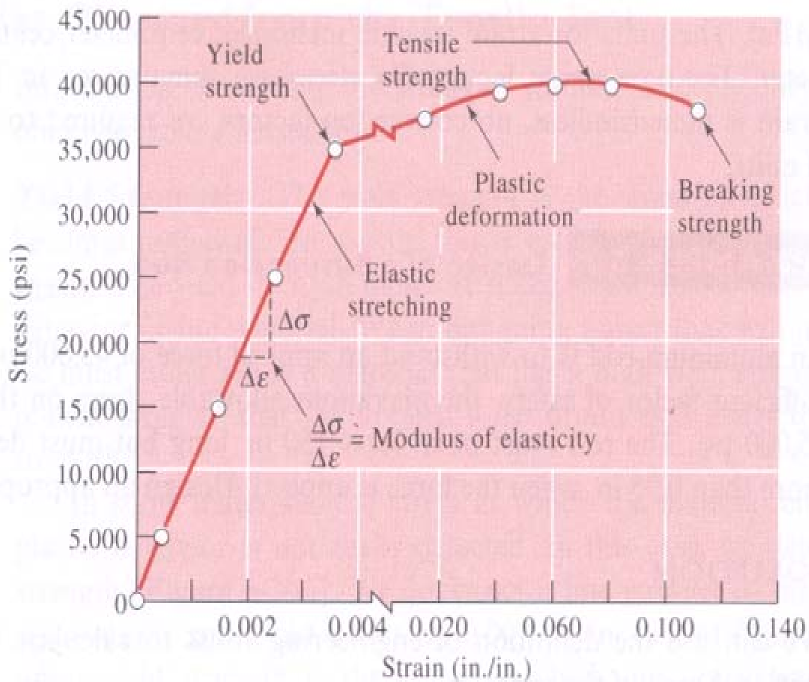
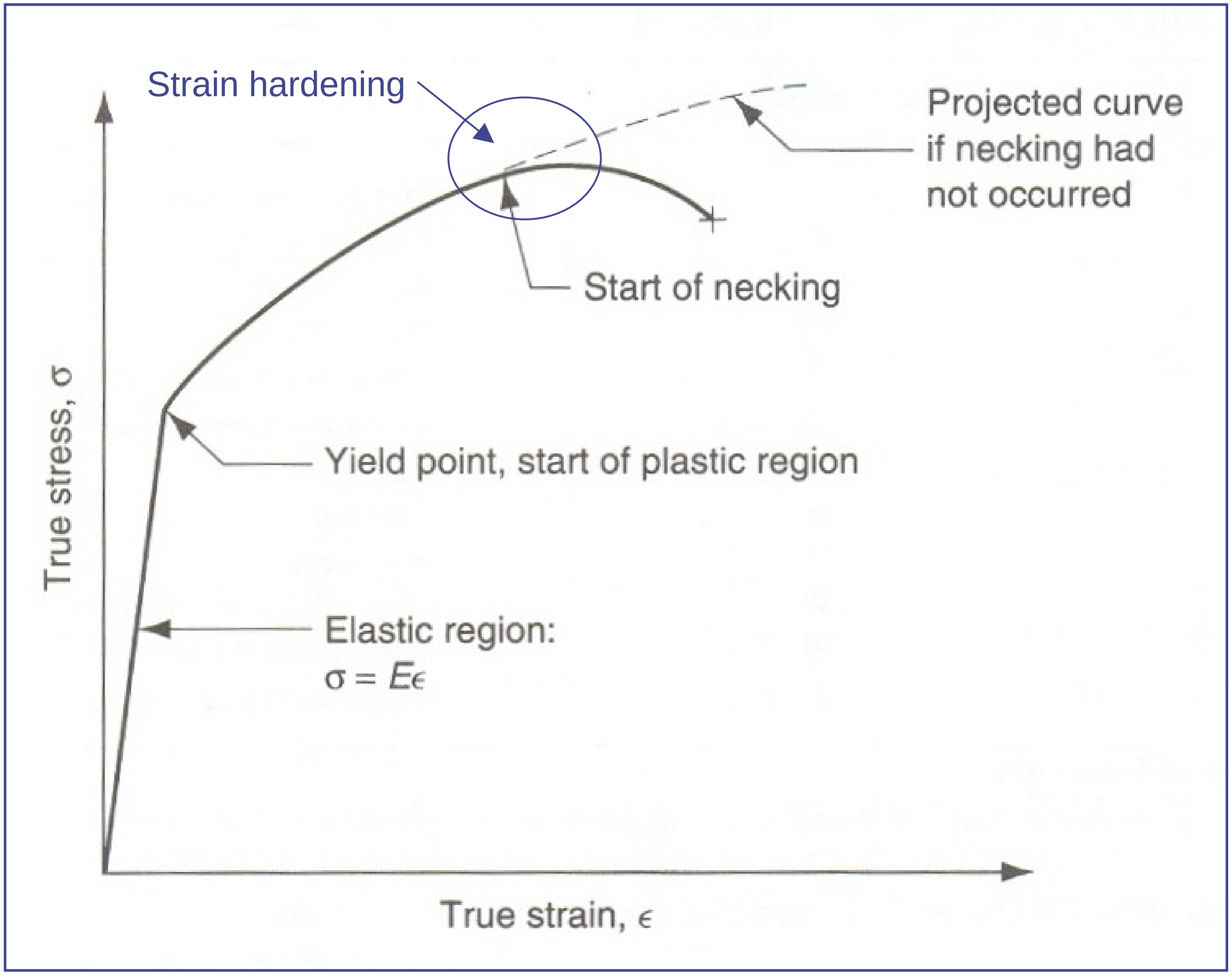


FIGURE 6-2 The stress-strain curve for an aluminum alloy from Table 6-1.

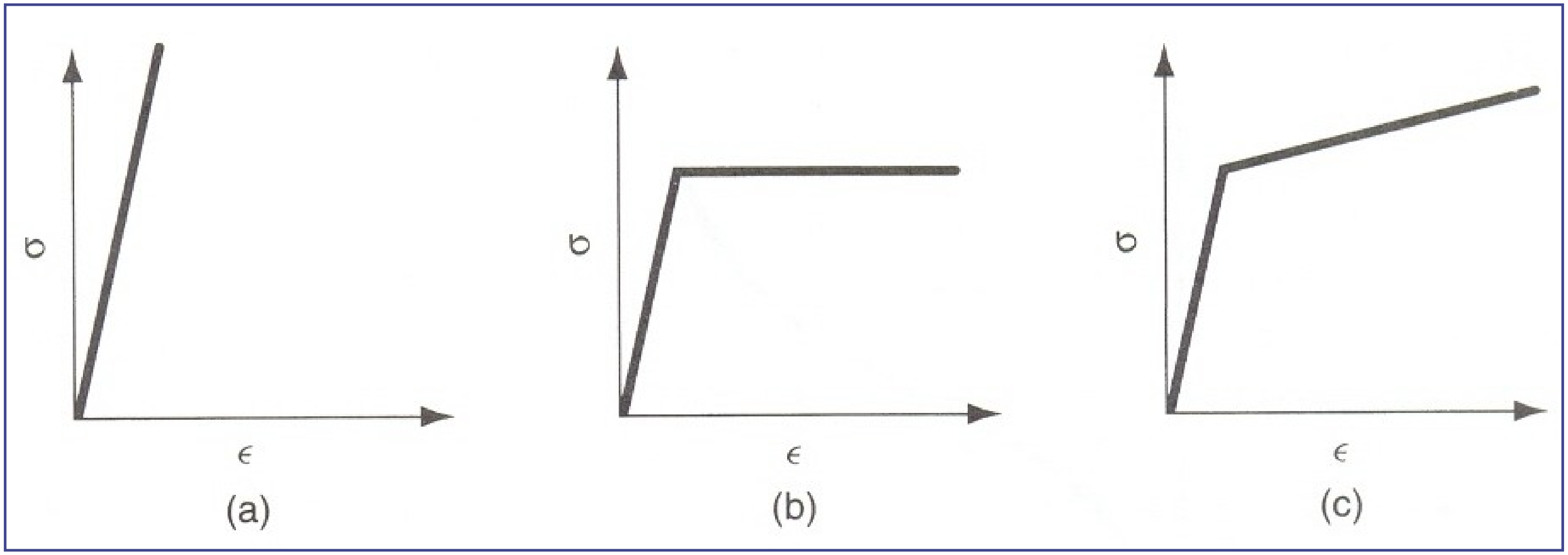
Ductility is defined as the ability of a solid material to deform under tensile loading
Gold happens to be the most ductile material.
Malleability is defined as a material's ability to deform under compressive stresses

True stress-strain curve



Strain hardening is the resistance of a metal to further plastic deformation. The tendency of a metal to strain harden is indicated by tangent moduli of the plastic curve (i.e. smaller slope refers to less tendency)

Material Models

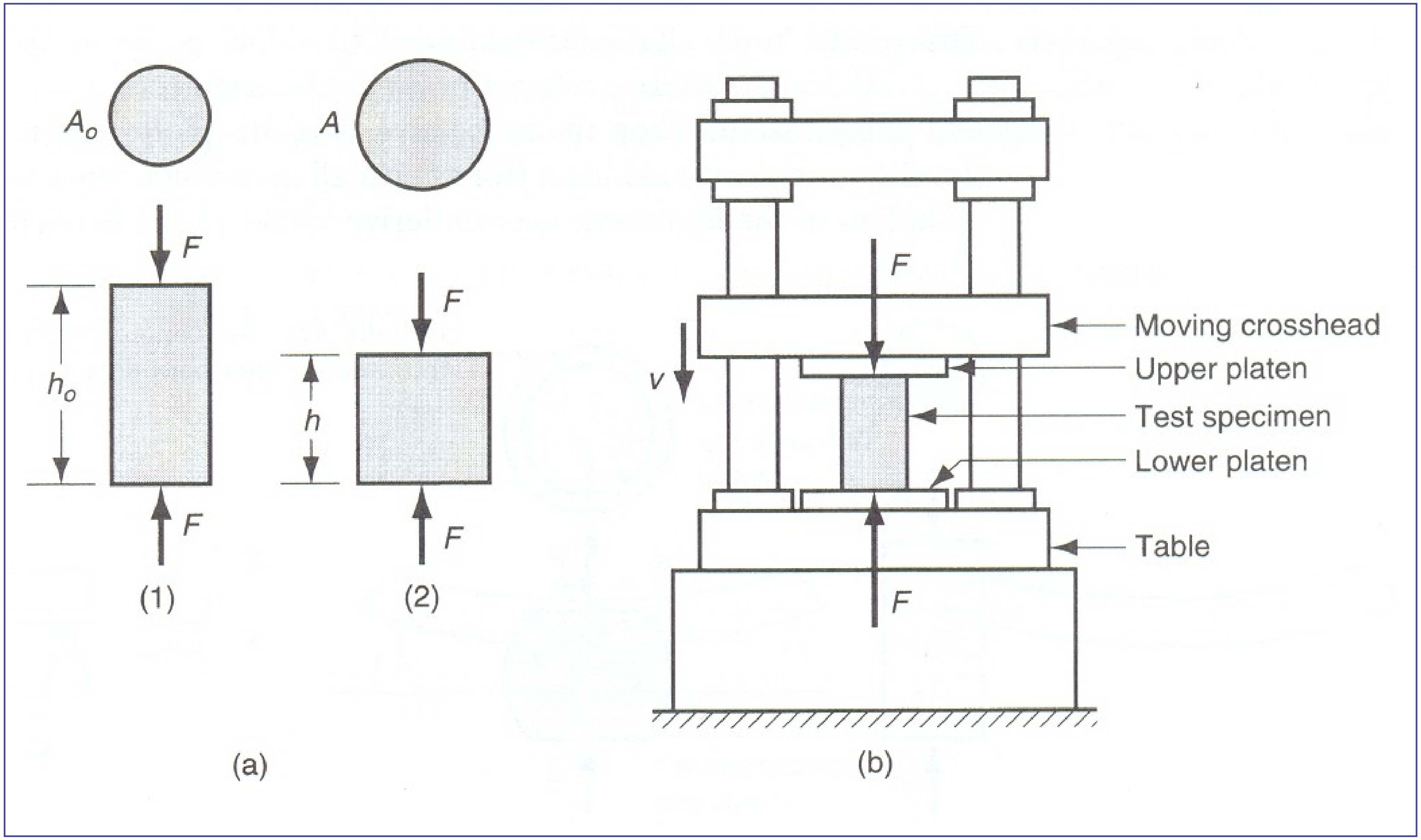


(a) Perfectly elastic

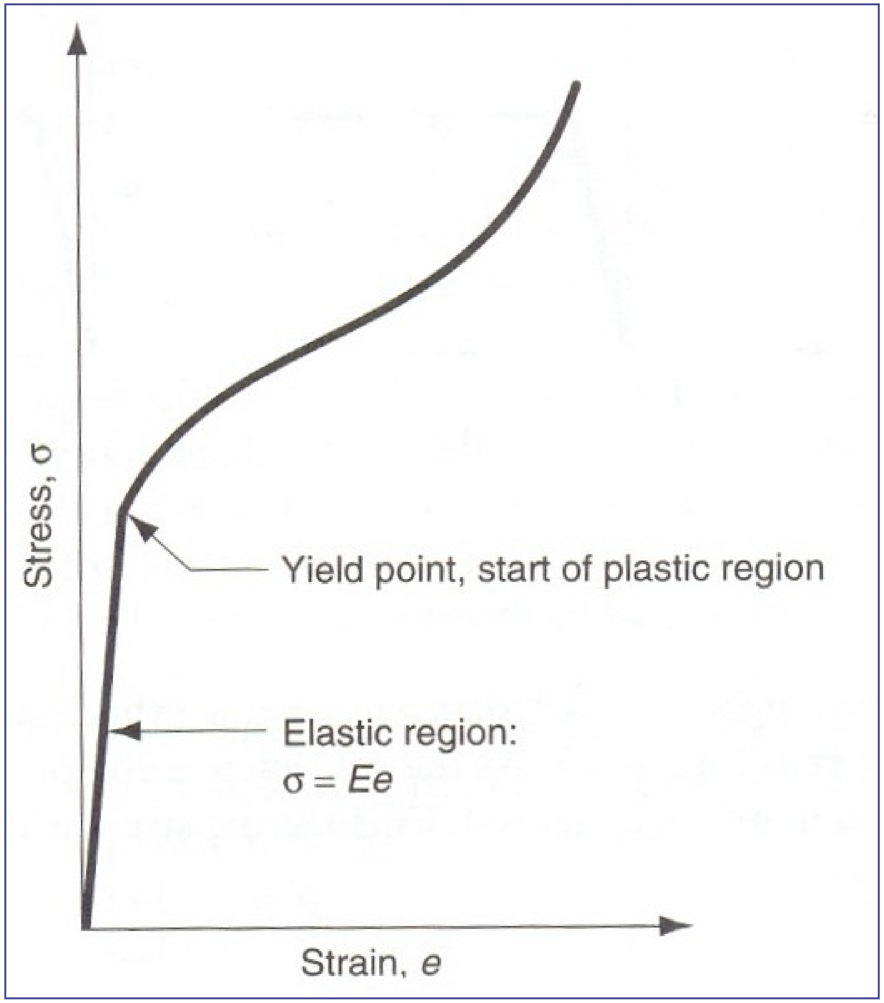
(b) Elastic and perfectly plastic

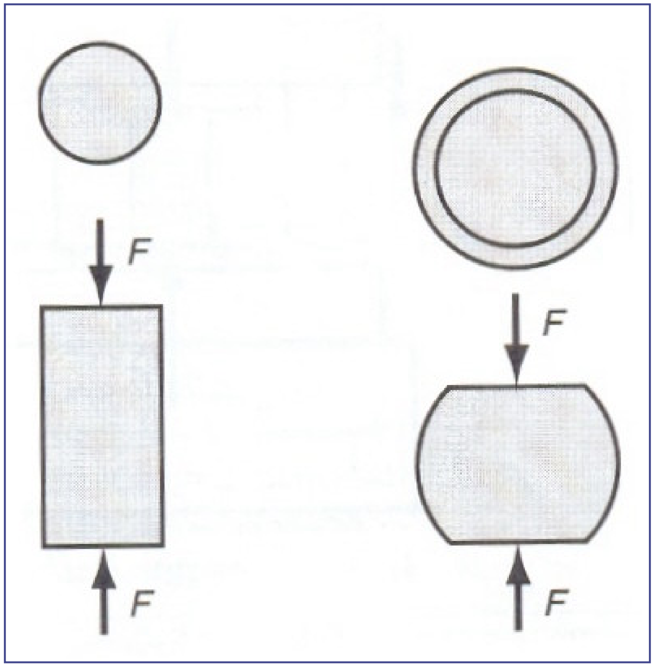
(c) Elastic and Plastic with strain hardening

Compression test



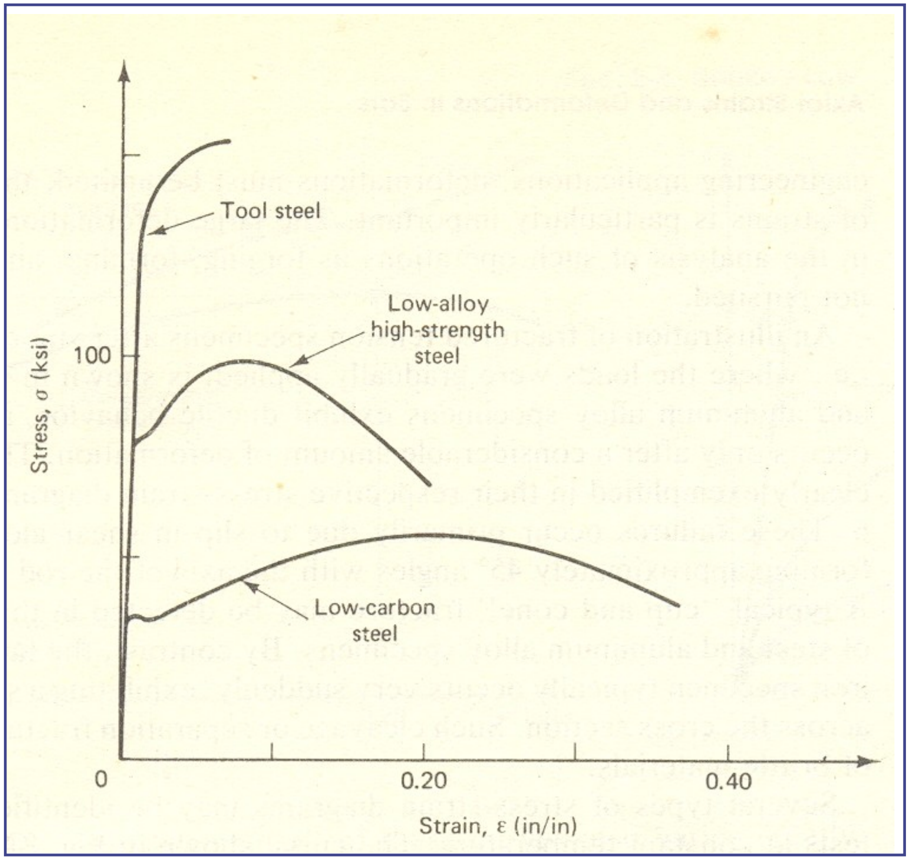
Typical engineering stress-strain curve for compression test

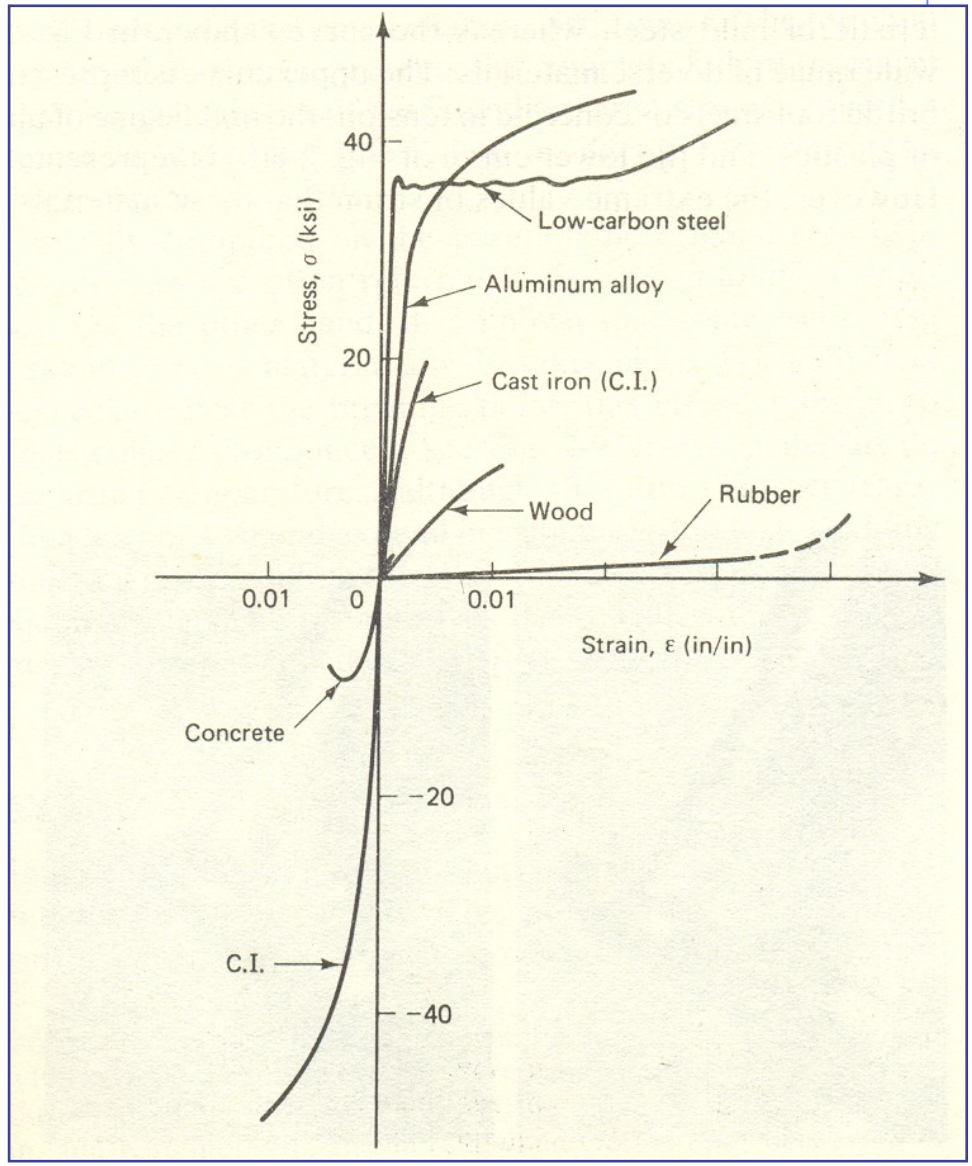


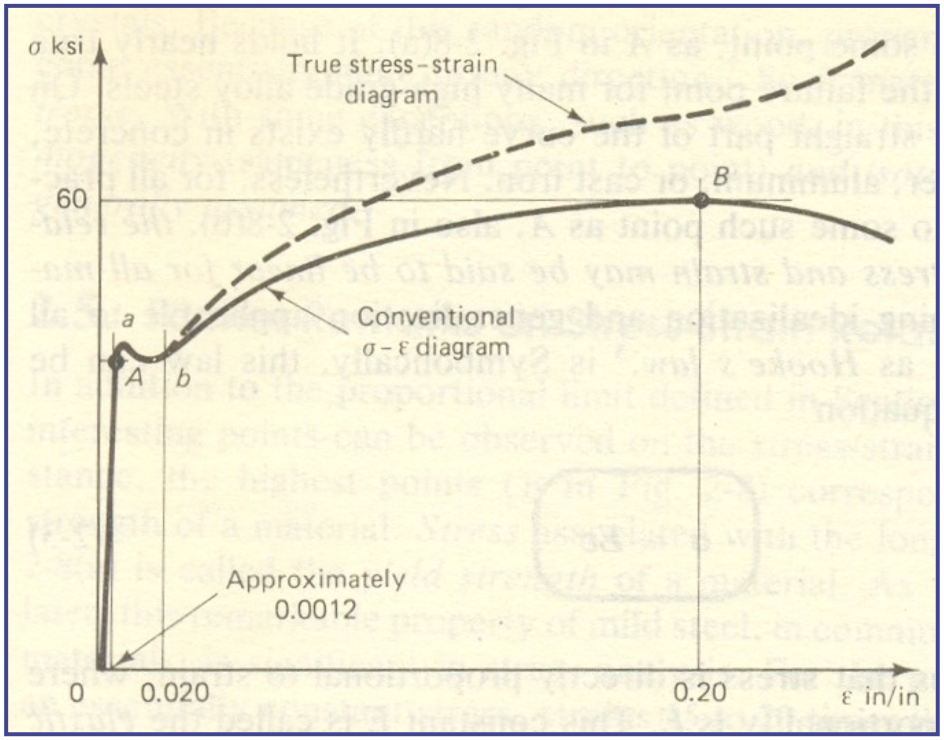


Barreling due to friction

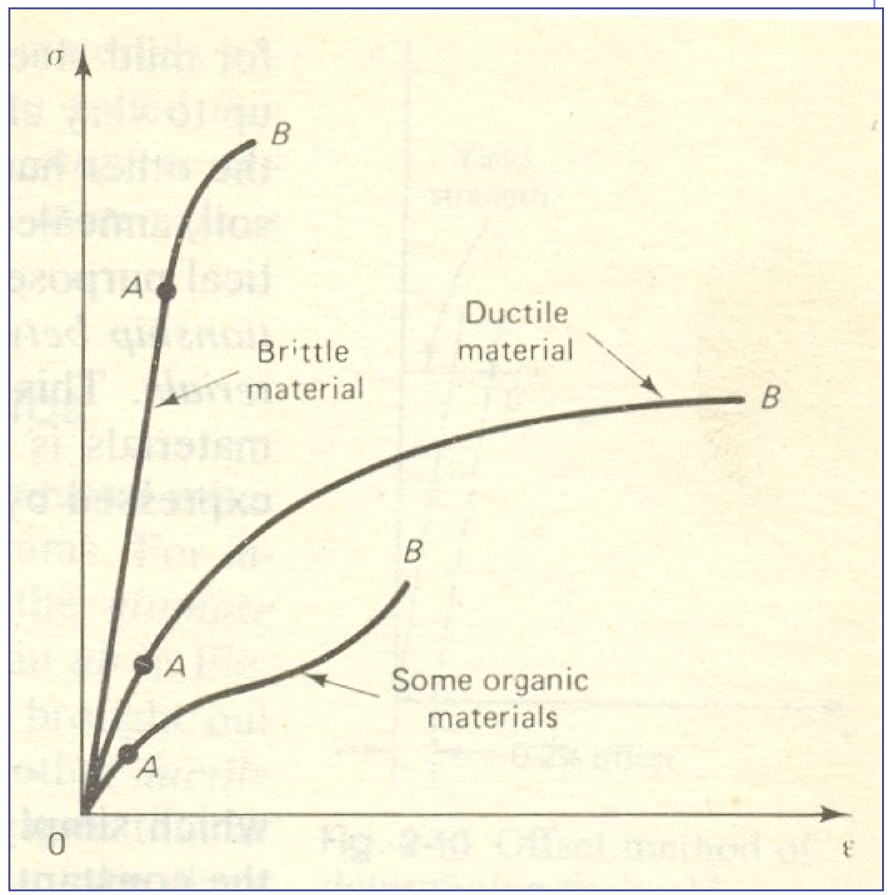
Typical stress-strain curves





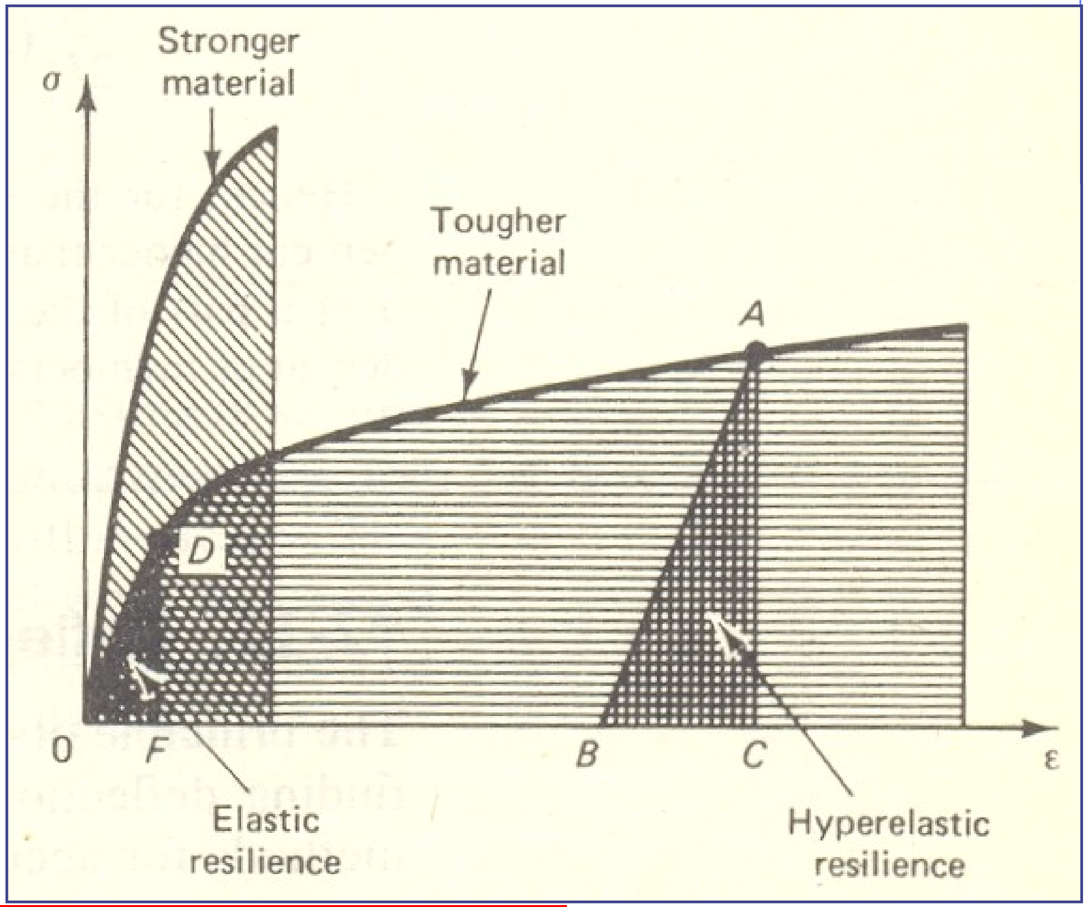

σ ksi
True stress–strain diagram
60
B
a
A
b
Conventional σ – ε diagram
Approximately 0.0012
0
0.020
0.20
ε in/in

Mild steel


σ
B
A
Brittle material
Ductile material
B
B
A
Some organic materials
A
0
ε

Resilience and Toughness

- Resilience: Amount of energy stored in material up to elastic limit per unit volume
- Toughness: Amount of energy stored in material up to fracture per unit volume



Hyperelastic resilience is the energy released when the plastic loading upon the specimen is removed

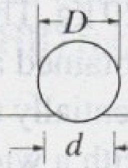
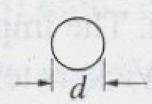
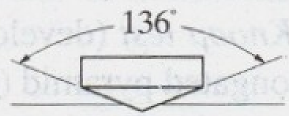
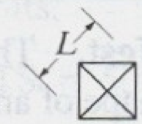
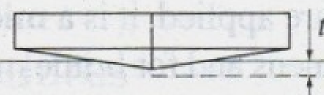
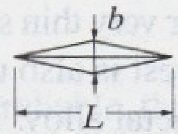
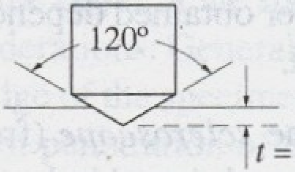
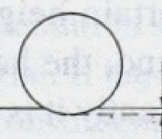
Hardness

- Resistance to permanent indentation. Good hardness generally mean that the material is resistant to scratching and wear. It is also an indication of strength.
- Not a fundamental property as the resistance to indentation depends on the shape of the indenter and on the load applied.

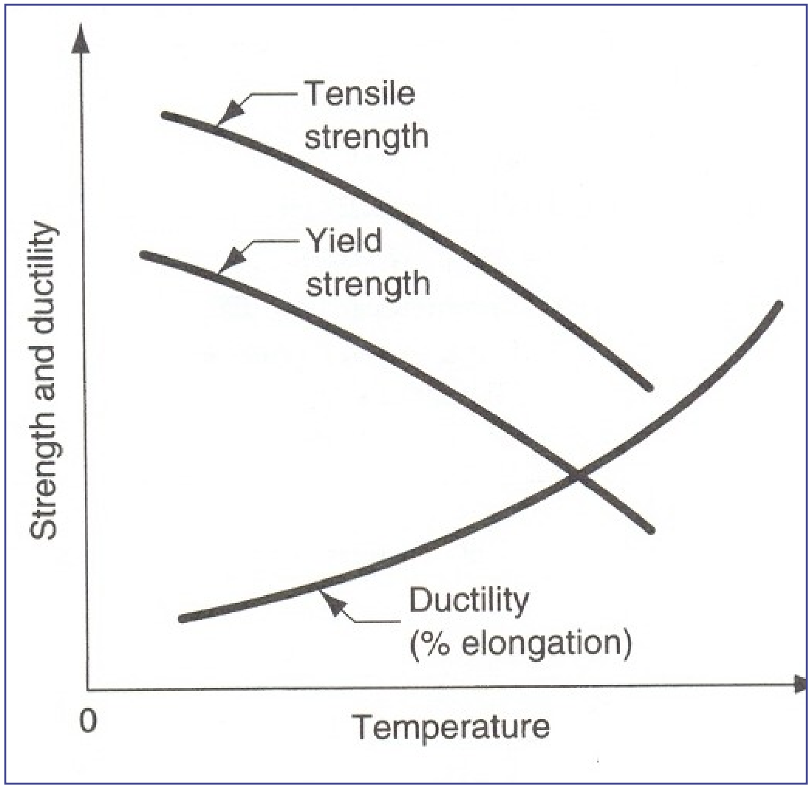
- Hardness Tests
  - Brinell Test
  - Vickers Test
  - Knoop Test
  - Rockwell Test

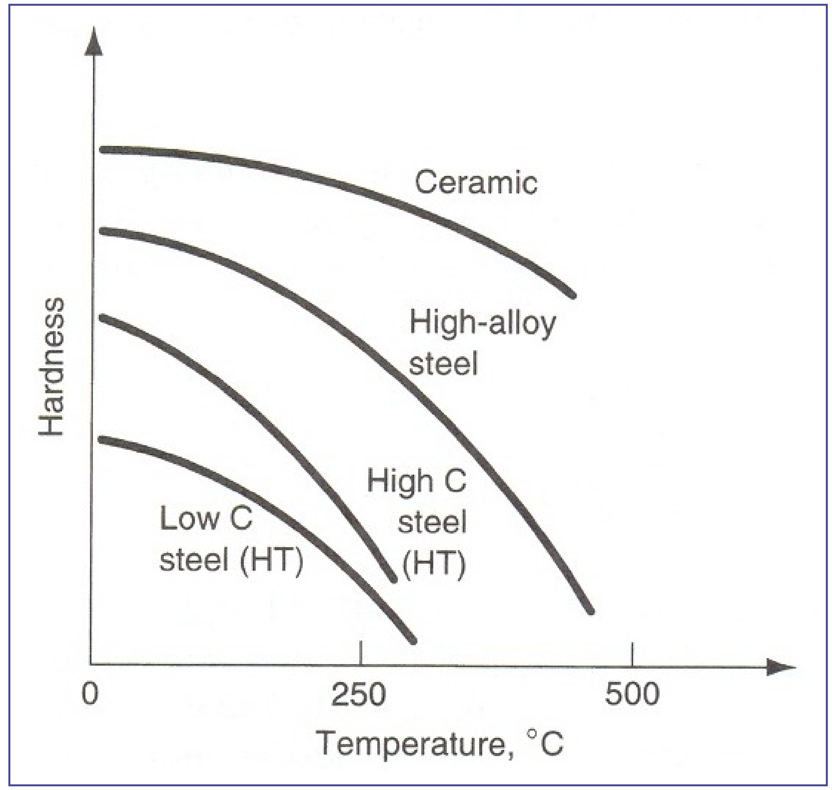
- Scleroscope *Refer Kalpakjian's book
- Mohs hardness
- Durometer

* Figure 2.14 Kpjn's book

Test	Indenter	Shape of indentation: Side view	Shape of indentation: Top view	Load, P	Hardness number
Brinell	10-mm steel or tungsten carbide ball			500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid			1-120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid	 $L/b = 7.11$ $b/t = 4.00$		25g-5kg	$HK = \frac{14.2P}{L^2}$
Rockwell				kg	
A C D	Diamond cone			60 150 100	HRA HRC HRD = $100 - 500t$
B F G	$\frac{1}{16}$ - in. diameter steel ball			100 60 150	HRB HRF HRG = $130 - 500t$
E	$\frac{1}{8}$ - in. diameter steel ball			100	HRE = $130 - 500t$

Effect of temperature on properties

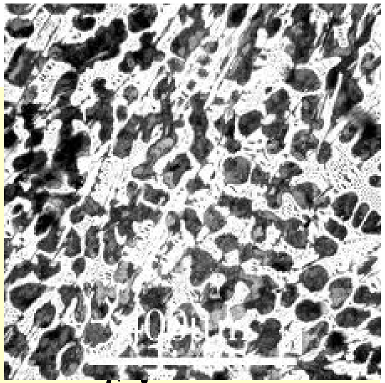




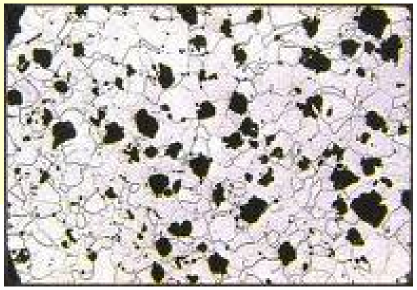
Ductility is measured by sometimes **percentage elongation** (δ_L) and sometimes **percentage reduction in area** (δ_A)

Cast Iron

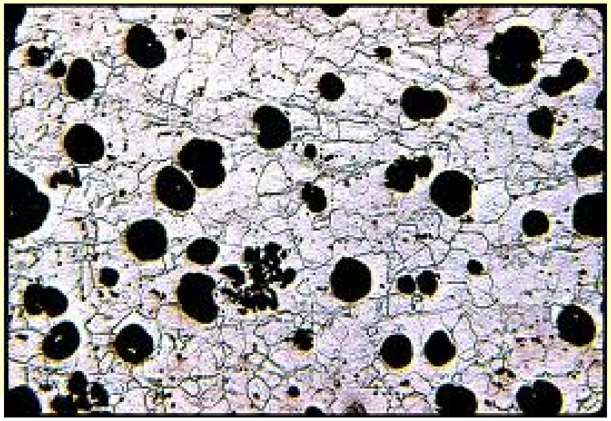
- Carbon is generally present from 2.11 to 4%, 0.5 to 3% Si, 0.4 to 1% Mn and few other elements to improve casting properties.
- Depending upon the form in which carbon is present, several type of C.I. are obtained
- Gray Cast Iron
  - Most commonly used
  - Carbon is present as graphite flakes distributed throughout
  - When it is fractured, the exposed surface of metal has gray appearance and graphite smudge is obtained on fingers when rubbed across surface
  - This dispersion of graphite flakes provides good internal lubricating property hence excellent machinability and vibration damping characteristics.
  - It has poor tensile strength and ductility
  - It posses good compressive strength, wear resistance and corrosion resistance
  - Commonly used for machine bodies, engine blocks, pumps an housings, etc.



- White Cast Iron
  - Produced by rapid cooing of molten gray CI
  - Carbon remains chemically combined in the form of iron carbide (cementite)
  - When fractured, it has white shining appearance
  - It is hard, brittle and posses excellent wear resistance
  - Used for applications requiring high wear resistance, e.g., railway brake shoes, grinding balls, crushing rollers, etc.
- Malleable Cast Iron
  - It is obtained by heat treatment of white CI and carbon is present in forms of clusters
  - This structure promoted toughness and ductility
  - It is used in making small tools, pipe fittings, automobile parts, farm implements, etc.



- Ductile or Nodular Cast Iron
  - This is obtained by adding Mg or Cesium (nodulizing agents) to molten Gray CI before pouring.
  - In this the carbon is present in the form of spheroids
  - It has good ductility, high strength, toughness, wear resistance and excellent casting properties.
  - Is is popular material for making intricate castings
- Cast irons are often alloyed with various elements and heat treated to achieve special properties like high hardness, temperature resistant, corrosion resistant etc.



Steels

C: 0.02 to 2.11 %, other alloying elements like Mn, Cr, Ni, Mo, etc.

- Plain carbon steels (other elements 0.4% Mn, 0.05% S, 0.04% P), The strength increases with increase in %C but ductility decreases.
  - Low carbon steels
    - Less than 0.2% C
    - Most common steel known as mild steel, high strength
    - Plates, sheets, rods, machine components, nut and bolts
  - Medium carbon steels
    - 0.2 to 0.5 % C
    - Used where high strength is required like engine components
  - High carbon steels
    - 0.5 to 2.11% C
    - Even high strength applications like tools, blades, springs, etc.

➢ Alloy steels

Additional alloying elements are added to improve the mechanical properties of plain carbon steel

commonly added elements are

Mn : To improve strength and hardness

Cr : To improve strength and wear resistance and hot hardness

Cu : To improve strength and corrosion resistance

Mo : To improve heat resistance and toughness

Ni : To improve strength and toughness

Si : To improve strength and toughness

- Total percentage of alloying elements <5% by weight. Generally Fe-C alloy containing more than 1.65% Mn or 0.6%Si or 0.6% of Cu are designated as alloy steels
- They have better strength to weight ratio
- Used in transportation, mining and agriculture equipments. Their structural sections are used in building and other structures

Stainless steels

- Alloy steels designed to provide high corrosion resistance along with high strength and ductility.
- Principal alloying element is Cr> 12%
- Other alloying elements include Ni, Mo, Ti, Si, Mn etc.
- Typical applications of these steel are for kitchen, surgical, chemical and food processing equipments.

Tool steels

- Highly alloyed steels designed for use as tools and dies in machining and forming process
- They are designed to provide high strength and toughness and wear resistance at both room and elevated temperatures
- In these materials wear resistance and toughness are balanced by various combination of following alloying elements

Tool steels

Tungsten (W)	1.5 – 20%
Chromium (Cr)	0.2 – 15%
Molybdenum (Mo)	0.8 – 15%
cobalt (Co)	0.75 – 12%
Vanadium (V)	0.15 – 3%
Silicon (Si)	0.5 – 2%
Manganese(Mn)	0.2 - 1.6%

- A variety of tool steels like high speed steel, mould steels, hot-work tool steels, cold-work tool steels etc. are obtained.

Non Ferrous Metals

- Not iron based
- They cover a wide variety of materials such as Al, Cu, Mn, to high strength , high temperature resistance alloy like W, tantulum and Mo.
- Important because resistance to corrosion high strength to weight ratio ,high electric and thermal conductivity

Al-Al Alloys

- Extensively used for aircraft, bus car and marine craft bodies, cooking utensils etc.
- High strength to weight ratio resistance to corrosion, good electrical and thermal conductivity

Cu – Cu Alloys

- Good conduction of heat and electricity
- Brass (65%Cu and 35% Zn), high conductivity adequate strength and ductility
- Bronze (90%Cu and 10%tin), Good strength and toughness and wear strength and corrosion resistance

Mg – Mg alloys

- Lightest engineering Material with specific gravity as 1.75
- Mg – alloy is used for various high-strength to weight ratio applications
- Applications: Aircraft & missile components, material handling equipments, sporting goods and general light weight components

Ni-Ni Alloys

- Silver white metal. Used for electroplating for appearance and for improving corrosion resistance.
- Ni alloys offer high strength and corrosion resistance at elevated temperature
- “Monel” a Ni- Cu alloy is used extensively in chemical and food processing industries due to corrosion resistance property.
- Super alloys of Ni are used for high temperature applications such as for jet engines, gas turbines, and rocket components and in nuclear power plants.

Zinc

- A low melting point metal
- Main use in galvanizing on iron and steel for providing corrosion resistance
- Zinc alloys are primarily used for die casting of components for automobile and appliance industries

Titanium

- High strength to weight ratio and corrosion resistant material at elevated temperature
- Ti- alloys with alloying elements such as Al, Va, Mo, Mn etc. can be used up to 550°c
- Attractive material for aerospace applications, marine, chemical and photo chemical equipments

Ceramics

- Compounds of metallic and non-metallic elements.
- Available in the form of oxides, carbide and nitrides
- They brittle, have high strength and hardness at elevated temperature, low thermal and electrical conductivity
- Clay, Alumina(Al_2O_3), Quartz, Sic ,WC, silicon nitride, CBN etc, are typical examples
- SiC : Heating element

  CBN,WC: Popular cutting tool material

  Silicon Nitride: Application in gas turbines and rocket engines
- Glass is also and inorganic –non-metallic compound and is a ceramic

Polymers

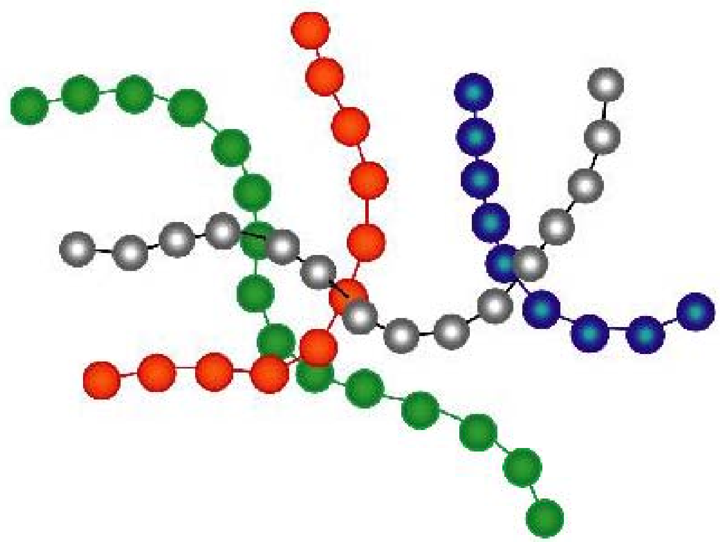
- Compounds of long chain molecules with each molecule made up of repeating units connected together. They are organic compound
- Low density, strength, thermal & electrical conductivity, good chemical resistance
- Low working range of temperature <350°C
  - Thermoplastics
  - Thermo sets
  - Elastomers

Classes and Properties: Polymers

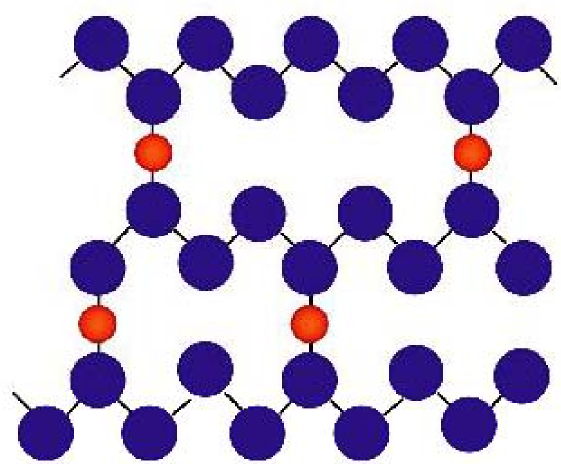
Two main types of polymers are thermosets and thermoplastics.

• Thermosets are cross-linked polymers that form 3-D networks, hence are strong and rigid.

• Thermoplastics are long-chain polymers that slide easily past one another when heated, hence, they tend to be easy to form, bend, and break.



THERMOPLASTIC



THERMOSET

Composite Materials

- Heterogeneous solids consisting of two or more different materials that are metallurgically or mechanically bonded together
- The combination of materials provides for superior properties as compare to constituents
- These materials possess unique combination of properties such as strength, weight stiffness, corrosion resistance, hardness conductivity etc.

➢ Laminar or layer composites: Plywood, coated tools, insulated wires

➢ Particulate composite:

  - Concrete (cement sand and gravel)
  - Abrasive particles and matrix in grinding wheels
  - Cemented carbides- particle of WC uniformly distributed used as a cutting tool
  - properties are uniform in all direction

➢ Fiber – reinforced composite:

- Thin fibers of one material are embedded in matrix of another material
- Glass is most widely used fiber with polymer as matrix. Other fibers are carbon, boron etc.
- Properties depend upon the fibred material volume fraction of fiber, orientation of fiber, properties of matrix, degree of bonding between fiber & matrix etc.
- Polymeric materials are used for low temperature applications (below 300°C), While MMC are used for high temperature application
- Steel reinforced concrete used in construction
- Nylon reinforced tires, glass fiber reinforced plastics for car bodies
- Boron-reinforced components for aircraft & rocket

Selection of Material

A particular material is selected is on the basis of following considerations

1. Properties of material
   - Mechanical properties – strength, ductility, toughness, hardness, strength to weight ratio etc.
   - Physical properties – density, specific heat, thermal expansion, conductivity , melting point etc.
   - Chemical properties – oxidation , corrosion flammability, toxicity etc.
   - Manufacturing properties – formed, casting, machined, welding

2. Cost of material
3. Availability of material (desired shape and size and quantity) & reliability of supply.
4. Service in life of material
   - Dimensional stability of material wear , corrosion etc., shorten life
5. Appearance of material
   - Color
   - Surface texture etc.