BULE HORA UNIVERSITY

COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

Course name: Engineering

Material II

Course code: MEng 2092

rgeted group: Mechanical Engineering & Mining Engineering

ar : 2nd

Prepared by: ***Kinisa Wareso***

CHAPTER 2
ALLOY STEELS

An alloy steel may be defined as one whose characteristic properties are due to some element other than CARBON.

PURPOSE OF ALLOYING

- Increases Hardenability
- Improve Strength at ordinary temperatures
- Improve mechanical properties at either high or low temperatures
- Improve toughness at any minimum hardness or strength
- Increases Wear Resistance
- Increase Corrosion Resistance
- Improve Magnetic Properties

TYPES OF ALLOYING ELEMENTS

GROUP I

- Elements which dissolve in ferrite

- GROUP II
- Elements which combine with carbon to form carbides

STEEL SPECIFICATIONS

AISI –SAE CLASSIFICATION	TYPE OF STEEL
10XX	Plain Carbon Steels
11XX	Resulphurized Grades
13XX	Manganese Steel
40XX	Mo Steel
43XX	Cr-Mo Steels
51XX	0.8 % Cr Steels
52XX	1.45 % Cr Steels
61XX	Cr – V Steels
92XX	Si – Mn Steels

STANDARDS

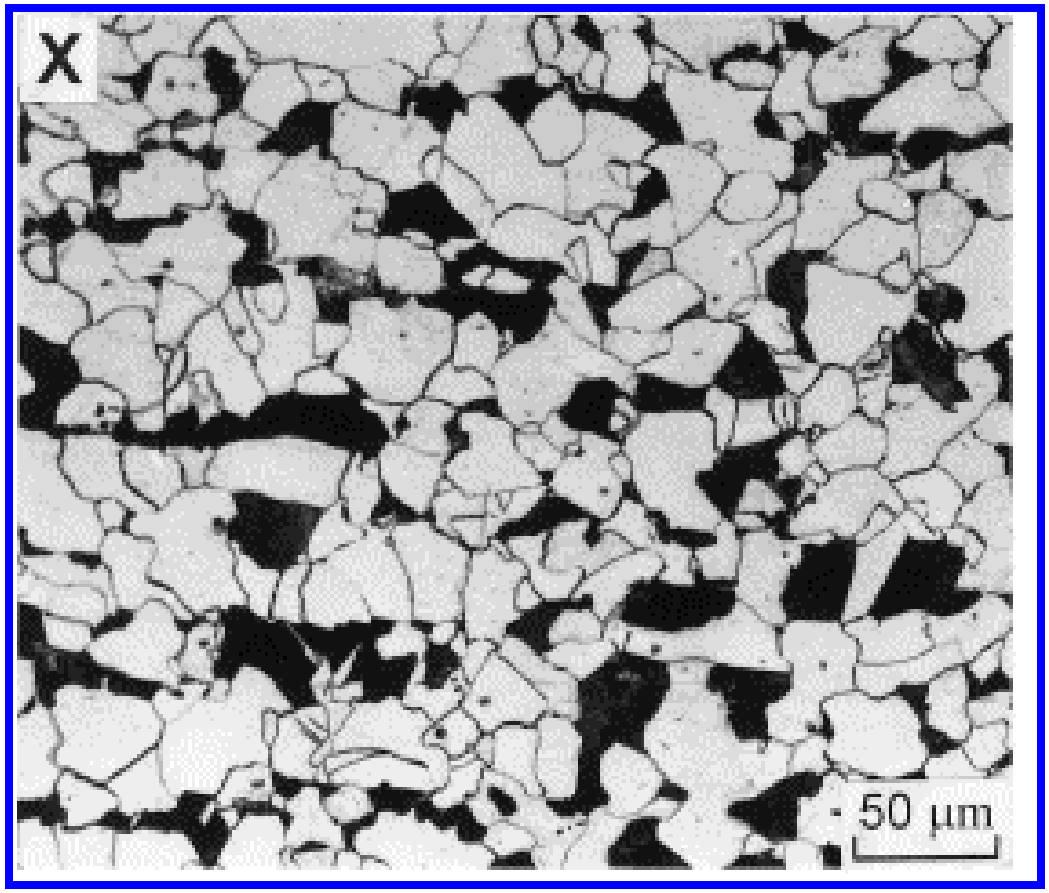
INDIAN	BRITISH (Old)	BRITISH (New)	AISI – SAE
55 Cr 70	En 11	526 M 60	5155
40Ni2Cr1Mo25	En 24	817 M 40	4340
C100	En 44	060 A 96	1095
50Cr1V23	En 47	735 A 50	6150

LOW CARBON STEELS

- Contains about 0.1 C
- Not heat treated, as hardenability is low to produce martensite
- Widely used in the form of cold rolled sheets
- Microstructure consists of essentially Ferrite, with a small amount of Pearlite

Typical Mechanical Properties

- Ys = 200 – 300 MPa
- Ts = 300 – 370 MPa
- % Elongation = 28 – 40 %



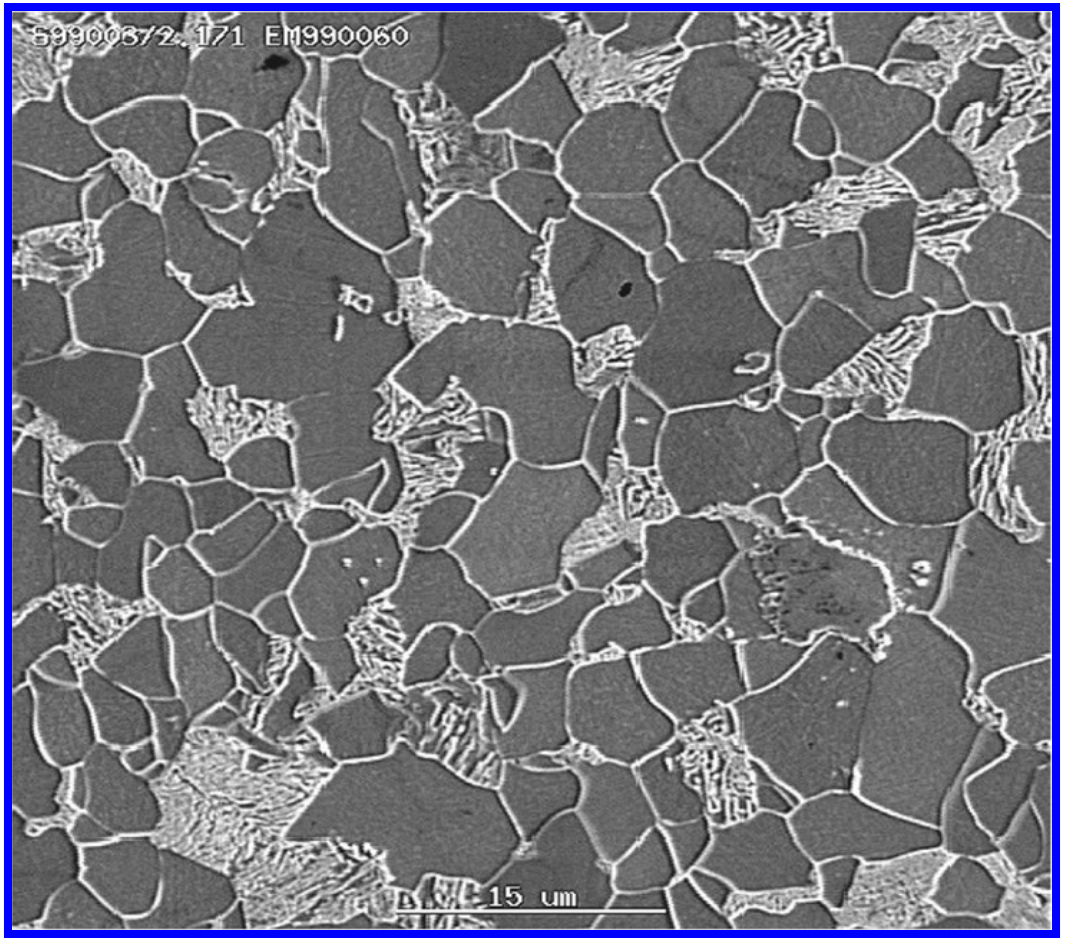
Low carbon steels
Fe–0.15%C–0.25%Si–1.1%Mn (in wt%)]

MILD STEEL

- Contains 0.15 % C – 0.25 % C
- Not heat treated, but used in asrolled and air-cooled conditions
- Micro-structure is about 25 % of fine Pearlite interspersed in Ferrite Matrix
- Possess Excellent Weldablity

Typical Mechanical Properties

- **YS = 300 – 350 MPa**
- **TS = 400 – 450 MPa**
- **% Elongation = 26 – 30 %**



Mild steel (0.18 % C)

MEDIUM CARBON STEEL

- Contains 0.3 – 0.5 % Carbon
- Micro-structure is fine ferrite-pearlite mixture
- Forged or hot rolled

Micro-Alloyed Steels

- To the basic composition of mild steel, small amounts of strong carbide forming elements such as Niobium, Vanadium, and Titanium are added.
- Total concentration of micro-alloying elements is less than 0.2 %
- Fine Ferrite grain size (ASTM 12-14)
- Yield Strength increases with decreasing grain size
- Fine Dispersion of alloy carbides result in Precipitation hardening
- Impact Transition Temperature (ITT) decreases with decreasing grain size

Typical Mechanical Properties

- **YS = 400-500 MPa**
- **TS = 600 – 650 MPa**
- **% Elongation = 20–22%**

HIGH STRENGHT STRUCTURAL STEELS

- Tensile Strength in excess of 600 MPa
- 600 – 1000 MPa --- High Strength Steels
- Less than 1000 MPa –Ultra high strength Steels

HIGH STRENGTH LOW ALLOYS

- Carbon 0.15 % - 0.25 % (same as MS)
- Small quantities of additional alloying elements

Microstructure

Ferrite and Bainite / Ferrite and Martensite

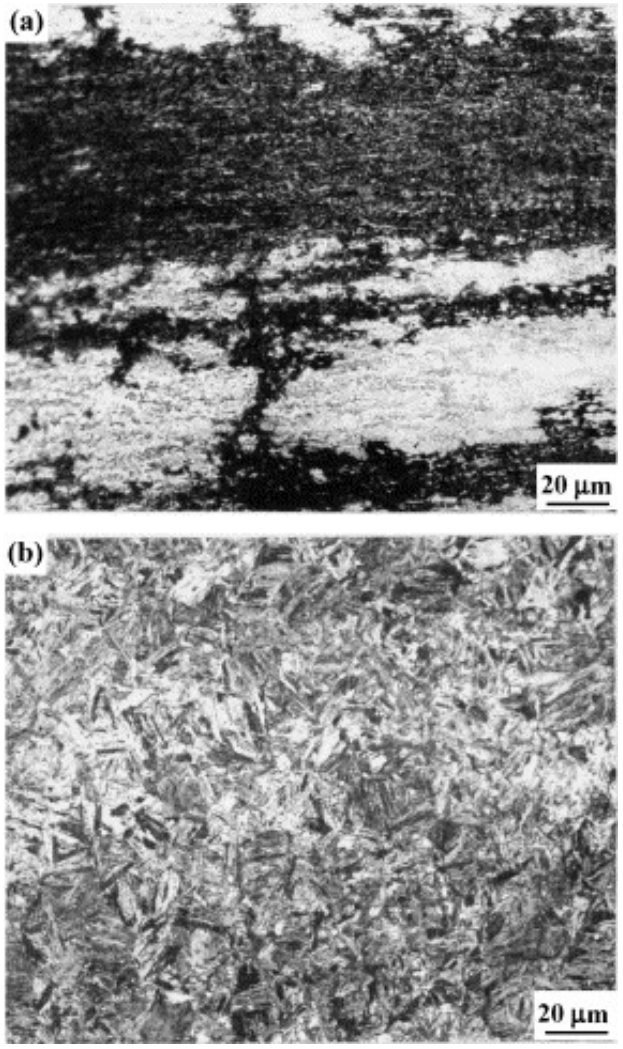
Typical Mechanical Properties

- **YS = 400-700 MPa**
- **TS = 500 – 800 MPa**
- **% Elongation = 18–25%**

MARAGING STEELS

- Ultra high strength group
- Martensite + Aging = Maraging
- C- 0.03 %; Ni-18%; Co-3.8%; Mo-3.8%; a fraction of Ti and Al
- Ys = 1800 MPa and FT $120MN^{-3/2}$
- Weldability is Good due to softness of Martensite

Maraging steels



Ni	Co	Mo	Ti	Al	C	S	P	Si	Mn	O	N	Fe
17.88	14.75	6.69	1.10	0.08	0.0037	0.002	0.001	0.02	0.007	0.0025	0.0015	Bal

Effect of Sulfur

- It should be less than 0.05%
- Sulfur combines with Iron to form Iron Sulfide (FeS)
- FeS concentrates at Grain Boundaries
- If steel is forged or rolled at elevated temperature, the steel will become brittle
- This phenomenon is known as ‘HOT SHORTNESS’
- Free Machining steels will contain 0.08%-0.35%

Effect of Phosphorous

- It should be below 0.04%
- Dissolves in Ferrite
- Increases strength and hardness slightly
- 0.07% - 0.12% improves cutting properties
- Larger quantities, reduces ductility.
- Phosphur combines with Iron and forms Iron Phosphide
- During cold working, the steels get cracked
- This phenomenon is known as “COLD SHORTNESS”

Effect of Mn and Si

- Mn will be 0.03 to 1.0%
- Counteract ill effects of Sulfur by forming MnS
- 2 to 8% times Sulfur is required
- Soundness or Steel Casting Improves

- Si will be 0.05 to 0.3%
- Si dissolves in Ferrite, increasing the strength of the Steel
- Promotes Oxidation

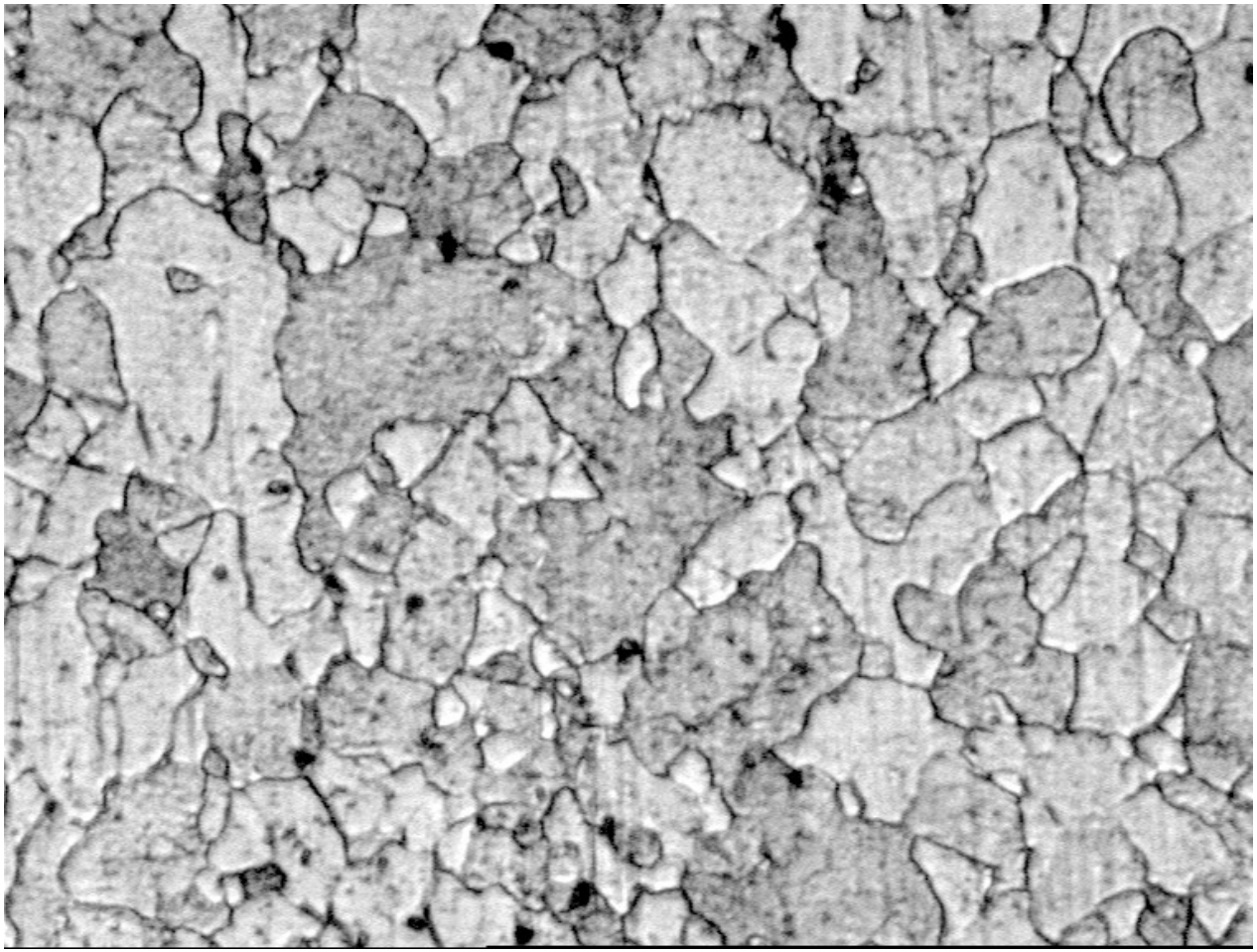
STAINLESS STEELS

- All SS will contain Cr which gives corrosion resistance
- Minimum Cr required is 12%
- Cr should be in the form of solute solution and not in the form of intermetallic
- Most of the SS are dominated by single phase
- Austenite Stabilisers: C, N, Mn, Ni
- Ferrite Stabilisers: Cr, Mo, V, W, Ti, Nb, Al

FERRITIC STAINLESS STEEL

- Cr:12-30%; C:0.10%; Fe: Remaining
- Cheaper (No Nickel)
- If Cr is 12-16%...Corrosion Resistance
- If Cr is above 16%...Heat Resistance

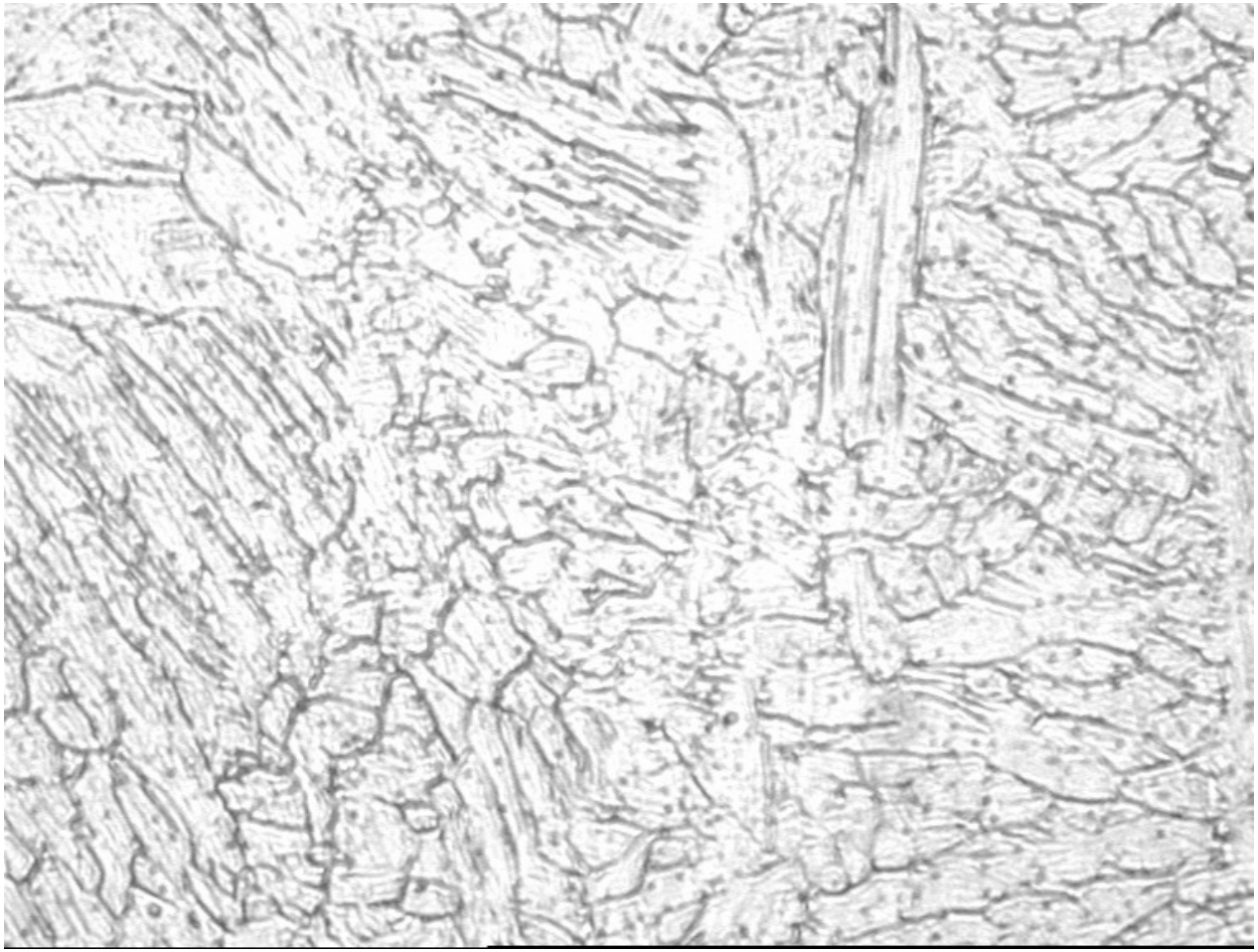
FSS



Austenitic Stainless Steel

- Cr: 12-18%; Ni:8%; C:0.10%; Fe: Balance
- Easily formable and weldable
- Good at elevated and low temperatures
- Excellent corrosion resistance
- Expensive because of Ni
- YS is not so high
- More than 90% used

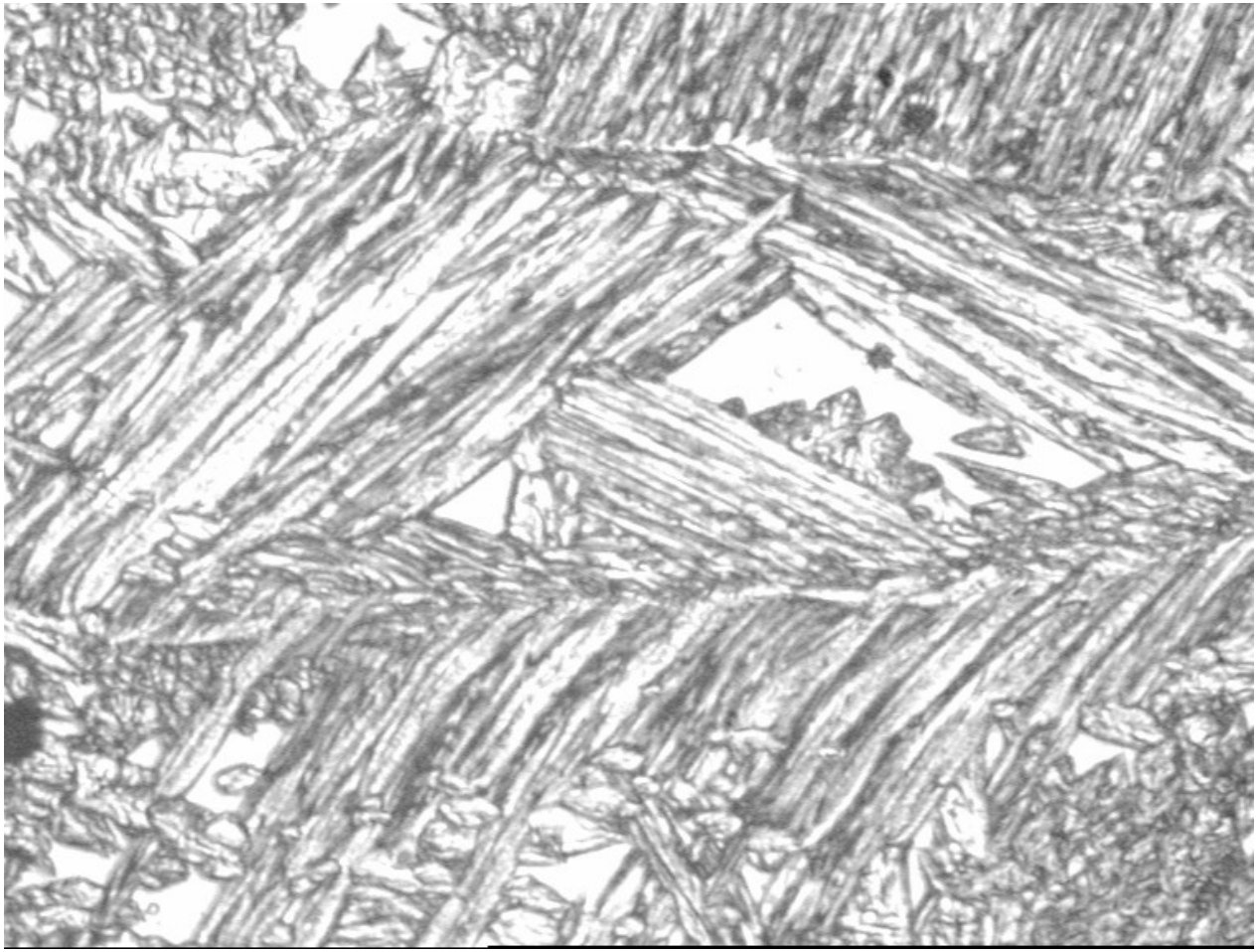
ASS



DUPLEX STAINLESS STEEL

- 50% Austenite and 50% Ferrite
- C:0.02%; Cr:22%; Ni:5%; Mo:3%; N:0.15%; Fe: Remaining
- More easily weld able than FSS
- Not as easily weld able than ASS
- YS is higher than ASS
- Widely used in Paper and Pulp industries, Petrochemical industries
- Excellent material for Pitting corrosion resistance

DSS



Martensitic Stainless Steel

- C:0.2%; Cr:12%; Mo:1%; Fe:Balance
- Hardest of all stainless steel
- Creep resistance is very good
- Least corrosion resistance
- High temperature applications
- Surgical applications

PH STAINLESS STEEL

- Precipitation Hardenable SS
- C:0.1%; Cr:17%; Ni:4%; Fe: Remaining
- Used in Aircraft applications
- High strength is derived from Precipitation
- UTS is 1200-1400 MPa

- AISI 300….Austenitic Stainless Steel
- AISI 400….FSS and MSS

Cast Iron

- Iron with 2.1 to 4.5% carbon and 0.5 to 3% silicon
- Lower melting point and more fluid than steel (better castability)
- Cast iron is a group of iron-carbon alloys which contains carbon greater than 2%.
- CI is obtained by refining the pig iron in cupola(a small form of blast furnace).
- CI is brittle & weak in tension.
- Low cost material usually produced by sand casting
- A wide range of properties, depending on composition & cooling rate
  - Strength, Ductility, Thermal conductivity
  - Damping capacity, Hardness.

Production of Cast Iron

- Pig iron, scrap steel, limestone and carbon (coke)
- Cupola
- Electric arc furnace
- Electric induction furnace
- Usually sand cast, but can be gravity die cast in reusable graphite moulds
- Not formed, finished by machining

Types of cast iron

- Grey cast iron - carbon as graphite
- White cast iron - carbides, often alloyed
- Ductile cast iron
  - nodular, spheroidal graphite
- Malleable cast iron
- Wear-Resistant High-Chromium Cast Iron

Grey (graphite)	White (cementite)
High C, Si	Low C, Si
Slow cooling	Fast cooling

Grey Cast Iron

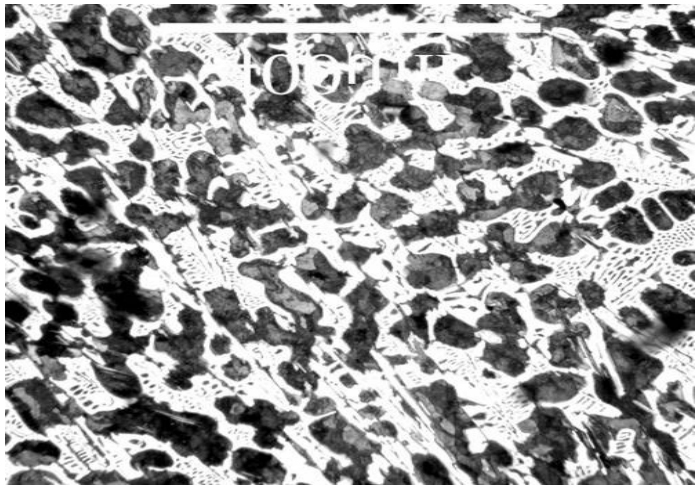
Fe, C 3.52, Si 3.26, Mn 0.47 (wt%)



Tensile strength – 25 MPa
Elongation - 0.5 %
Hardness – 180 Hv

- **When carbon is not chemically combined with iron.**
- **Among least expensive metallic materials**
- **High fluidity – can cast complex shapes**
- **Graphite flakes – high damping capacity and good machinability**
- **Used as base structure for machines and heavy equipment**
- **But brittle due to shape of graphite flakes – (nodular iron is always better)**

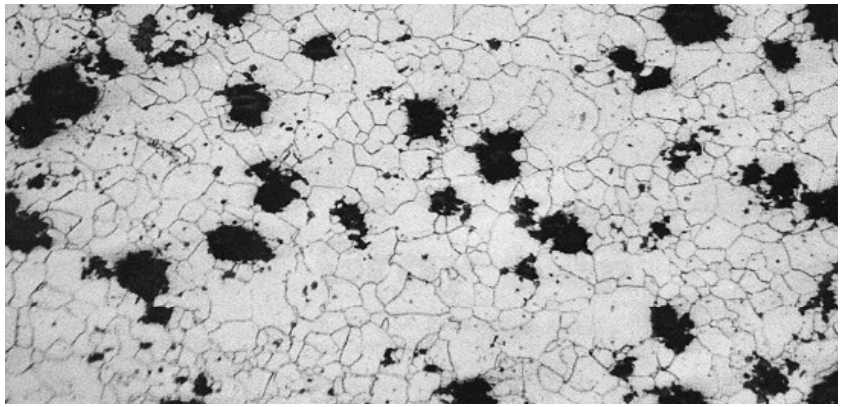
White Cast Iron



- Tensile strength – 25 Mpa
- Elongation - 0
- Hardness – 450 Hv
- Exceptionally hard, but brittle
- Almost impossible to machine
- Used in very few application e.g. rollers in rolling mills
- Used as intermediary in production of malleable iron
- Heat treatment at 800-900^{o}C causes decomposition of cementite – graphite clusters.
- Resulting microstructure and properties similar to nodular iron

Malleable Iron

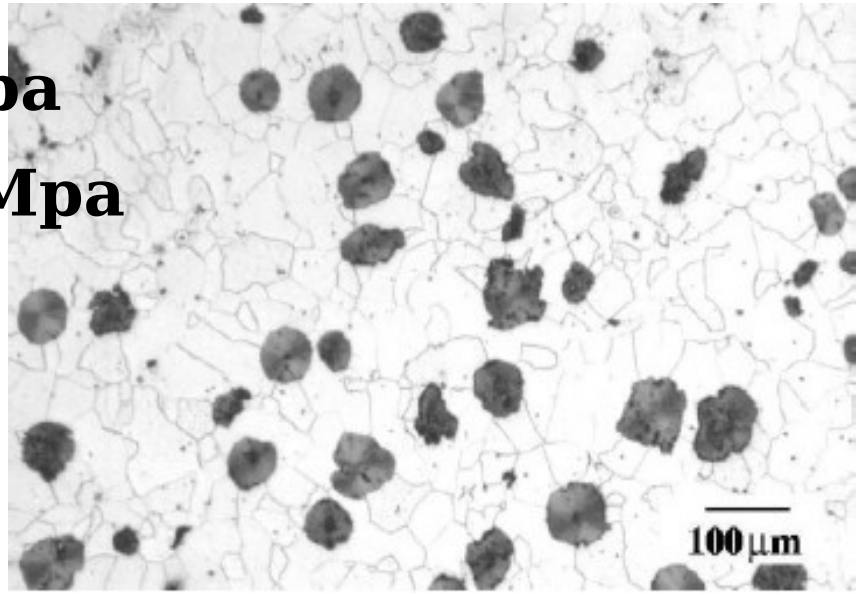
Yield strength - 33 MPa
Tensile strength – 52 MPa
Elongation - 12 MPa
Hardness – 130 Hv



- **Obtain by heat treatment in which all the combined carbon of a special white CI has been changed to free or temper carbon.**
- **Starts as a white iron casting, that is then heat treated at about 900 °C.**
- **Graphite in nodular form**
- **exhibits good ductility**
- **Produced by heat treatment of white cast iron**
- **Graphite nodules are irregular clusters**

Ductile / Nodular Cast Iron

Fe, C 3.2, Si 2.5, Mg 0.05 (wt%)



Yield strength - 53 – 108 Mpa

Tensile strength – 70 – 115 Mpa

Elongation - 5-18 Mpa

Hardness – 170 – 310 Hv

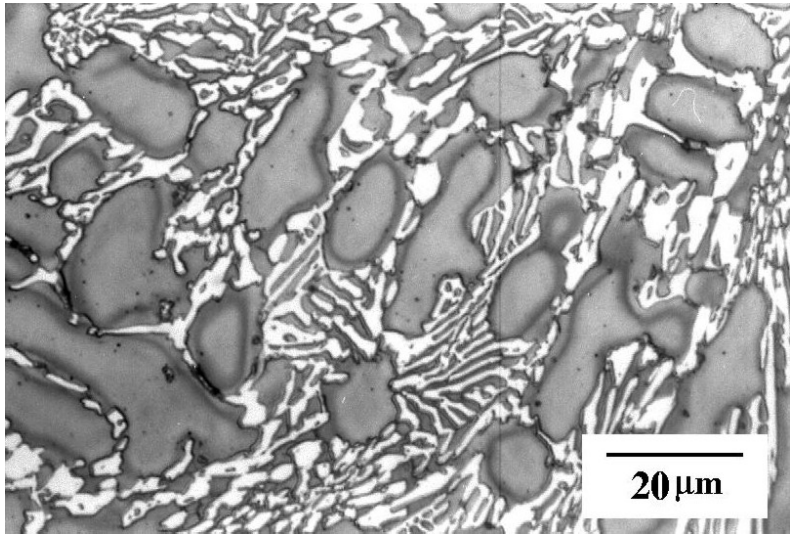
- **Addition of Mg/Ce to grey iron**
- **Graphites forms as spheres rather than flakes**
- **improved toughness**

Applications

Gear, valves cams, crankshafts

Wear-Resistant High-Chromium Cast Iron Fe-2.6C-17Cr-2Mo-2Ni wt%.

- very high wear resistance
- a combination of very strong carbide-forming alloying elements



The white phase is a chromium-rich carbide known as M_7C_3

The matrix consists of dendrites of austenite,

Cast Irons and cast iron production

- carbon content is above 2.14 wt%;

properties

- Cast irons become completely liquid at temperatures between approximately 1150°C and 1300°C
  - They are easily melted.
- Some cast irons are very brittle, and casting is the most convenient fabrication technique.

What is Cast Iron and how is it Made?

- **It is made by remelting raw iron scrap iron and steel**
- **Phosphorus and sulfur is removed**
- **Contains more than 2% carbon and 1% silicon**
- **Melted in a blast furnace**

Advantages

It is very strong and can be molded into almost any form for mass production. Also the silicon improves the products corrosion resistance.

Disadvantages

It is brittle and once a crack begins it is nearly impossible to stop. It has less tensile strength and shock resistance than steel.

Cast Irons

- Cementite (Fe_3C) is a metastable compound,
  - under some condition it can dissociate or decompose to form α ferrite and graphite

$$Fe_3C \rightarrow 3Fe\,(\alpha) + C\,(\text{graphite})$$

  - This tendency to form graphite is regulated by the composition and rate of cooling.

- Slow cooling favours the formation of graphite & low hardness
- Rapid cooling promotes carbides with high hardness
- Thick sections cool slowly, while thin sections cool quickly

Types of cast iron

- Gray cast iron
- Machinability is excellent
- Ductility is low (0.6%), impact resistance low
- Damping capacity high
- Thermal conductivity high
- Dry and normal wear properties excellent

Cast Irons: *Gray Iron*

- Contain carbon between 2.5 and 4.0 wt% and silicon between 1.0 and 3.0 wt%.
- The graphite exists in the form of flakes

.

Cast Irons: *Gray Iron*

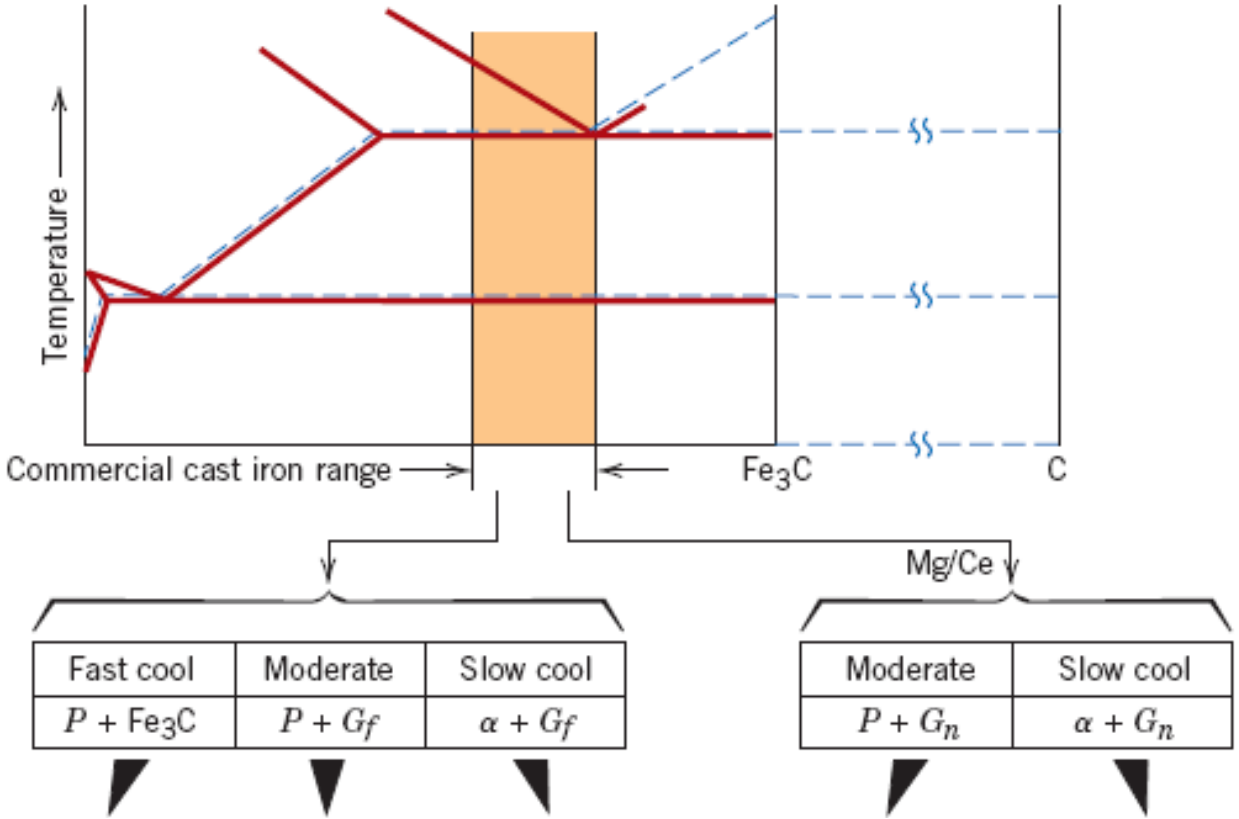
properties

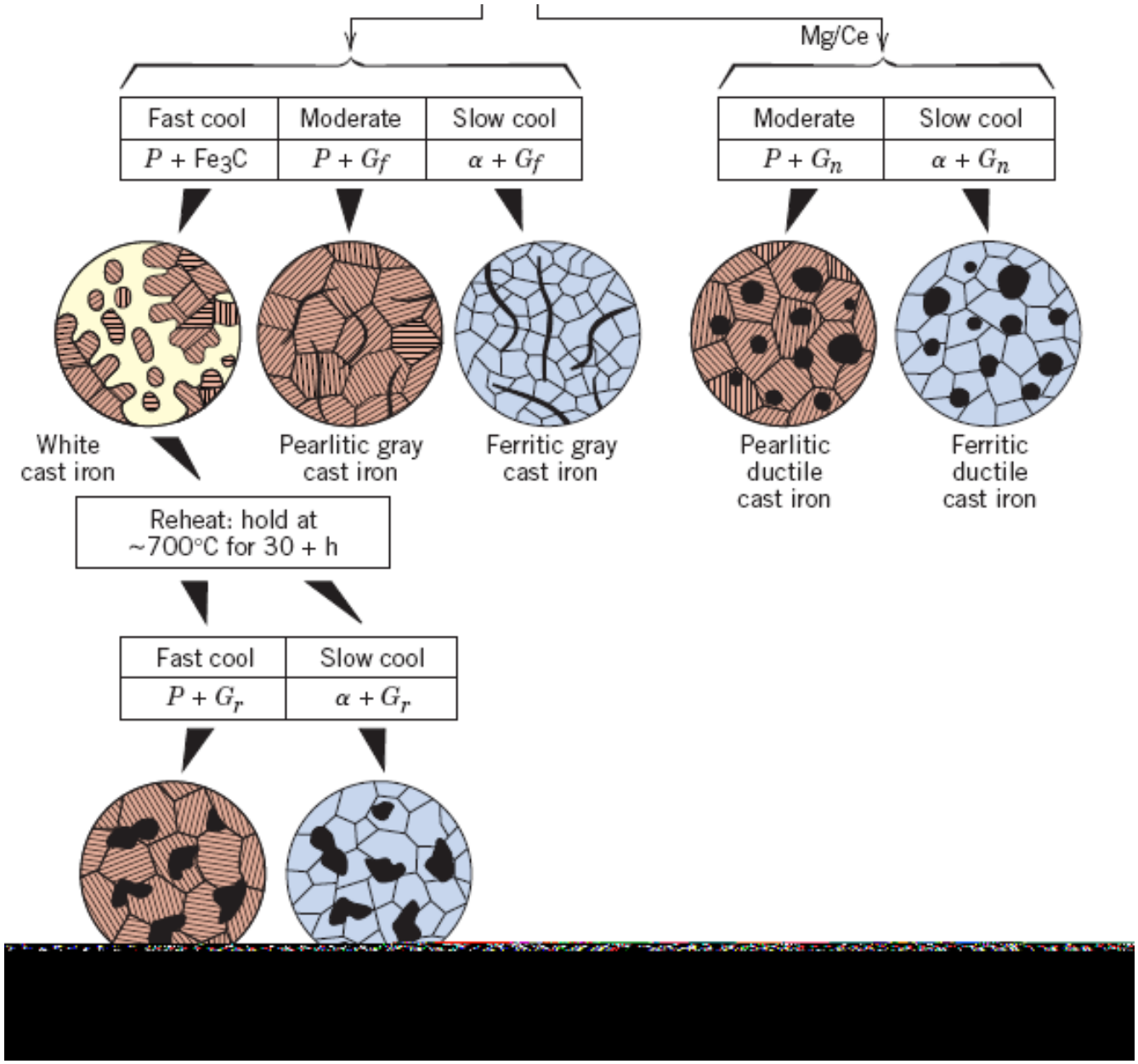
Mechanically, gray iron is comparatively weak and brittle

- the tips of the graphite flakes are sharp and pointed,
- Strength are much higher under compressive loads

- very effective in damping vibration energy.
- exhibit a high resistance to wear.
- among the least expensive of all metallic materials.

- Typical applications include:
  - engine cylinders,
  - pistons,
  - gear box casing,
  - transmission casing,
  - machine tool bases,
  - balance weight of large cranes,


Temperature
Commercial cast iron range
Fe_3C
C
Mg/Ce
Fast cool
Moderate
Slow cool
$P + Fe_3C$
$P + G_f$
$\alpha + G_f$
Moderate
Slow cool
$P + G_n$
$\alpha + G_n$


Mg/Ce
Fast cool
Moderate
Slow cool
$P + Fe_3C$
$P + G_f$
$\alpha + G_f$
Moderate
Slow cool
$P + G_n$
$\alpha + G_n$
White cast iron
Pearlitic gray cast iron
Ferritic gray cast iron
Pearlitic ductile cast iron
Ferritic ductile cast iron
Reheat: hold at ~700°C for 30 + h
Fast cool
Slow cool
$P + G_r$
$\alpha + G_r$

Cast Irons: *Ductile (or Nodular) Iron*

- Fe-1%Ni-0.4%Mn-0.06%Mg-3.4%C
- Produced by addition of RE or Mg to molten metal just before casting) grey iron. This converts graphite flakes into granules or nodules
- These irons are much stronger and tougher than grey irons, but more expensive
- They are produced and used for high specification applications.

Cast Irons: *Ductile (or Nodular) Iron*

- Typical applications include:
  - gears,
  - Crankshafts
  - pump bodies
  - pressure valves
  - rollers.

Cast Irons: *White Cast Iron*

- For low-silicon cast irons (containing less than 1.0 wt% Si) and rapid cooling rates, most of the carbon exists as cementite instead of graphite.
- A fracture surface of this alloy has a white appearance.

properties

very brittle; virtually unmachinable

Cast Irons: *White Cast Iron*

application area

It is used very hard and wear-resistant surface, without a high degree of ductility

- for example, as rollers in rolling mills.

Cast Irons: *Compacted Graphite Iron (CGI)*

- **Microstructurally, the graphite in CGI alloys has a worm-like shape.**
  - However, sharp edges (characteristic of graphite flakes) should be avoided;

Table 11.5 **Designations, Minimum Mechanical Properties, Approximate Compositions, and Typical Applications for Various Gray, Nodular, Malleable, and Compacted Graphite Cast Irons**

				Mechanical Properties			
Grade	*UNS Number*	*Composition (wt%)*[a]	*Matrix Structure*	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
				Compacted Graphite Iron			
ASTM A842							
Grade 250	—	3.1–4.0 C, 1.7–3.0 Si, 0.015–0.035 Mg, 0.06–0.13 Ti	Ferrite	250 (36)	175 (25)	3	Diesel engine blocks, exhaust manifolds, brake discs for high-speed trains
Grade 450	—		Pearlite	450 (65)	315 (46)	1	

[a] The balance of the composition is iron.

Source: Adapted from *ASM Handbook*, Vol. 1, *Properties and Selection: Irons, Steels, and High-Performance Alloys*, 1990. Reprinted by permission of ASM International, Materials Park, OH.

CHAPTER 3
NONFERROUS ALLOYS

- Steel and other ferrous alloys have a wide range of mechanical properties, may be fabricated with relative ease, and are economical to produce.
- Some distinct limitations of steel and ferrous alloys:
  1. a relatively high density,
  2. a comparatively low electrical conductivity,
  3. an inherent susceptibility to corrosion in some common environments.

Copper and Its Alloys

- Have been utilized in quite a variety of application.
- Unalloyed copper is so soft and ductile that it is difficult to machine;
  - it has an almost unlimited capacity to be cold worked.
  - it is highly resistant to corrosion in diverse environments including the ambient atmosphere, seawater, and some industrial chemicals.

Copper and Its Alloys

- The mechanical and corrosion-resistance properties of copper may be improved by alloying.
- Most copper alloys cannot be hardened or strengthened by heat-treating procedures;
  - Only cold working and/or solid-solution alloying.

Copper Alloys: brasses

- The most common copper alloys
  - Zinc is the predominant alloying element.
- The α phase is stable for concentrations up to approximately 35 wt% Zn.
  - This phase has an FCC crystal structure,
  - α brasses are relatively soft, ductile, and easily cold worked.

Copper Alloys: brasses

- The β' phase has an ordered BCC crystal structure and is harder and stronger than the α phase;
  - consequently, $\alpha + \beta'$ alloys are generally hot worked.

Copper Alloys: brasses

- Some of the common brasses are:
  - yellow, naval, and cartridge brass, muntz metal, and gilding metal.
- Some of the common uses for brass alloys:
  - costume jewelry, cartridge casings, automotive radiators, musical instruments, electronic packaging, and coins.

Copper Alloys: bronzes

- Alloys of copper and several other elements, including tin, aluminum, silicon, and nickel.
- Bronzes are somewhat stronger than the brasses,
  - Yet they still have a high degree of corrosion resistance.
- Generally bronzes are utilized when, in addition to corrosion resistance, good tensile properties are required.

Beryllium Coppers

- The most common heat-treatable copper alloys.
- Possess a remarkable combination of properties:
  - tensile strengths as high as 1400 MPa (200,000 psi),
  - excellent electrical and corrosion properties, and wear resistance when properly lubricated;
  - they may be cast, hot worked, or cold worked.
  - High strengths are attained by precipitation-hardening heat treatments.
- These alloys are costly because of the beryllium additions, which range between 1.0 and 2.5 wt%.
- Applications include:
  - jet aircraft landing gear bearings and bushings,
  - springs, and surgical and dental instruments.

Aluminum and Its Alloys

- Al and its alloys are characterized by
  - relatively low density (2.7 g/cm^3 as compared to 7.9 g/cm^3 for steel),
  - high electrical and thermal conductivities,
  - resistant to corrosion in some common environments, including the ambient atmosphere.
- Many of these alloys are easily formed due to high ductility;

Aluminum and Its Alloys

- The chief limitation:
  - low melting temperature [660°C],
    - restricts the maximum temperature at which it can be used.

Aluminum and Its Alloys

- The mechanical strength of aluminum may be enhanced by cold work and by alloying;
  - however, both processes tend to diminish resistance to corrosion.
- Principal alloying elements include copper, magnesium, silicon, manganese, and zinc.

Aluminum and Its Alloys

- applications of aluminum alloys:
  - aircraft structural parts, beverage cans, bus bodies, and automotive parts (engine blocks, pistons, and manifolds).

Magnesium and Its Alloys

- The most outstanding characteristic of magnesium is its density, 1.7 g/cm3, which is the lowest of all the structural metals;
  - therefore, its alloys are used where light weight is an important consideration (e.g., in aircraft components).
  - properties
- Magnesium has an HCP crystal structure, is relatively soft, and has a low elastic modulus: 45 GPa (6.5×10^6 psi).
- At room temperature magnesium and its alloys are difficult to deform; in fact, only small degrees of cold work may be imposed without annealing.

Magnesium and Its Alloys

- Magnesium, like aluminum, has a moderately low melting temperature [651°C].
- Chemically, magnesium alloys are relatively unstable and especially susceptible to corrosion in marine environments.
  - Fine magnesium powder ignites easily when heated in air;

Table 11.8 **Compositions, Mechanical Properties, and Typical Applications for Six Common Magnesium Alloys**

ASTM Number	*UNS Number*	*Composition (wt%)*[a]	*Condition*	*Mechanical Properties*			*Typical Applications*
				Tensile Strength [MPa (ksi)]	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	
				Wrought Alloys			
AZ31B	M11311	3.0 Al, 1.0 Zn, 0.2 Mn	As extruded	262 (38)	200 (29)	15	Structures and tubing, cathodic protection
HK31A	M13310	3.0 Th, 0.6 Zr	Strain hardened, partially annealed	255 (37)	200 (29)	9	High strength to 315°C (600°F)
ZK60A	M16600	5.5 Zn, 0.45 Zr	Artificially aged	350 (51)	285 (41)	11	Forgings of maximum strength for aircraft
				Cast Alloys			
AZ91D	M11916	9.0 Al, 0.15 Mn, 0.7 Zn	As cast	230 (33)	150 (22)	3	Die-cast parts for automobiles, luggage, and electronic devices
AM60A	M10600	6.0 Al, 0.13 Mn	As cast	220 (32)	130 (19)	6	Automotive wheels
AS41A	M10410	4.3 Al, 1.0 Si, 0.35 Mn	As cast	210 (31)	140 (20)	6	Die castings requiring good creep resistance

[a] The balance of the composition is magnesium.

Titanium and Its Alloys

- Titanium and its alloys are relatively new engineering materials that possess an extraordinary combination of properties.
- The pure metal has a relatively low density (4.5 g/cm3), a high melting point [1668°C], and an elastic modulus of 107 GPa.
- Titanium alloys are extremely strong;
  - room temperature tensile strengths as high as 1400 MPa (200,000 psi).
  - the alloys are highly ductile and easily forged and machined.

CHAPTER 4
COPPER ALLOYS

- **Individual Assignment (Minimum 10 page)**

- Explain briefly;
  - **Copper and Copper Alloys-Brass**
  - **Bronze and Cupronickel compositions**
  - **Characteristics and uses - Cu-Al, Cu-Si**
  - **Properties and applications- Al-Cu**
  - **Cu-Mn composition**
  - **Heat treatment of CI.**

CHAPTER 5
Nonmetallic Materials: Plastics, Elastomers, Ceramics, and Composites

Introduction

Plastics, ceramics, and composites are nonmetallic materials that are commonly used in different application.

In general Plastics, elastomers, ceramics, and composites have become important materials Can be manufactured so that a wide range of properties may be obtained.

Plastics

- Plastics are engineered materials
  - Large molecules that are composed of smaller molecules
  - Made from natural or synthetic resins and compounds
  - IT Can be molded, extruded, cast, or used for coatings
  - Has Low density, low tooling costs, good corrosion resistance, low cost
  - Plastics are very versatile materials and are used more than steel, aluminum, and copper.
  - Used in applications such as cars, artificial organs, shower curtains, contact lenses, computers, etc.

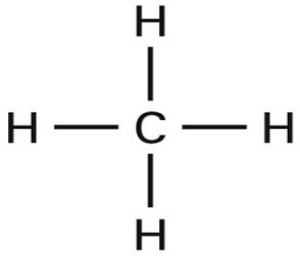
Molecular Structure of Plastics

- Hydrocarbons
  - C_nH_{2n+2}
  - Covalent bonding
  - When no additional atoms can be added to the chain, the molecule is said to be saturated
  - Double or triple covalent bonds may also be present
  - Common hydrocarbons
    - Ethylene and acetylene

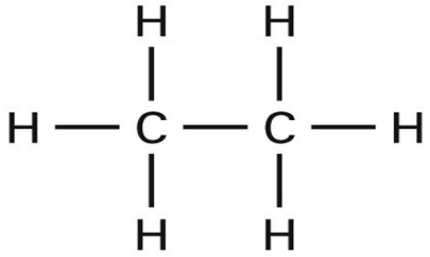
- Made by Polymerization
  - Small molecules (monomers or mers) link to form larger molecules with the same constituent atoms

Examples of Hydrocarbons

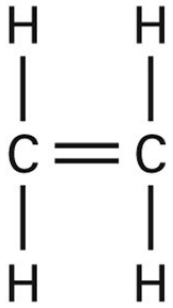
Figure 9-1 (Right) The linking of carbon and hydrogen to form methane and ethane molecules. Each dash represents a shared electron pair or covalent bond.



Methane



Ethane



Ethylene



Acetylene

Figure 9-2 (Left) Double and Triple covalent bonds exist between the carbon atoms in unsaturated ethylene and acetylene molecules.

Forming Molecules by Polymerization

- Molecules can be linked by addition or condensation methods
- Monomers are the basic building blocks
- Monomers can be linked together to produce polymers
- Increasing the chain length increases toughness, creep resistance, melting temperature, melt viscosity, and difficulty in processing
- Copolymers are similar to alloys in metals when two monomers are combined
- Condensation polymerization occurs when a polymer is formed plus byproducts (such as water)

Copolymerization and Condensation Polymerization

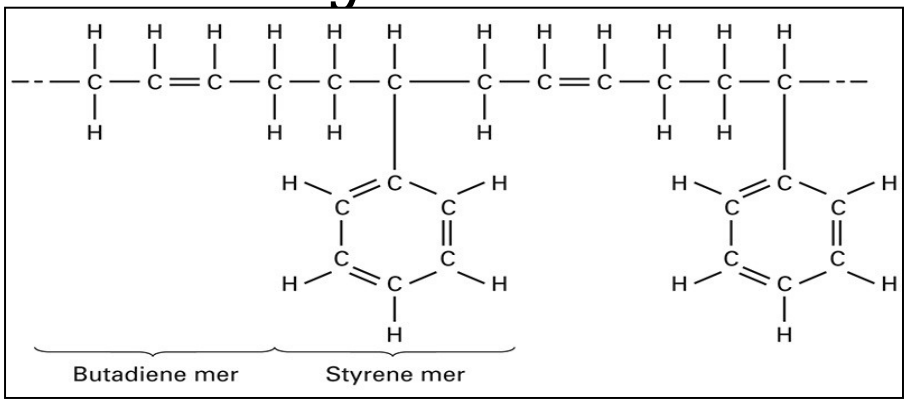


Figure 9-5 Addition of Polymerization with two kinds of mers- here, the copolymerization of butadiene and styrene. Terpolymers utilize three kinds of mers

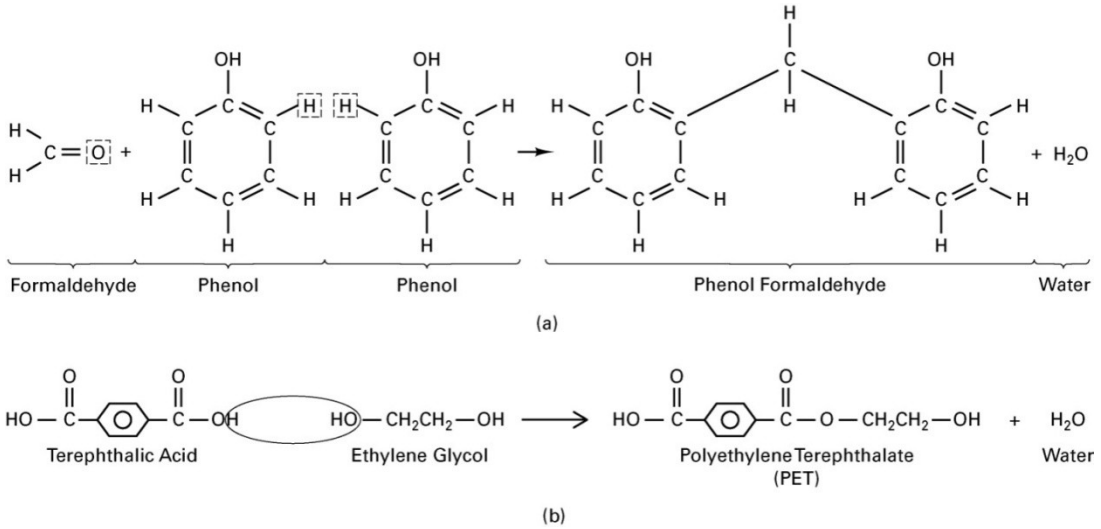


Figure 9-6 The formation of (a) phenol-formaldehyde (Bakelite) and polyethylene terephthalate (PET) by condensation polymerization. Note the water by-product.

Thermosetting and Thermoplastics

- Thermosets and thermoplastics are classified based on their response to heat
  - Internal bonding is covalent [thermoset]
  - Intermolecular bonds are van der Waal forces
- Linear polymers are typically flexible and tough
  - Soften with increasing temperature
  - Slide over each other in molding processes

Thermoplastics

- Contain molecules of different lengths
- Do not have a definite melting temperature
- Above the melting temperature, the material can be poured and cast

- Application of a force deforms the material both elastically and plastically
  - Plastic deformation occurs by adjacent fibers and chains slipping past one another

Thermoplastics

- If cooled below the melting temperature, thermoplastics crystallize
  - Polymer of thermoplastics is stiffer, harder, less ductile, and more resistant to solvents and heat
- Common thermoplastics
  - Polyethylene (PE)
  - Polypropylene (PP)
  - Polystyrene (PS)
  - Polyvinyl Chloride (PVC)

Thermosets

- Significantly stronger and more rigid than thermoplastics
- Able to resist higher temperatures
- Greater dimensional stability
- Lower ductility
- Poorer impact properties
- Heating changes their structure permanently

Properties and Applications of Plastics

- Light weight
- Corrosion resistance
- Electrical resistance
- Low thermal conductivity
- Variety of optical properties
- Formability
- Surface finish
- Low cost
- Low energy content

Plastics vs. Metals

- Unless they are in the form of composites, plastics do not have strength properties close to the engineering metals
- Coefficient of thermal expansion is higher for plastics
- Good corrosion resistance
- UV and radiation can alter plastics' properties
- Plastics are difficult to repair

TABLE 9-3 Property Comparison of Metals and Polymers

Material	Condition	TS (ksi)	E (10^s psi)	Elongation
Polyethylene	Branched	2	0.025	90–650
Polyethylene	Crystallized	4	0.100	50–800
Polyvinylchloride	Cl-sides	8	0.375	2–40
Polystyrene	Benzene-sides	7	0.500	1–3
Bakelite	Framework	7	1.0	1
Aluminum	Annealed	13	10.0	15–30
1040 steel	Annealed	75	30.0	30

TABLE 9-4 Comparison of Varoius Materials (Modulus and Cost)[a]

Material	Modulus ($\times 10^6$ psi)	$/pound	$/in.^{3}
Aluminum	10.0	1.30	0.132
Steel	30.0	30–50	0.075–0.125
Nylon	0.1	1.80	0.129
ABS	0.3	0.92	0.031
High-density polyethylene	0.1	0.75	0.028
Polycarbonate	0.35	1.45	0.063
Polypropylene	0.2	0.94	0.029
Polystyrene	0.3	0.85	0.026
Epoxy (bisphenol)	0.45	1.06	0.033

[a] Cost figures are 2010 values and are clearly subject to change.

Applications of Plastics

- Almost any color material is possible with plastics
- Used in packaging and containers
- Household appliances, clock cases, exteriors of electronic products
- Cushioning materials
- Rigid foams are used in sheet metals for compressive strength
- Gears, lenses, safety helmets and unbreakable windows

Common Types or Families of Plastics

lists common properties of plastics

- Thermoplastics
  - ABS
  - Nylon
  - Polyethylene
  - Polypropylene
  - Polystyrene
  - Polyvinyl Chloride
  - Vinyl
- Thermosets
  - Epoxies
  - Polyesters
  - Silicones

TABLE 9-1 Properties and Major Characteristics of Some Common Types of Plastics

Material	Specific Gravity	Tensile Strength (1000 lb/in.^{2})	Impact Strength Izod (ft-lb/in. of Notch)	Top Working Temperature [°F(°C)]	Dielectric Strength[b] (V/mil)	24-Hour Water Absorption (%)	Special Characteristics[a]				Common Forms											
							Weatherability	Colorability	Optical Clarity	Chemical Resistance	Injection Molding	Extrusions	Formable Sheet	Film	Fiber	Compression or Transfer Moldings	Castings	Reinforced Plastics	Moldings	Industrial Thermosetting Laminates	Foam
Thermoplastics																					
ABS material	1.02–1.06	4–8	1.3–10.0		300–400	0.2–0.3	0	×		0	•	•	•								
Acetal	1.4	10	1.5	250(121)	1200	0.22		×		0	•	•									
Acrylics	1.12–1.19	5.5–10	0.2–2.3	200(93)	400–530	0.2–0.4	×		×	0	•	•	•		•			•			
Cellulose acetate	1.25–1.50	3–8	0.75–4.0	260(127)	300–600	2.0–6.0		×	×		•	•	•	•	•						
Cellulose acetate butyrate	1.18–1.24	2–6	0.6–3.2	130(54)	250–350	1.8–2.1	×	×	×												
Cellulose propionate	1.19–1.24	1–5	0.8–9	140(60)	300	1.8–2.1		×	×		•	•	•	•							
Chlorinated polyether	1.4	6	3.3	300(149)	400	0.01				×	•	•									
Ethyl cellulose	1.16	3–6	1.8–4.0	150(66)	350	1.6–2.2		×			•	•									
TFE-fluorocarbon	2.1–2.3	1.5–3	2.5–4.0	500(260)	450	0	×			×		•	•	•	•	•					
CFE-fluorocarbon	2.1–2.15	4.5–6	3.5–3.6	390(199)	550	0	×			×	•	•	•	•							
Nylon	1.1–1.2	8–10	2	250(121)	385–470	0.4–5.5		0	0	0	•	•	•	•	•						
Polycarbonate	1.2	9.5	14	250(121)	400	0.15	×	0		×	•	•									
Polyethylene	0.96	4	10	200(93)	440	0.003		0	×	×	•	•	•	•	•						•
Polypropylene	0.9–1.27	3.4–5.3	1.02	230(110)	520–800	0.03		0	×	×	•	•	•	•	•						
Polystyrene	1.05–1.15	5–9	0.3–0.6	190(8)	400–600	<0.2		×	×	0	•	•	•	•							
Modified polystyrene	1.0–1.1	2.5–6	0.25–11.0	212(100)	300–600	0.03–02		×		×	•	•	•	•							
Vinyl	1.16–1.55	1–5.9	0.25–2.0	220(104)	25–500	0.2–1		×	×	×	•	•	•	•	•						•
Thermosetting plastics																					
Epoxy	1.1–1.7	4–13	0.4–1.5	325(163)	500	0.1–0.5	×	×		×							•	•		•	•
Melamine	1.76–1.98	5–8		350(177)	460	0.1		×		0						•		•		•	
Phenolic	1.2–1.45	5–9	0.25–5	300(149)	100–500	0.2–0.6				0						•	•	•		•	•
Polyester (other than molding compounds)	1.06–1.46	4–10	0.18–0.4	300(149)	340–570	0.5		×	×	0				•	•		•	•	•		
Polyester (alkyd, DAP)	1.6–1.75	3.2–8	3.6–8			0.16–0.67										•		•		•	
Silicone	2.0	3–5	0.2–3.0	550(288)	250–350	0.4–0.5										•	•	•		•	•
Urea	1.41–1.80	4–8.5	0.2–0.5	185(85)	300–600	1–3		×	0												

[a] X denotes a principal reason for its use; 0 indicates a secondary reason.
[b] Short-time ASTM test.

Additives

- Fillers
  - Improve strength, stiffness, and toughness
  - Reduce shrinkage and weight
  - Common fillers: wood flour, cloth fibers, macerated cloth, glass fibers, mica, calcium carbonate
- Coloring agents
  - Dyes are soluble and pigments are insoluble
- Plasticizers
  - Added in small amounts to reduce viscosity

Additives

- Lubricants
  - Improve moldability
  - Facilitates part removal
- Stabilizers and antioxidants
  - Retard the effects of heat, light, and oxidation
- Antimicrobial
  - Long-term protection from bacteria and fungus
- Fibers
  - Increase strength and stiffness

TABLE 9-2 Additive Agents in Plastics and Their Purpose

Type	Purpose
Fillers	Enhance mechanical properties, reduce shrinkage, reduce weight, or provide bulk
Plasticizer	Increase flexibility, improve flow during molding, reduce elastic modulus
Lubricant	Improve moldability and extraction from molds
Coloring agents (dyes and pigments)	Impart color
Stabilizers	Retard degradation due to heat or light
Antioxidants	Retard degradation due to oxidation
Flame retardants	Reduce flammability
Conductive/antistatic additives	Impart various degrees of electrical conductivity

Additional Plastics

- Oriented plastics
  - Processing aligns the molecules in parallel give the material higher strength
  - May be stretched, rolled, or extruded
  - If thermoplastics are heated, molecules tend to revert back to their original orientation (viscoelastic memory)
- Engineering plastics
  - Enhanced impact and stress resistance
  - High rigidity, superior electrical resistance, excellent processing properties
  - Polyamides, polyacetals, polyketones, etc.

Additional Plastics

- Plastics as adhesives
  - May be used to bond metals to nonmetals
  - Hot-melt glues
  - Two-part epoxies
- Plastics for tooling
  - Jigs, forming-dies
- Foamed plastics
  - Incorporate gases in their structure
  - Cushioning in upholstery and automobile seats
  - Flotation devices, insulation, disposable food trays
- Polymer coatings
  - Enhance appearance and provide corrosion resistance

Additional Considerations

- Plastics have replaced many other materials
  - Glass with transparent plastics
  - Copper and brass piping with PVC
- Due to weight concerns in automobiles, plastics have replaced many components
- Recycling of plastics
  - Materials must be sorted based on resin type, fillers, and color
  - Packaging is the largest usage for plastics
    - PET, HDPE, PE, PS

TABLE 9-5 Symbols for Recyclable Plastics and Some Common Uses

Symbol	Abbreviation[a]	Polymer Name	Recycled Uses
	**PETE** or **PET**	Polyethylene terephthalate	Polyester fibres, thermoformed sheet, strapping, and soft drink bottles
	**HDPE**	High density polyethylene	Bottles, grocery bags, milk jugs, recycling bins, agricultural pipe, base cups, car stops, playground equipment, and plastic lumber
	**PVC** or **V**	Polyvinyl chloride	Pipe, fencing, and non-food bottles
	**LDPE**	Low density polyethylene	Plastic bags, 6 pack rings, various containers, dispensing bottles, wash bottles, tubing, and various molded laboratory equipment
	**PP**	Polypropylene	Auto parts, industrial fibers, food containers, and dishware
	**PS**	Polystyrene	Desk accessories, cafeteria trays, plastic utensils, toys, video cassettes and cases, and insulation board and other expanded polystyrene products (e.g., Styrofoam)
	**OTHER** or **O**	Other plastics, including acrylic, acrylonitrile butadiene styrene, fiberglass, nylon, polycarbonate, and polylactic acid	Bottles, plastic lumber applications

[a] Often found under symbol

Elastomers

  - Return to their original shape when the load is removed
- Cross-linking restricts the viscous deformation; retains the elastic response
- Rubber
  - Natural and synthetic
  - Natural rubbers have good flexibility, good electrical insulation, low internal friction, and resistance to most inorganic acids, salts, and alkalis
  - Poor resistance to oil, gasoline, and other petroleum products

Selection of an Elastomer

- Used in applications that require
  - Shock absorption
  - Noise and vibration control
  - Sealing
  - Corrosion resistance
  - Abrasion protection
  - Friction
  - Insulation
  - Waterproofing

Ceramics

- Is a traditional materials such as

  Brick, pottery
- Typical properties
  - High temperature usage
  - Hard and brittle
  - High melting point
  - Low thermal expansion
  - Good creep resistance
  - High compressive strength

Nature and Structure of Ceramics

- Compounds of metallic and nonmetallic elements which has:
  - High melting temperatures
  - High rigidity
  - High compressive strength
- Noncrystalline structures are possible
  - Amorphous condition is observed in glasses
- Both crystalline and noncrystalline ceramics are brittle
- Clay and white ware are commonly used ceramics

Special Ceramics

- Refractory materials
  - Ceramics that have been designed to provide mechanical or chemical properties at high temperatures
- Abrasives
  - Ceramics have high hardness
  - Can be used in grinding applications
  - Diamond and cubic boron nitride are super abrasives
- Ceramics may be used for electrical and magnetic applications.

Special Ceramics

- Glasses
  - Soft and moldable when hot; easily shaped
  - Strong in compression but brittle and weak in tension
  - Excellent corrosion resistance
- Cermets are combinations of metals and ceramics

  found in Crucibles, nozzles, aircraft brakes

- Ceramic coatings
  - Enamels, porcelains, glazes

Ceramics for Mechanical Applications

- Ceramics have strong ionic or covalent bonds
  - Most ceramics have small cracks, pores, and impurities
  - Act as mechanical stress concentration points
- Advanced ceramics
  - Alumina
  - Silicon carbide
  - Sialon
  - Zirconia
- Advanced ceramics may be used as cutting tools

Composite Materials

- Nonuniform solid consisting of two or more different materials
  - Mechanically or metallurgically bonded
  - Each of the constituent materials maintains its identity
- Properties depend on:
  - Properties of individual components
  - Relative amounts
  - Size, shape, and distribution
  - Orientation
  - Degree of bonding

Laminar or Layered Composites

- Distinct layers of materials
- Layers are bonded together
- Typical example is plywood
- Bimetallic strips have two metals with different coefficients of thermal expansion

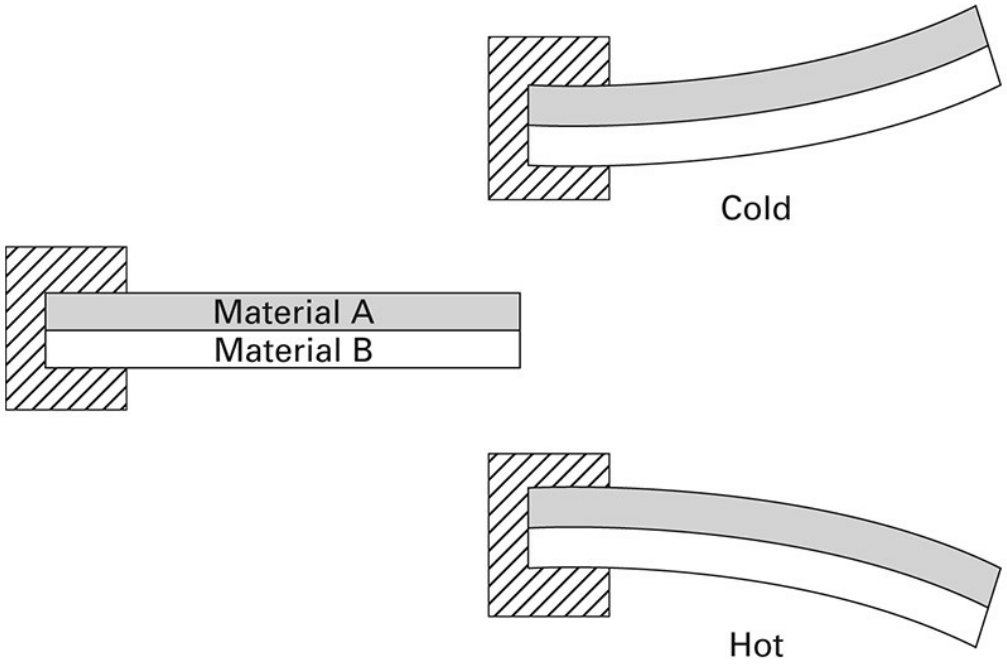


Figure 9-12 Schematic of a bimetallic strip where material A has the greater coefficient of thermal expansion.

Particulate Composites

- Consist of discrete particles of one material in a matrix of another material

  such as Concrete

True particulate composites have large amount of coarse particles

Fiber-Reinforced Composites

- Discontinuous thin fibers of one material are embedded in a matrix
  - Wood and bamboo are naturally occurring fiber composites
  - Bricks of straw and mud
  - Automobile tires
    - Fibers of nylon, rayon, Kevlar, or steel to reinforce the rubber
  - Glass fibers
  - Graphite
  - Ceramic fibers, metal wires
- Common objective is high strength and lightweight
  - Orientation of the fibers is important

Properties of Fiber-Reinforced Composites

- Advanced fiber-reinforced composites
  - Organic or resin matrix composites
    - Used in Sports equipment, light-weight armor, low-temperature aerospace applications
  - Metal-matrix composites
    - Nonflammable, do not absorb water or gases, corrosion resistance
  - Carbon-carbon composites
    - High temperature applications
  - Ceramic-matrix composites
    - High temperature strength, stiffness, and environmental stability

Design and Fabrication

- Select the component materials
- Determine the relative amounts of each component
- Determine the size, shape, distribution, and orientation
- Select the proper fabrication method
  - Compression molding
  - Filament winding
  - Pultrusion
- Composites may be tailored to specific applications
- Manufacturing with composites is labor intensive

Failures

- Defects
  - Delamination voids
  - Missing layers
  - Contamination
  - Fiber breakage

Thank you!