Materials (Part 3)

Material Properties

Chapter 11

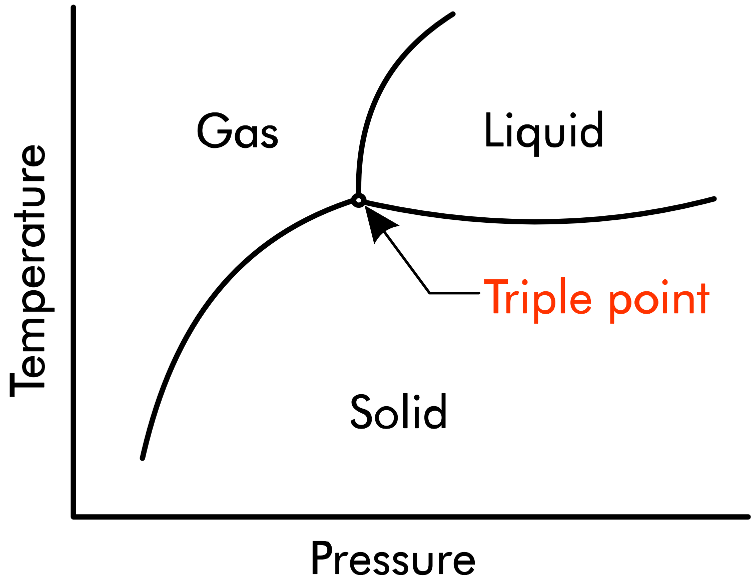
Structure of Matter

- *Matter* can be defined as anything that has mass and occupies space
- May consist of one element alone, or elements in combinations called *compounds*

3 States of Matter

- Gases: Substances that have no definite shape and no definite volume
- Liquids: Substances that have no definite shape, but do have a definite volume.
- Solids: Substances that have a definite shape and definite volume.

Special Temperature Condition



F 11-1 Phase diagram

Properties

- Chemical properties involve the ways substances act when the amounts or nature of the substances change.

- Physical properties are related to any change in which the amounts or nature of the substances do not change.

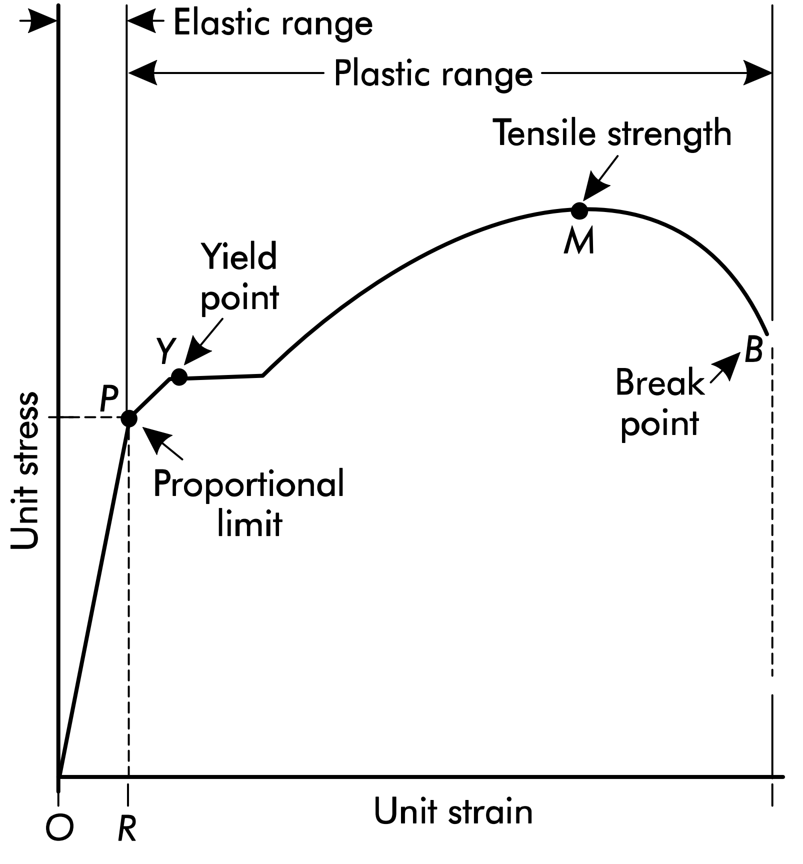
Physical Properties of Materials

- Color
- Density
- Electrical conduction
- Magnetism
- Melting temperature
- Thermal conduction
- Thermal expansion
- Specific gravity
- Specific heat

Mechanical Properties

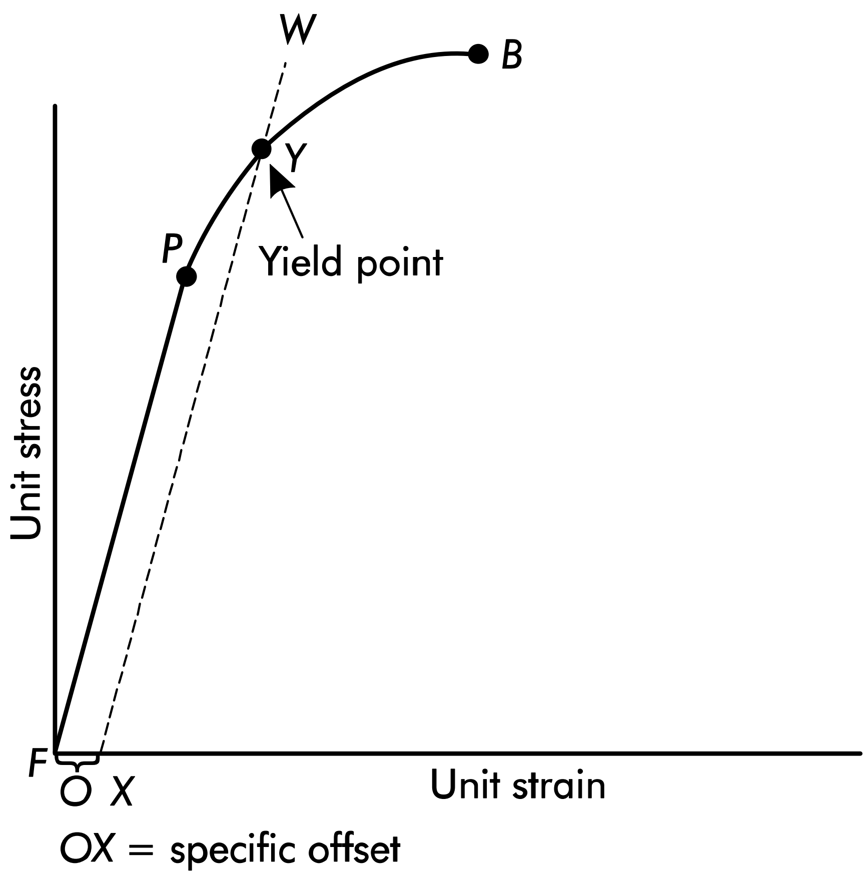
- Brittleness
- Compressive strength
- Creep
- Ductility
- Elastic limit
- Elasticity
- Elongation
- Endurance limit
- Fatigue failure
- Fatigue strength
- Hardness
- Impact strength
- Load
- Malleability
- Mechanical property
- Modulus of elasticity
- Notch toughness
- Physical property
- Plasticity
- Proportional limit
- Strain
- Strength
- Stress
- Tensile strength
- Toughness
- Ultimate tensile strength
- Yield point
- Yield strength

Stress-Strain Diagram



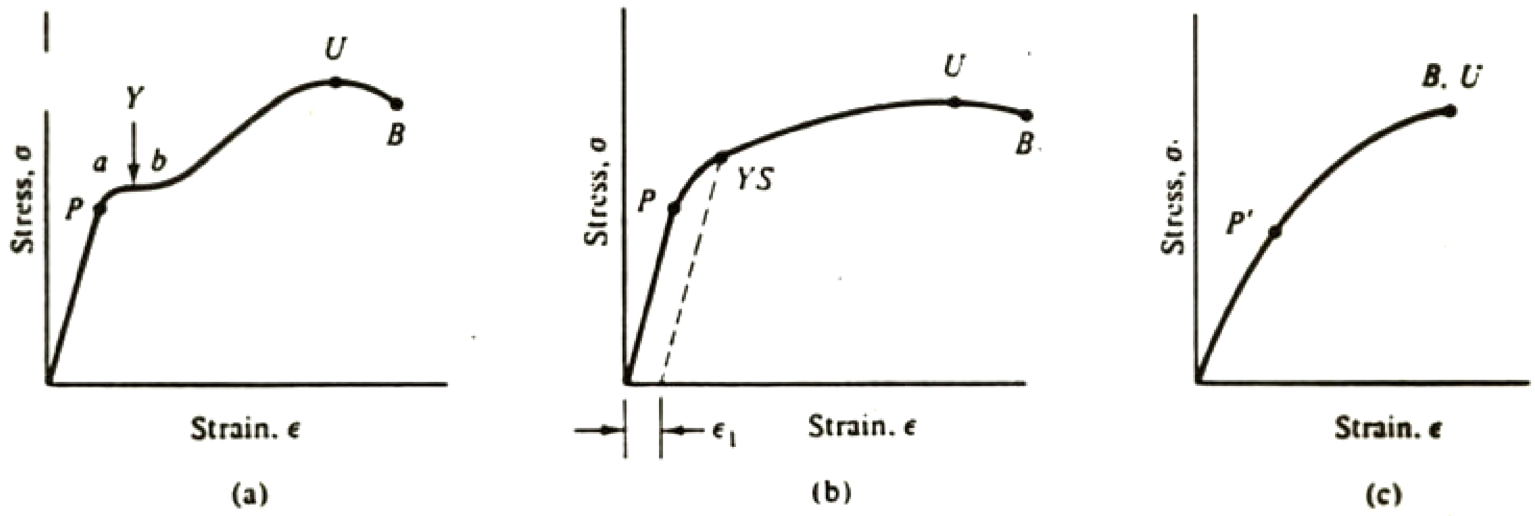
F 11-2 Ductile steel

Stress-Strain Diagram



F 11-3 Brittle material

- 1. Low carbon steel, a ductile material with a yield point
- 2. A ductile material, such as aluminum alloy, which does not have a yield point.
- 3. A brittle material, such as cast iron or concrete in compression.



Stress Strain Curves

3 Most Examined Properties

- Ductility
- Hardness
- Toughness

Ductility

- **Is the property which enables a metal to be bent, twisted, drawn out, or changed in shape without breaking.**
  - **3 types**
    - **1. Tension**
    - **2. Compression**
    - **3. Shear**
  - **Measured by tensile strength**

Hardness

- Resistance to penetration
  - Most tested mechanical property
  - Measured by:
    - **Brinell**
    - **Rockwell**
    - **Shore scleroscope (elasticity)**

Brinell Hardness Test

- Measured by the diameter of the dent with a microscope
- Used on nonferrous, soft, and medium-hard steel.
- BHN ranges from 150 for soft, low carbon steel to BHN of 730+ for hardened, high carbon steel.

$$BHN = \frac{L}{(\pi \times D/2)(D - \sqrt{(D^2 - d^2)}}$$

Rockwell Hardness Test

- Based on the depth of penetration made in metal by a penetrator point under a given load.
- Rockwell-B (RB) scale uses a 1.5mm diameter ball made of hardened steel. Used for testing unhardened steel, cast iron, and nonferrous metal.
- Rockwell-C (RC) scale requires a diamond point penetrator.
- Used for testing the hardness of heat-treated or hardened steels.
- The hardness is read from either a dial or digital readout.

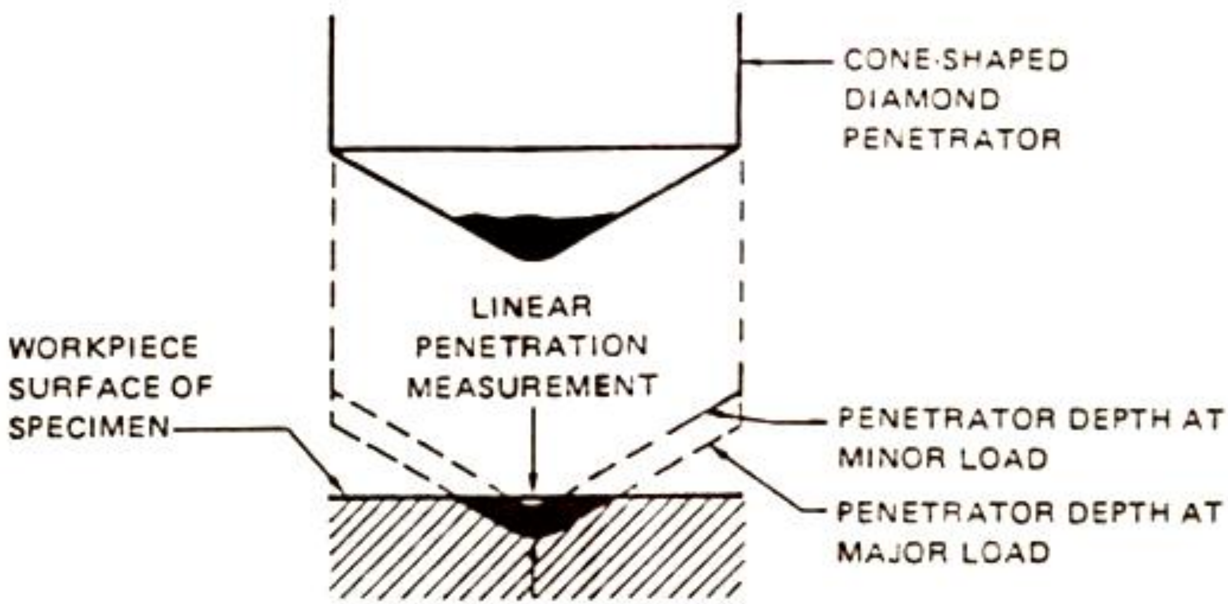
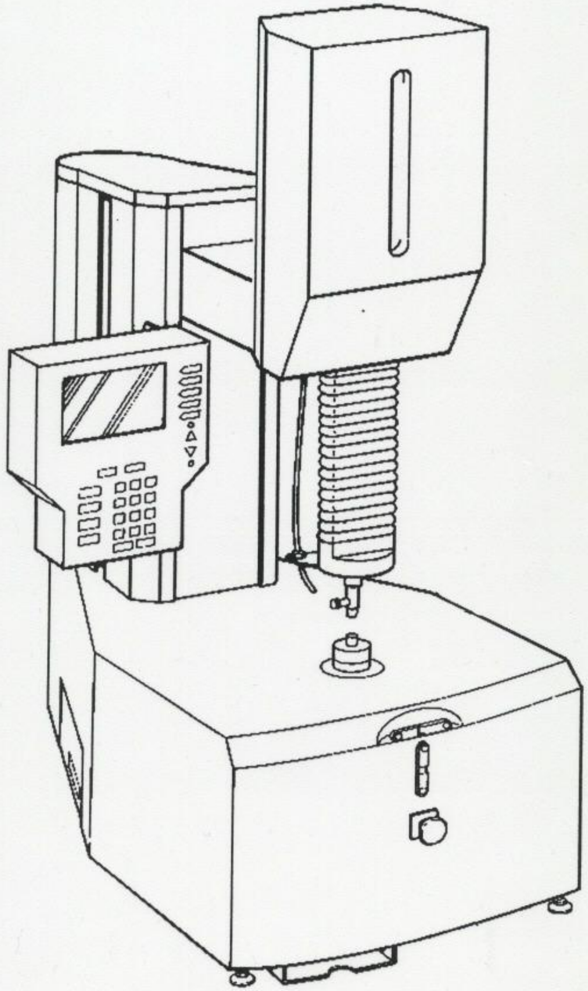
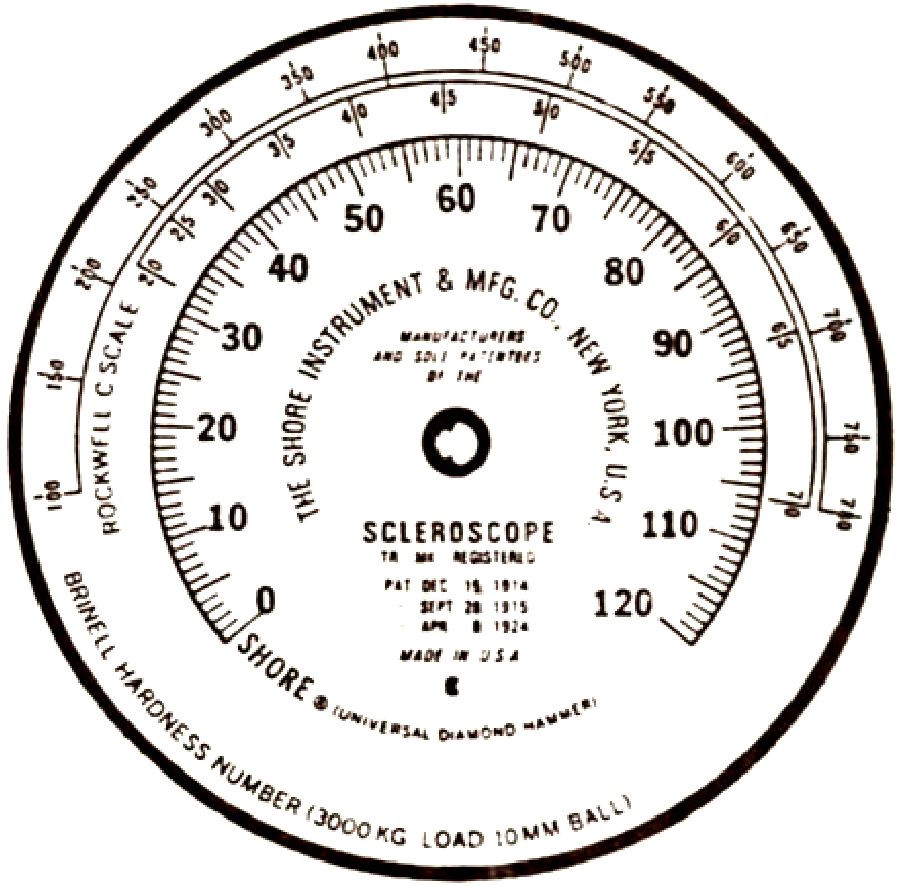


FIGURE 44-3 LINEAR PENETRATION—BASIS OF ROCKWELL HARDNESS TEST READINGS



Shore Scleroscope Testing

- Operates on the rebound principle
- Considered a nonmarring test
- Hardness number is read directly on a dial

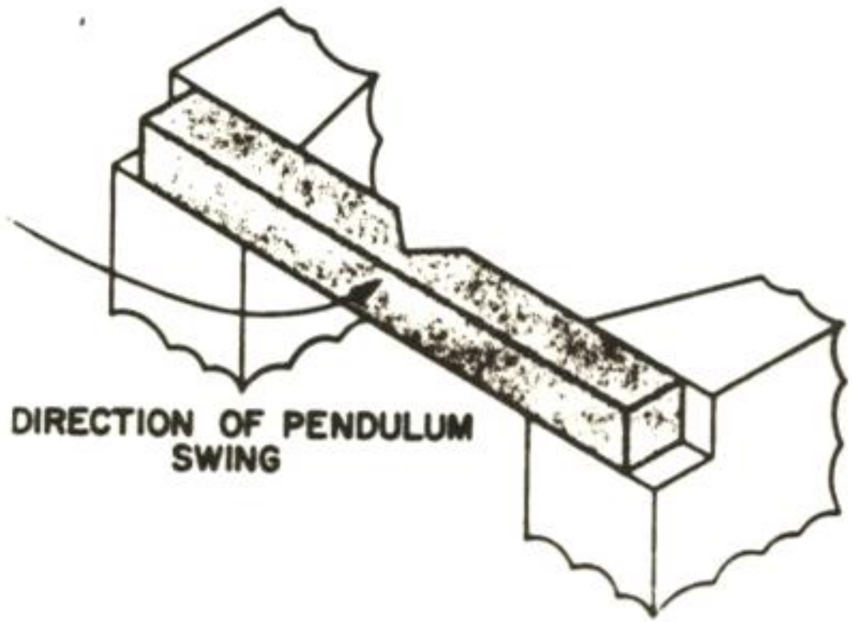


Direct-reading dial on sclerooscope with equivalent Rockwell C Scale and Brinell Hardness numbers.

Toughness

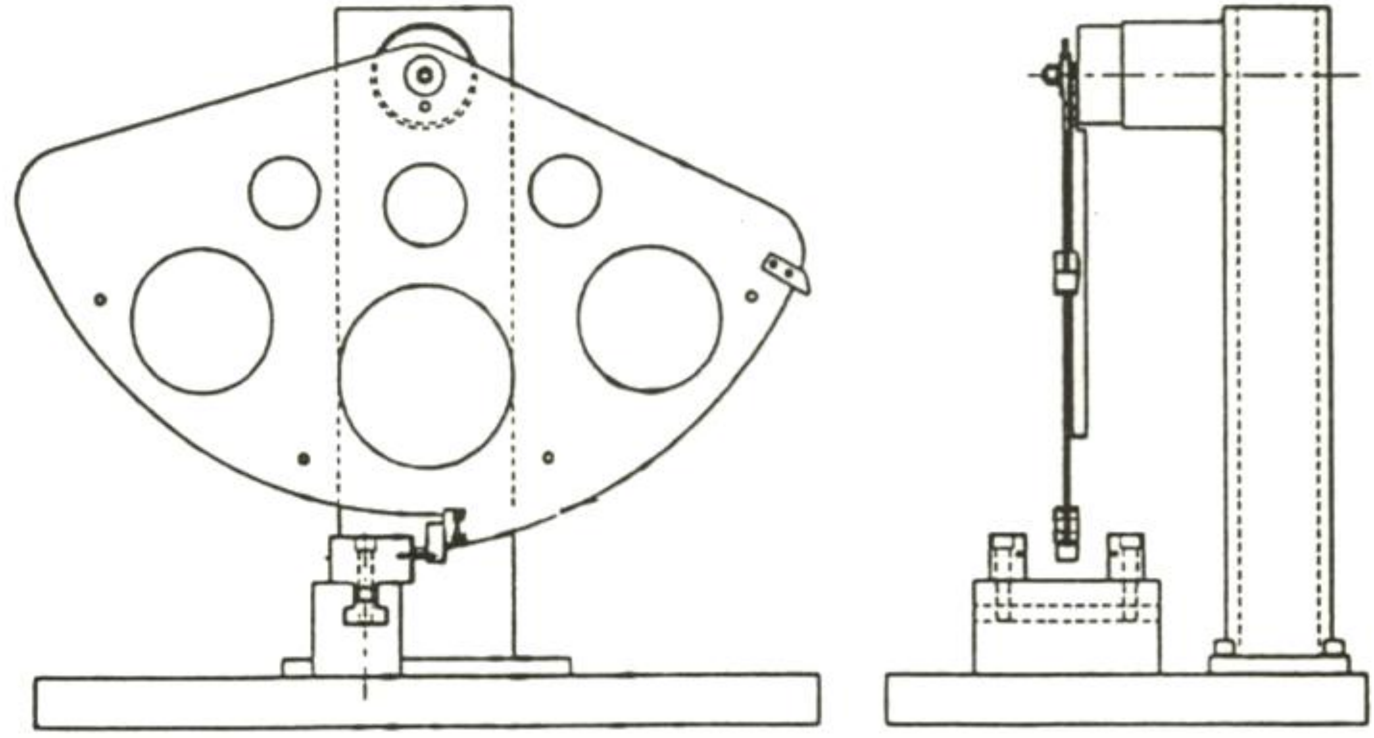
- The ability to absorb energy from impact
  - Measured by:
    - Charpy test
    - Izod test

Charpy Test



139-4. Specimen mounted for Charpy impact-toughness test.

Charpy Impact Testing



CHARPY IMPACT TESTING

Izod Test

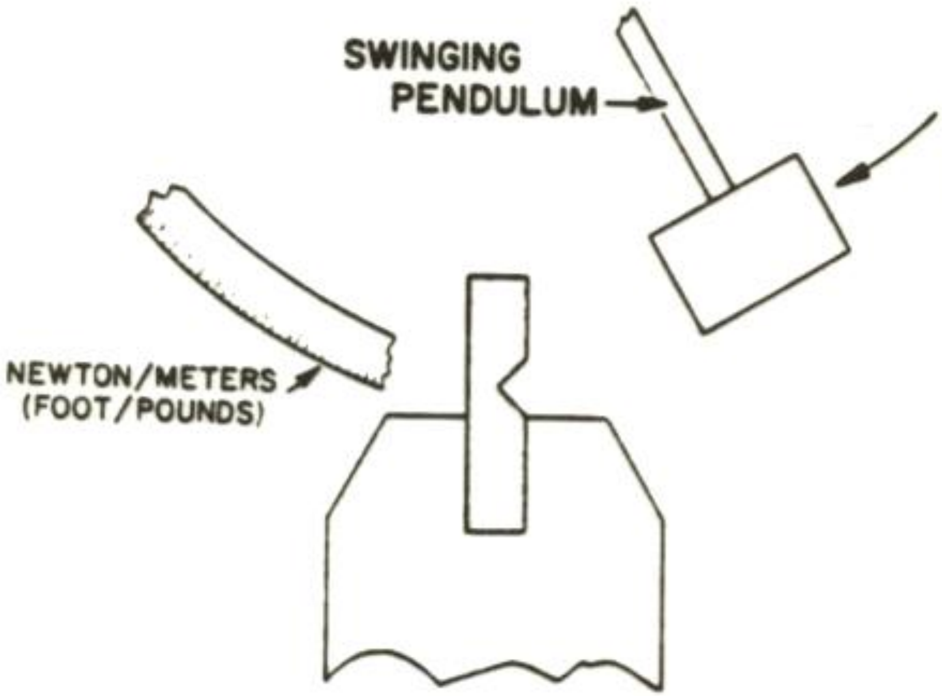
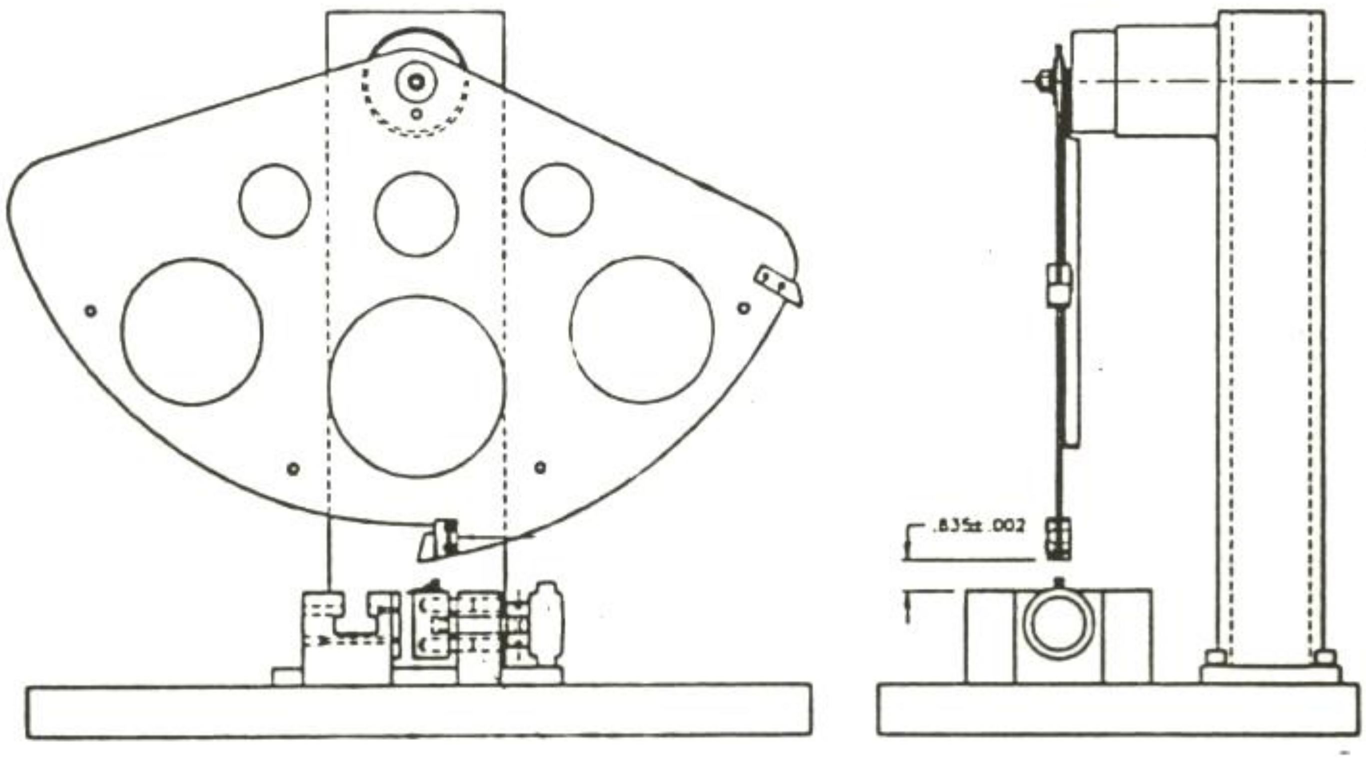


Fig. 139-3. Specimen mounted for Izod impact-toughness test.

Izod Impact Testing



IZOD IMPACT TESTING

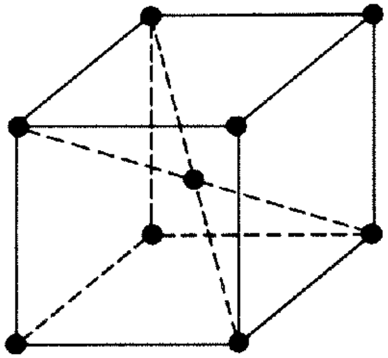
Metals

Chapter 12

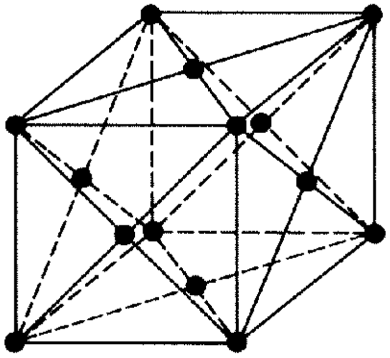
Metals

- Metals generally are:
  - Solid at room temperature
  - Good conductors of heat
  - Good conductors of electricity
  - Shiny and become reflective when smooth
  - Malleable and ductile

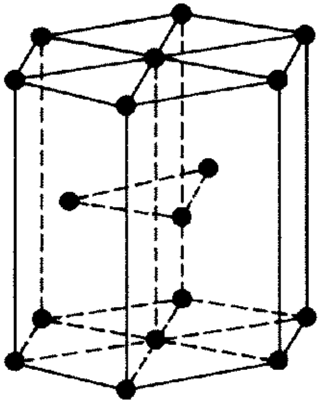
Crystalline Structures



Body-Centered
Cubic

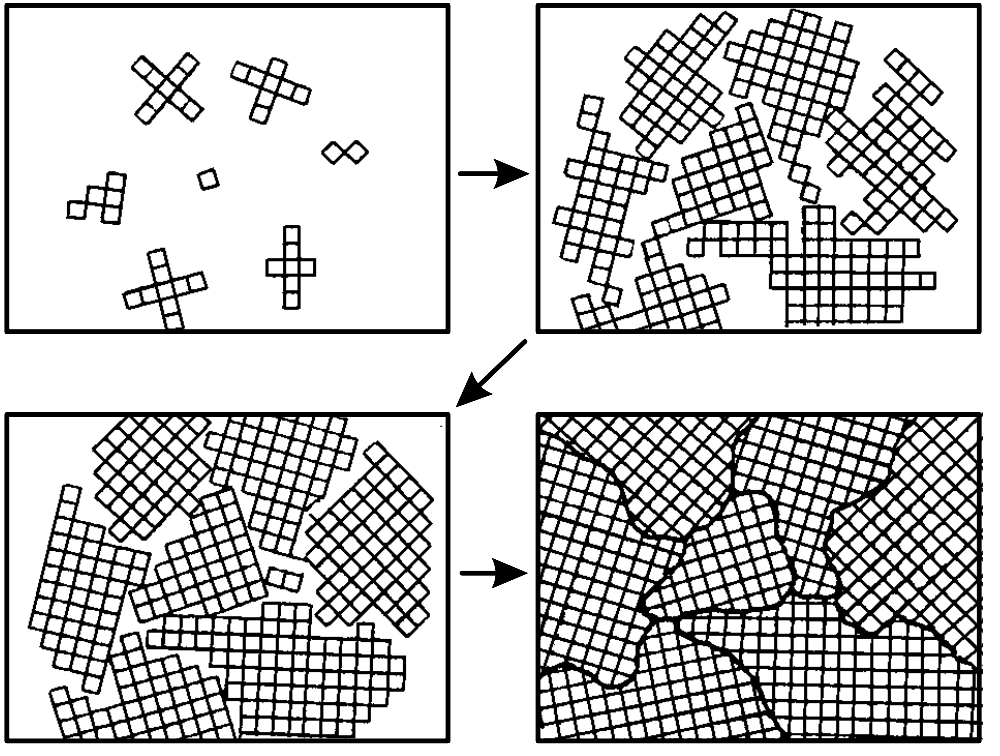


Face-Centered
Cubic



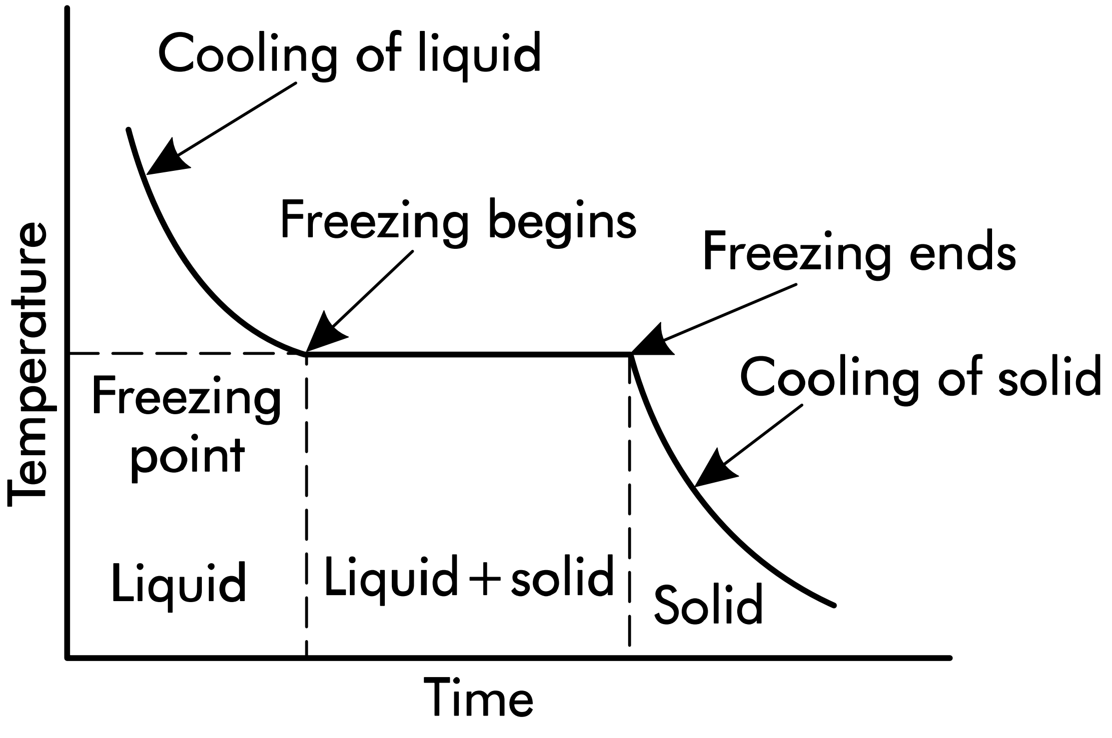
Hexagonal
Close Packed

Crystalline Grain Structure



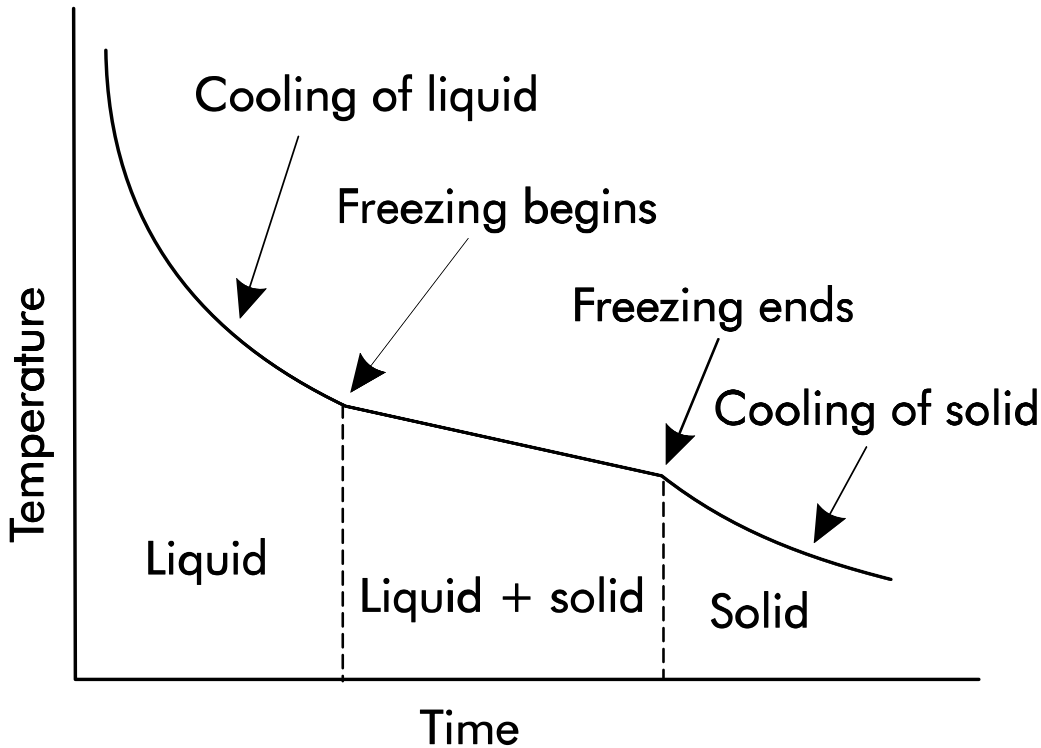
F 12-2 Growth of crystalline grains

Cooling Curve



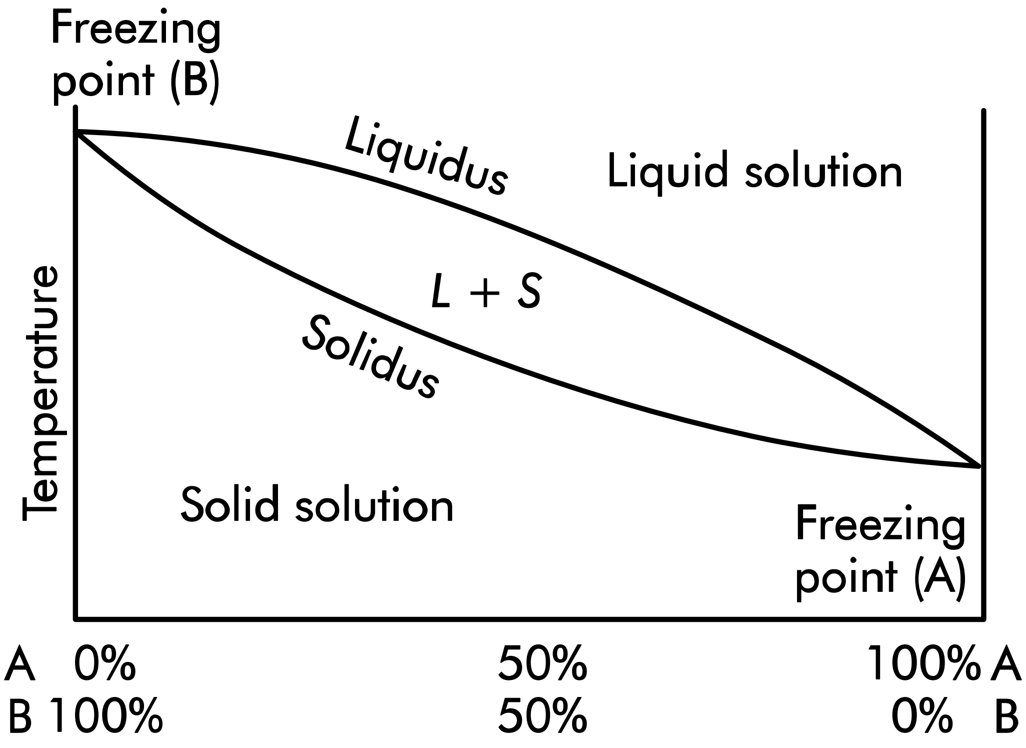
F 12-3 Cooling curve of a pure metal

Cooling Curve



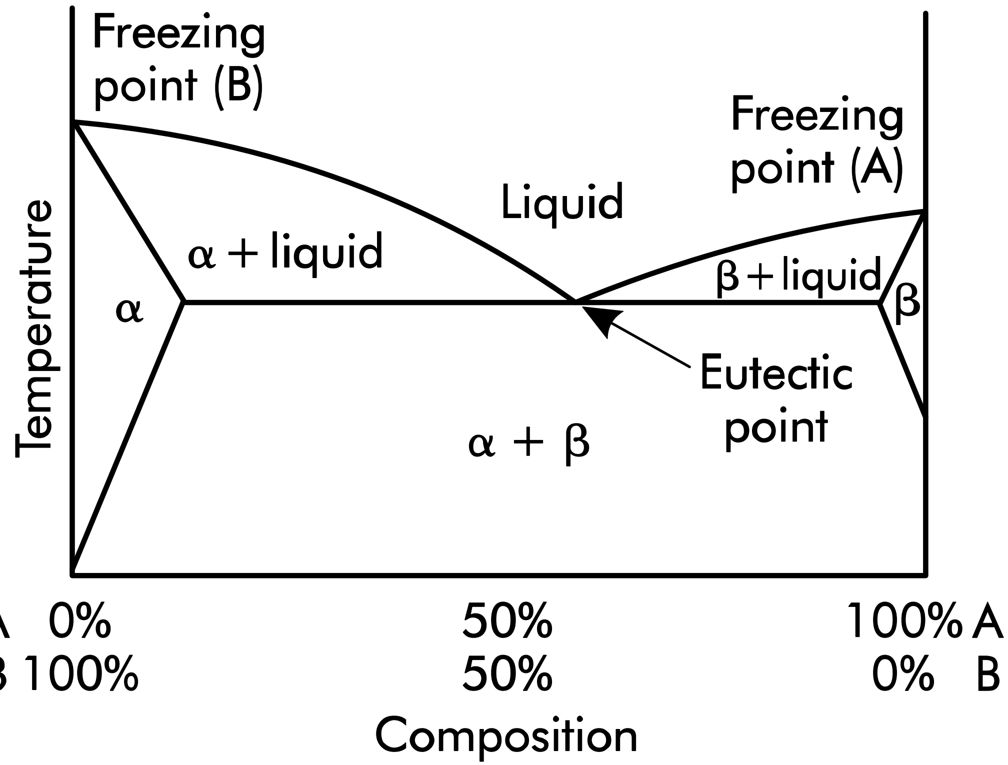
F 12-4 Cooling curve of an alloy

Type 1 Equilibrium Diagram

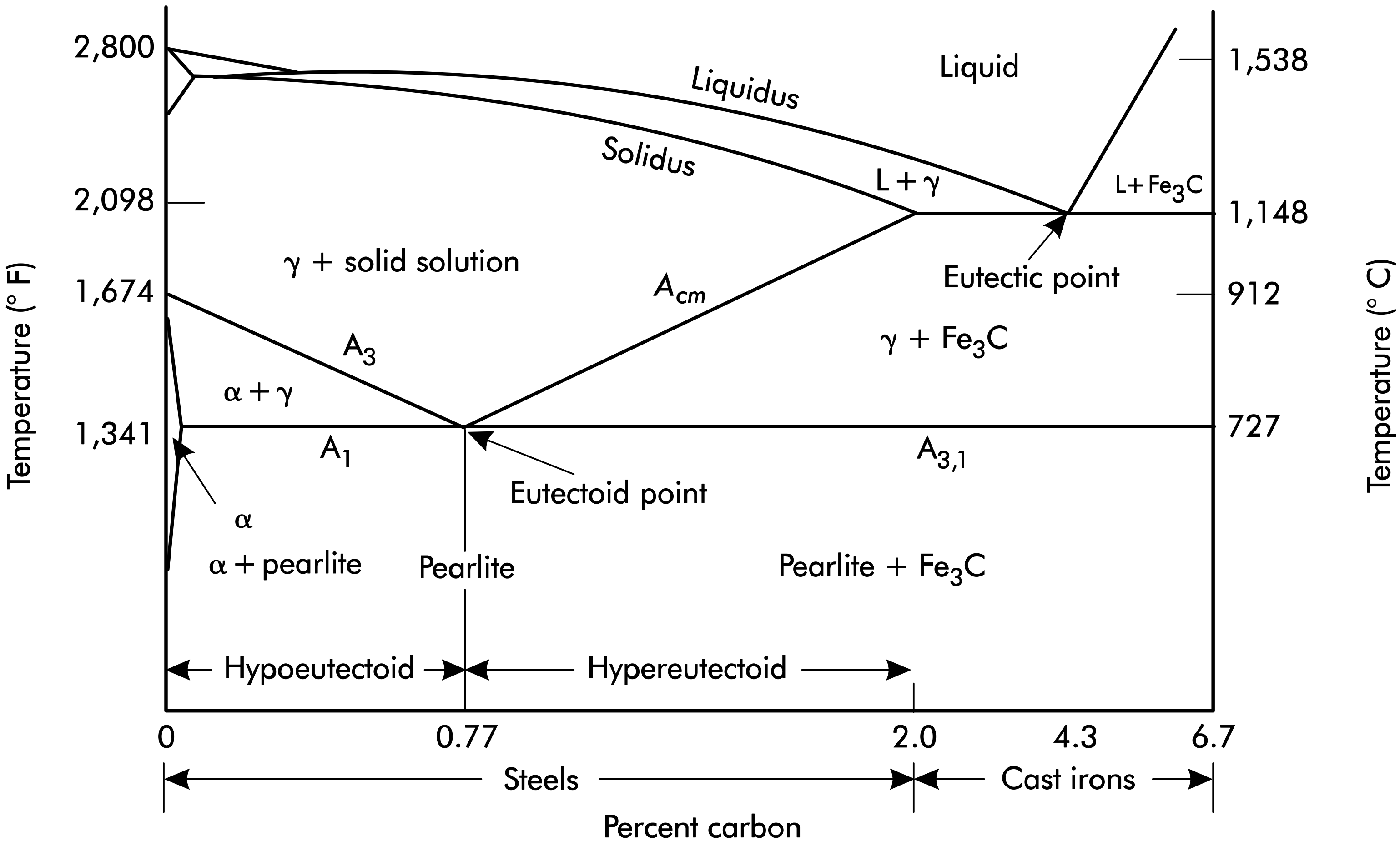


F 12-5 Phase diagram of an alloy

Type 2 Equilibrium Diagram



F 12-6 Phase diagram of an alloy with a eutectic point



α = ferrite (iron)
γ = austenite
Fe_3C = cementite (iron carbide)
pearlite = mixture of α + Fe_3C
A_1 = eutectoid temperature to left of eutectoid point
A_3 = boundary between γ and α + γ
$A_{3,1}$ = eutectoid temperature to right of eutectoid point (same as A_1)
A_{cm} = limit of solubility of carbon in γ

F 12-7 Iron-carbon diagram

Heat Treatment Processes

- Heating and cooling of metals in a solid state without altering their chemical composition.
- Hardening
- Annealing (Softening)

Severity of Quenching

(The faster the cooling, the higher the hardness)

Relative Severity	Quenching Media
5	Agitated brine
1	Still water
0.3	Still oil
0.02	Still air

Heat Treatment Processes

- Heating and cooling according to a time-temperature cycle by
  - A. Heating to prescribed temperature
  - B. Holding at temperature (soaking)
  - C. Cooling at a prescribed rate of quenching in air, water, oil, or brine

Heat Treatment Improves

- Tensile Strength
- Formability
- Toughness
- Bending
- Wear Resistance
- Magnetic Property
- Machinability
- Corrosion Resistance

Heat Treatment Processes

- Surface Hardening
  - Carburizing
  - Cyaniding
  - Nitriding
  - Flame hardening
  - Induction hardening
- Annealing
  - Full annealing
  - Spheroidize annealing
  - Stress relief annealing
  - Normalizing
  - Tempering

Steel Alloy Elements

- Carbon
- Chromium
- Cobalt
- Lead
- Molybdenum
- Nickel
- Vanadium

See Table 12-2

Steel Alloying Elements

Element	Effect
Carbon	Improves hardenability, strength, and wear resistance. Reduces ductility and weldability.
Chromium	Improves toughness, wear and corrosion resistance, and high-temperature strength.
Cobalt	Improves strength and hardness at elevated temperatures.
Lead	Improves machinability. Causes embrittlement.
Molybdenum	Improves hardenability, wear resistance, toughness, elevated temperature strength, and creep resistance.
Nickel	Improves strength, toughness, and corrosion resistance.
Vanadium	Improves strength, toughness, abrasion resistance, and hardness at elevated temperatures.

Characteristics of AISI-SAE Steel Series

AISI Number	Characteristics
10XX	Plain carbon
13XX	Manganese—increases strength in as-rolled state and increases ductility after heat treatment
23XX-25XX	Nickel—increases tensile strength without loss of ductility
3XXX	Nickel/chromium—tough and ductile due to nickel, wear and corrosion due to chromium
4XXX	Molybdenum—significant increase in tensile strength and hardenability
5XXX	Chromium—high wear resistance
6XXX	Chromium/vanadium—high yield strength, good fatigue properties
8XXX-9XXX	Chromium/nickel/molybdenum—exhibits benefits of each

Stainless Steels

- Austenitic
- Ferritic
- Martensitic

See Table 12-4

Austenitic

- Nonmagnetic and cannot harden by heat treatment
- Hardened by cold working and has superior corrosion resistance
- Most ductile type of stainless steel
- Applications: kitchen utensils, fittings, and welded construction

Ferritic

- Magnetic and cannot harden by heat treatment
- Good corrosion resistance
- Less ductile than austenitic stainless steel
- Applications: nonstructural in corrosive environments

Martensitic

- Magnetic and are hardenable by heat treatment
- Moderate corrosion resistance
- Do not contain nickel
- Applications: valves, springs, and cutlery

Characteristics of AISI-SAE Stainless Steel Series

AISI Number	Characteristics
2XX	Chromium/nickel/manganese composition, nonhardenable by heat treatment, austenitic and nonmagnetic
3XX	Chromium/nickel composition, nonhardenable by heat treatment, austenitic and nonmagnetic
4XX	Chromium composition, hardenable by heat treatment, martensitic and magnetic or nonhardenable by heat treatment, ferritic and magnetic
5XX	Low chromium composition, hardenable by heat treatment and martensitic

Cast Iron

- Contains 2%-6.67% carbon
- Very brittle
- Low-melting temperature therefore easy to pour into complex shapes

Basic Types of Cast Iron

- Gray
- White
- Malleable
- Nodular

Aluminum

- Characteristics
  - High strength to weight ratio
  - Resistance to corrosion
  - High thermal and electrical conductivity
  - Appearance
  - Machinability and formability
- Two Types
  - Wrought aluminum alloys (See table 12-5, p. 104)
  - Cast aluminum alloys (See table 12-6, p. 105)

Aluminum Casting Alloys

Number	Alloy	Properties
1XX.X	Commercially pure	Corrosion resistant
2XX.X	Copper	High strength and ductility
3XX.X	Silicon	Good machinability (with copper or magnesium)
4XX.X	Silicon	Good castability, corrosion resistant
5XX.X	Magnesium	High strength
6XX.X	Unused	
7XX.X	Zinc	High strength, excellent machinability

Aluminum Heat Treatment Processes

- Strain hardening (Cold Working)
- Annealing
- Solution heat treatment
- Precipitation hardening

Plastics

Chapter 13

Advantages of Plastics

- Adapting to mass production at a comparatively low cost.
- Resistance to corrosion, solvents, water, etc.
- Quiet, smooth movement with limited, if any, lubrication required.
- Qualities of an electrical and thermal insulator.
- Light mass and great range of translucent and opaque colors.
- High quality of surface finish
- Availability in solid form as powder, granules, sheets, tubes, and castings, or in liquid forms as adhesives.

Plastics

- Types
  - Thermosetting: Chemical bonding by cross-links in their molecular chain structure
    - Cannot be easily reprocessed
  - Thermoplastic: Has a linear chemical bond in its molecular structure
    - Can be reformed

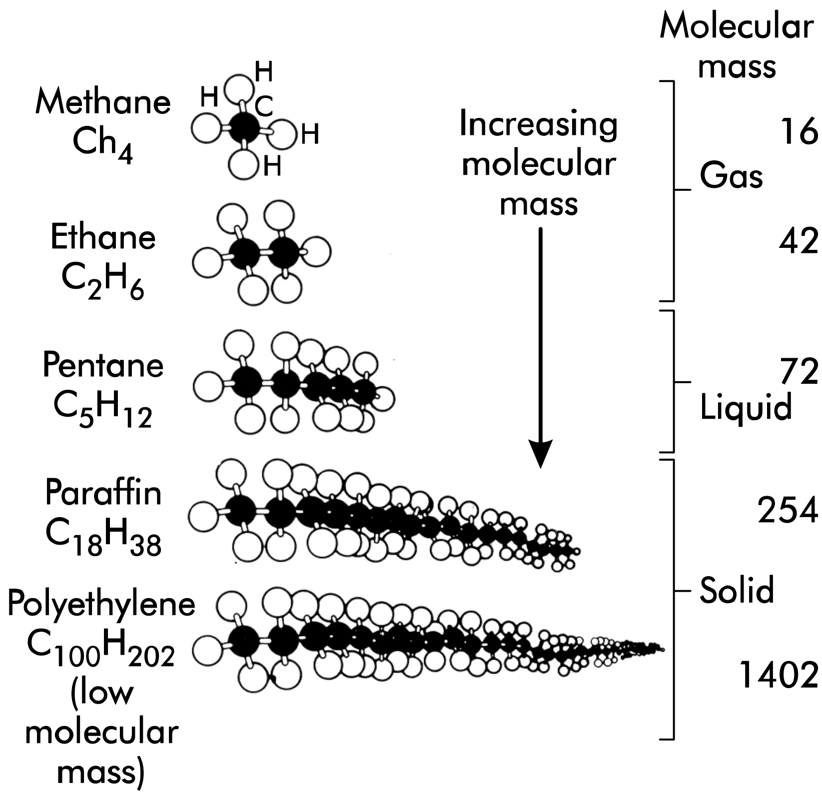
Polymerization

- Polymerization: The process brings together small molecules and forces them to chemically combine with each other.

- Chemicals required for production:
  - A. Crude oil

  - B. Natural gas supply

Polymerization



F 13-1 Gas to a solid plastic

Polymer Structures
(Three Most Common)

- Homopolymers
- Copolymers
- Terpolymers

Homopolymer

- Consists of one building block or monomer.
- Most common types: polyethylene, polypropylene, polyvinyl chloride, and polystyrene
- Can be either amorphous or semicrystalline line arrangements of their molecular chains

Copolymers

- Copolymers contain two chemically different mers
- Common types: Polysytrene (PS), and polyvinyl chloride (PVC)
- Can be either amorphous or semicrystalline line arrangements of their molecular chains

Terpolymers

- Three basic mers combine to create a polymer
- Common types: Acrylic, styrene, acrylonitrile (ASA) monomers
- May have amorphous or semicrystalline arrangements

Commodity Thermoplastics Types

- Polyethylene (PE)
- Polypropylene (PP)
- Polyvinyl Chloride (PVC)
- Polystyrene (PS)
- Polyethylene Terphalate (PETE)

Engineering Thermoplatics Properties

- Thermal, mechanical, chemical, and corrosion resistance, and usability
- Ability to sustain high mechanical loads, in harsh environments, for long periods of time
- Predictable, reliable, and polycarbonate

Most Common

- Nylon
- Acetal-Polyphenylene Oxide (PPO)
- Polycarbonate

Rubber

- Origin: Hevea Brasiliensis Tree
- Properties: Higher resilience and generates less heat than synthetic rubber

Synthetic Rubber

- Products are copolymers of a diene monomer and an additive such as styrene or acrylonitrile

- Properties: Superior to natural rubber in abrasion resistance

Four Dominate Hard Thermosets

- Phenolics
- Urea-Formaldehydes
- Epoxides
- Polyesters

Four Dominate Hard Thermosets

- Phenolics: Hard heat resistant and dark in color
- Urea-formaldehydes: Cheaper and lighter in color than phenolics
- Epoxides: Tough and high adhesion properties
- Polyesters: Forms the matrix that bonds many composite materials together

Composites

Chapter 14

Composites

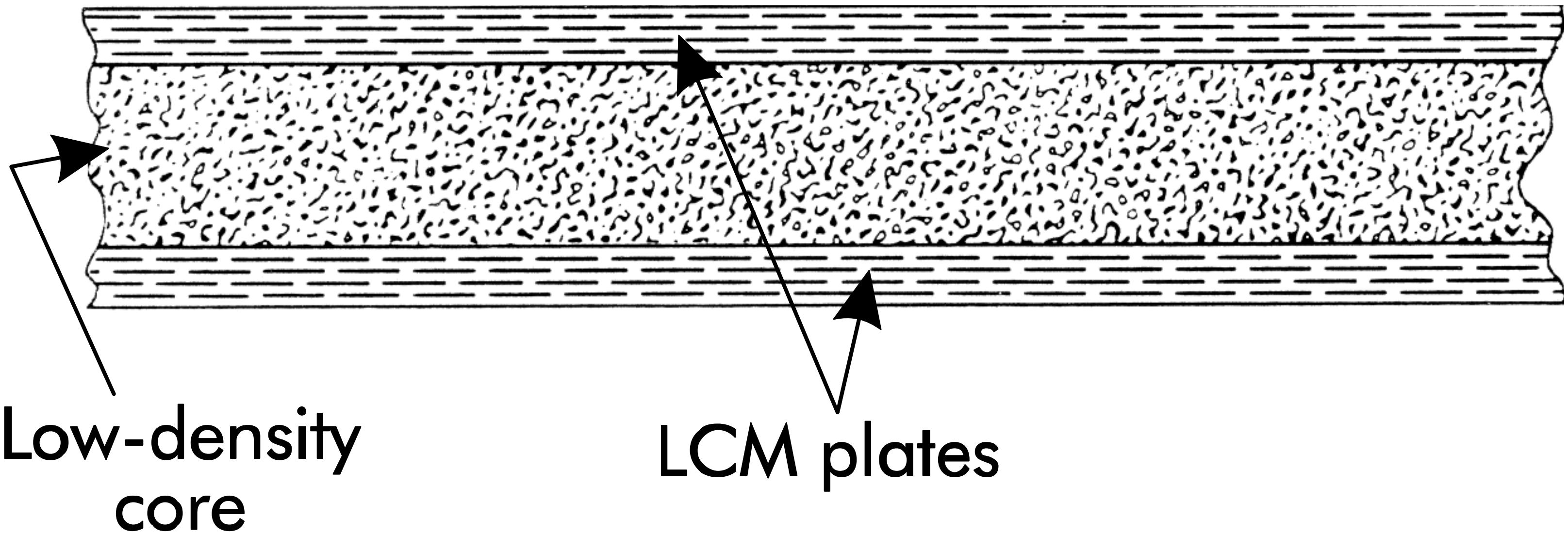
- Two or more materials - a reinforcing element and a resin binder (Matrix)
  - Holds the fibers in place
  - Deforms and distributes the stress to the fibrous constituent
  - Separate components still physically identified
  - Do not chemically merge

Composite Categories

- Laminates: Consists of layers bonded together

- Sandwiches: Multiple-layer structure materials containing a low density core between thin faces of composite materials

Sandwich Construction



F 14-2 (Bakerjain and Mitchell, 1992)

Advanced Composites
Fabrication Methods

- Lamination: Flat pieces
- Filament winding: Drawing fibers through a resin bath and wound on a mandrel. Round or cylindrical objects from pressure bottles to drive shafts.
- Pultrusion: Equivalent of metal extrusion, can be used for complex parts with constant cross sections (tubing - channels).
- Resin Transfer Molding

Ceramics

Chapter 15

Ceramics

- An inorganic compound containing metals, semimetals, and nonmetals
- Ionic bonds are extremely strong and stable
- Complex crystalline structure compared to metals

Ceramics Materials

- Clay based: bricks, tiles, porcelain, stoneware, and earthenware
- Glass: windowpanes, lenses, bottles and fibers
- Cement: construction and roadways
- Abrasives and grinding wheels
- Cutting tools: tungsten carbide

Corrosion Resistance of Ceramics

	Hydrochloric Acid	Hydrofluoric Acid	Hot Sodium Hydroxide	Fused Sodium Hydroxide
Glass	A	D	D	D
Quartz	A	D	C	D
Aluminum oxide (99.5%)	A	B	C	D
Mullite	A	C	D	D
Zirconium oxide	B	C	A	A
Silicon carbide (sintered)	A	A	A	C
Silicon nitride	A	C	A	C
Titanium diboride	C	C	C	C

Key: A: No reaction
B: Slight reaction
C: Appreciable attack
D: Dissolves

(Bakerjian and Mitchell 1992)

F 15-1 (Bakerjian and Mitchell, 1992)

Advanced Ceramic Materials Properties

Property	Alumina	Partially Stabilized Zirconia	Mullite	Silicon Carbide	Silicon Nitride	Titanium Diboride
Density, lb/in.^{3} (g/cc)	0.141 (3.90)	0.208 (5.75)	0.101 (2.80)	0.11 (3.1)	0.11 (3.1)	0.162 (4.48)
Color	White	Ivory	Tan	Black	Gray	Black
Flexural strength, ksi (MPa)	55 (379)	90 (620)	25 (172)	80 (552)	80 (552)	50 (345)
Elastic modulus, Mpsi (GPa)	54 (372)	35 (241)	22 (152)	58 (400)	40 (276)	78 (538)
Poisson's ratio	0.22	0.22	0.22	0.20	0.22	0.19
Hardness, kg/mm^2	1,440	1,200	750	2,800	1,500	2,700
Fracture toughness, MPa $\times$ m$^{0.5}$	3.5	12	2	4	6	5
Coefficient of thermal expansion, 10^{-6} ° F (10^{-6} ° C)	4.6 (8.3)	5.7 (10.3)	2.9 (5.2)	2.4 (4.3)	1.7 (3.0)	4.6 (8.3)

(Bakerjian and Mitchell 1992)

F 15-2 (Bakerjian and Mitchell, 1992)