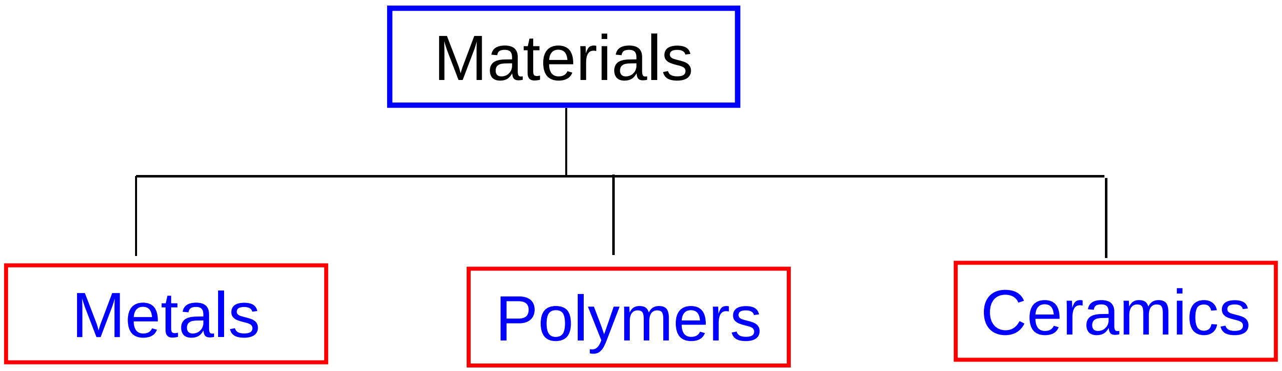
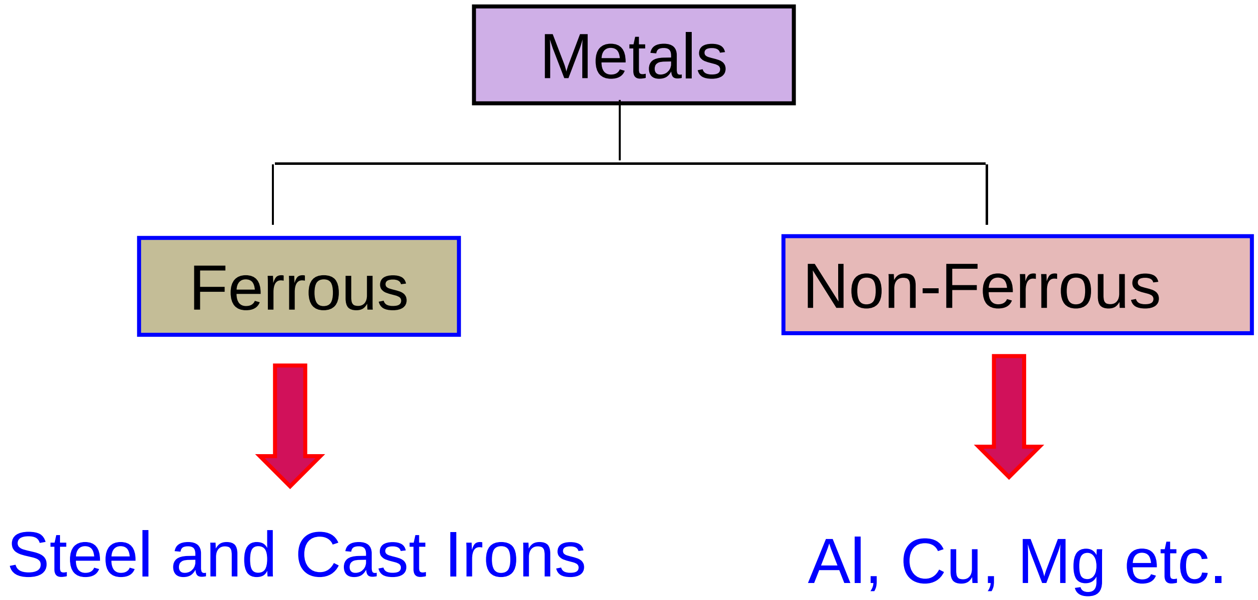
Properties and Applications of Materials

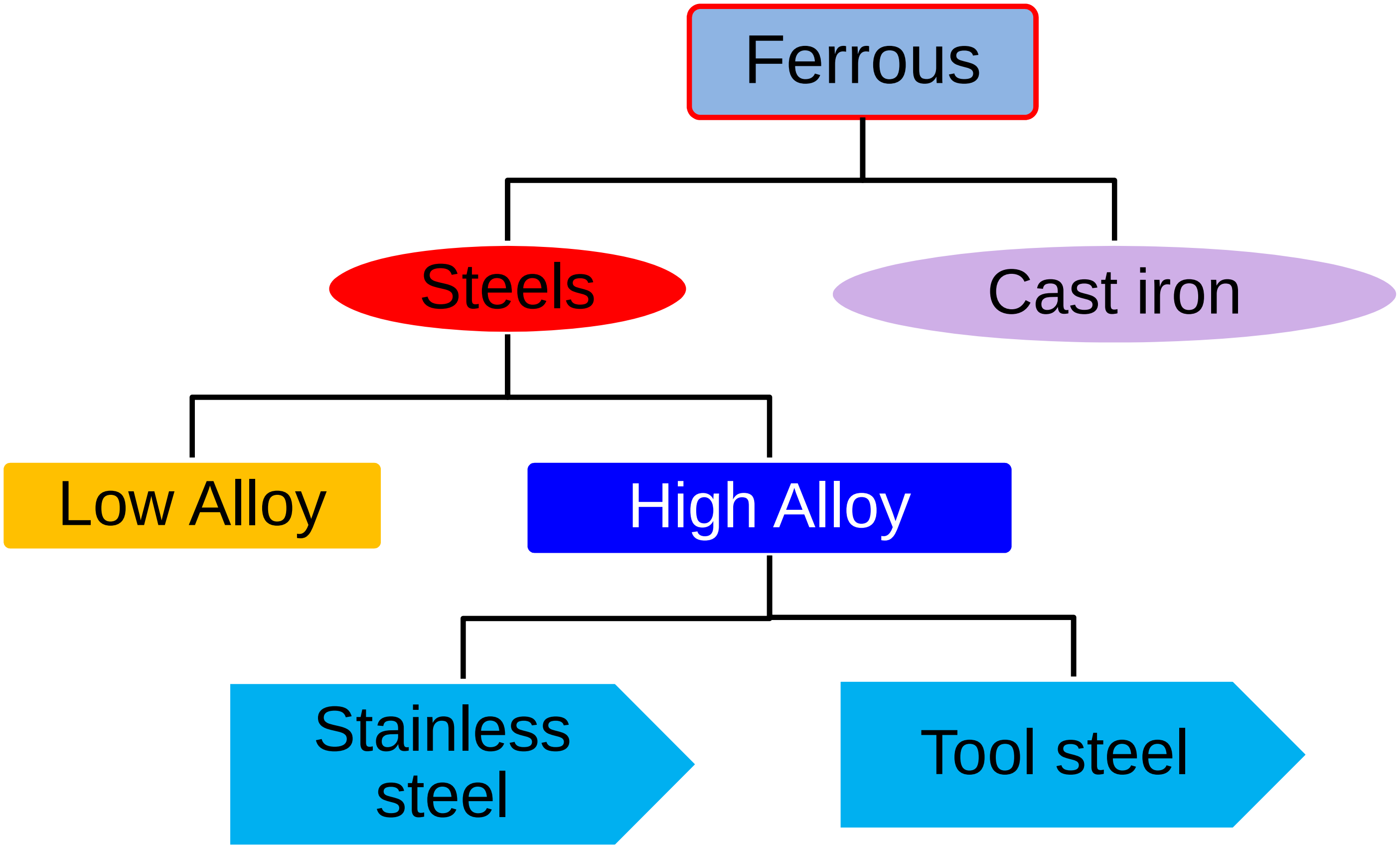
Classification of Materials



Metals

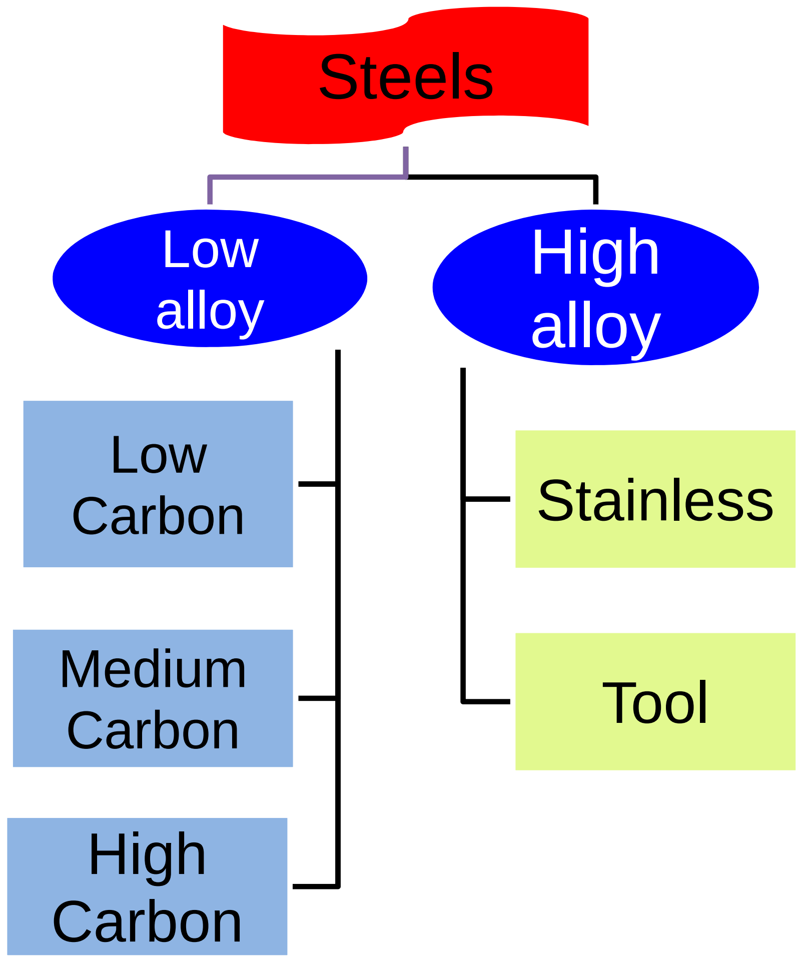


Ferrous Materials



Ferrous Materials - Steels

- Steels - alloys of iron-carbon. May contain other alloying elements.
- Several grades are available.
- Low Alloy (<10 wt%)
  - –Low Carbon (<0.25 wt% C)
  - –Medium Carbon (0.25 to 0.60 wt%)
  - –High Carbon (0.6 to 1.4 wt%)
- High Alloy
  - –Stainless Steel (> 11 wt% Cr)
  - –Tool Steel



Low Carbon Steel

- Plain carbon steels - very low content of alloying elements and small amounts of Mn.
- Most abundant grade of steel is low carbon steel - greatest quantity produced; least expensive.
- Not responsive to heat treatment; cold working needed to improve the strength.
- Good Weldability and machinability
- High Strength, Low Alloy (HSLA) steels - alloying elements (like Cu, V, Ni and Mo) up to 10 wt %; have higher strengths and may be heat treated.

Low carbon steel

Compositions of some low carbon and low alloy steels

Designation		Composition (wt%)		
AISI/SAE or ASTM Number	***UNS Number***	***C***	***Mn***	***Other***
		Plain Low-Carbon Steels		
1010	G10100	0.10	0.45	
1020	G10200	0.20	0.45	
A36	K02600	0.29	1.00	0.20 Cu (min)
A516 Grade 70	K02700	0.31	1.00	0.25 Si
		High-Strength, Low-Alloy Steels		
A440	K12810	0.28	1.35	0.30 Si (max), 0.20 Cu (min)
A633 Grade E	K12002	0.22	1.35	0.30 Si, 0.08 V, 0.02 N, 0.03 Nb
A656 Grade 1	K11804	0.18	1.60	0.60 Si, 0.1 V, 0.20 Al, 0.015 N

Properties and typical application of some low carbon and low alloys steels

AISI/SAE or ASTM Number	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
		Plain Low-Carbon Steels		
1010	325 (47)	180 (26)	28	Automobile panels, nails, and wire
1020	380 (55)	210 (30)	25	Pipe; structural and sheet steel
A36	400 (58)	220 (32)	23	Structural (bridges and buildings)
A516 Grade 70	485 (70)	260 (38)	21	Low-temperature pressure vessels
		High-Strength, Low-Alloy Steels		
A440	435 (63)	290 (42)	21	Structures that are bolted or riveted
A633 Grade E	520 (75)	380 (55)	23	Structures used at low ambient temperatures
A656 Grade 1	655 (95)	552 (80)	15	Truck frames and railway cars

Medium Carbon Steel

- Carbon content in the range of 0.3 – 0.6%.
- Can be heat treated - austenitizing, quenching and then tempering.
- Most often used in tempered condition – tempered martensite
- Medium carbon steels have low hardenability
- Addition of Cr, Ni, Mo improves the heat treating capacity
- Heat treated alloys are stronger but have lower ductility
- Typical applications – Railway wheels and tracks, gears, crankshafts.

Composition of some alloyed medium carbon steels

AISI/SAE Designation	UNS Designation	Composition Ranges (wt% of Alloying Elements in Addition to C)			
		Ni	Cr	Mo	Other
10xx, Plain carbon	G10xx0				
11xx, Free machining	G11xx0				0.08–0.33S
12xx, Free machining	G12xx0				0.10–0.35S, 0.04–0.12P
13xx	G13xx0				1.60–1.90Mn
40xx	G40xx0			0.20–0.30	
41xx	G41xx0		0.80–1.10	0.15–0.25	
43xx	G43xx0	1.65–2.00	0.40–0.90	0.20–0.30	
46xx	G46xx0	0.70–2.00		0.15–0.30	
48xx	G48xx0	3.25–3.75		0.20–0.30	
51xx	G51xx0		0.70–1.10		
61xx	G61xx0		0.50–1.10		0.10–0.15V
86xx	G86xx0	0.40–0.70	0.40–0.60	0.15–0.25	
92xx	G92xx0				1.80–2.20Si

High Carbon Steel

- High carbon steels – Carbon content 0.6 – 1.4%
- High C content provides high hardness and strength. Hardest and least ductile.
- Used in hardened and tempered condition
- Strong carbide formers like Cr, V, W are added as alloying elements to from carbides of these metals.
- Used as tool and die steels owing to the high hardness and wear resistance property

Compositions and Application of some Tool steels

AISI Number	UNS Number	Composition (wt.%)						Typical Allpications
		C	Cr	Ni	Mo	W	V	
M1	T11301	0.85	3.75	0.30 max	8.70	1.75	1.20	Drills, saws, lathe and planer tools
A2	T30102	1.0	5.15	0.30 max	1.15	-	0.35	Punches, embossing dies
D2	T30402	1.5	12	0.30 max	0.95	-	1.10 max	Cutlery, drawing dies
O1	T31501	0.95	0.50	0.30 max	-	0.50	0.30 max	Shear blades, cutting tools
S1	T41901	0.50	1.40	0.30 max	0.50 max	2.25	0.25	Pipe cutters, concrete drills
W1	T72301	1.10	0.15 max	0.20 max	0.10 max	0.15 max	0.10 max	Balcksmith tools

Effects of Alloying Elements on Steel

- Manganese – strength and hardness; decreases ductility and weldability; effects *hardenability* of steel.
- Phosphorus – increases strength and hardness and decreases ductility and notch impact toughness of steel.
- Sulfur decreases ductility and notch impact toughness Weldability decreases. Found in the form of sulfide inclusions.
- Silicon – one of the principal deoxidizers used in steel making. In low-carbon steels, silicon is generally detrimental to surface quality.
- Copper – detrimental to hot-working steels; beneficial to corrosion resistance (Cu>0.20%)
- Nickel - ferrite strengthener; increases the *hardenability* and impact strength of steels.
- Molybdenum increases the *hardenability*; enhances the creep resistance of low-alloy steels

Stainless steel

•Stainless steels - A group of steels that contain at least 11% Cr. Exhibits extraordinary corrosion resistance due to formation of a very thin layer of Cr_2O_3 on the surface.

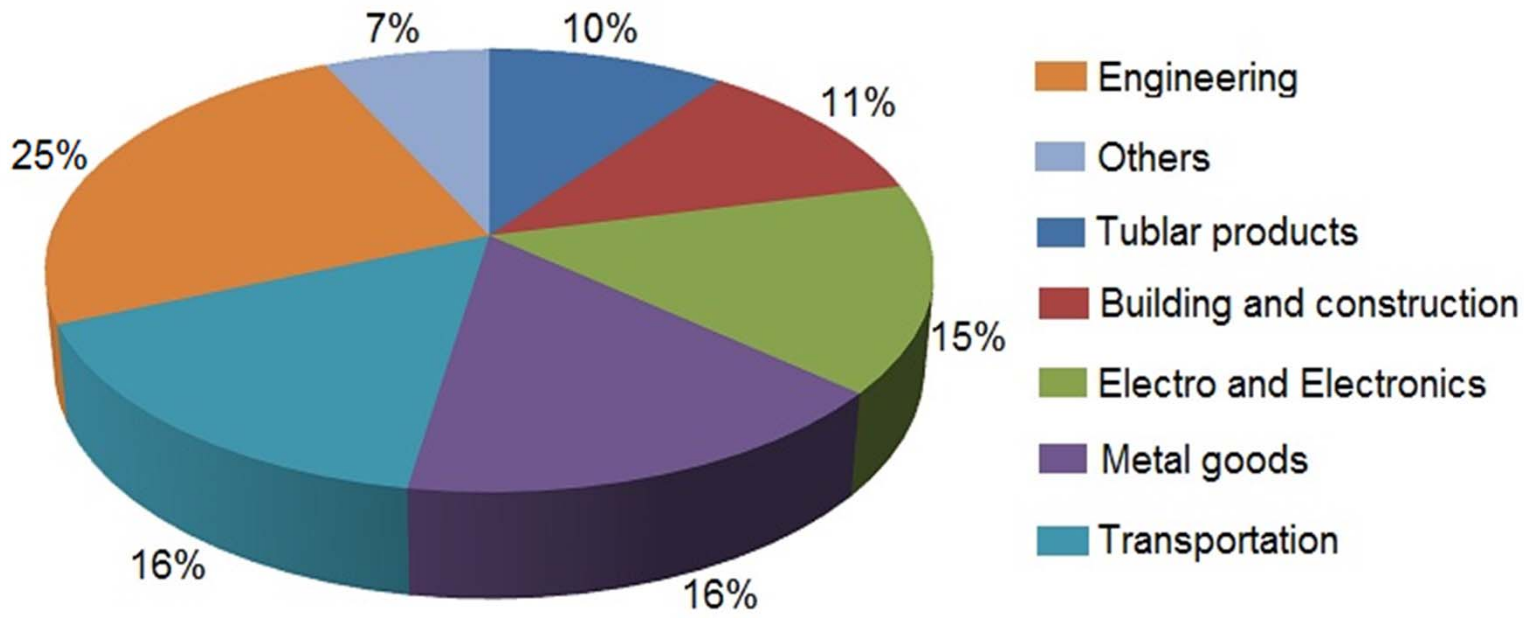
❑Categories of stainless steels:

- Ferritic Stainless Steels – Composed of α ferrite (BCC)
- Martensitic Stainless Steels – Can be heat treated.
- Austenitic Stainless Steels – Austenite (γ) phase field is extended to room temperature. Most corrosion resistant.
- Precipitation-Hardening (PH) Stainless Steels – Ultra high-strength due to precipitation hardening.
- Duplex Stainless Steels – Ferrite + Austenite

Composition and Properties of some stainless steels are given in the next slide

AISI Number	*UNS Number*	*Composition (wt.%)*	*Condition*	*Mechanical Properties*			*Typical Applications*
				UTS (MPa)	*YS (MPa)*	*Ductility (%EL)*	
				Ferritic			
409	S40900	0.08 C, 9.0 Cr, 1.0 Mn, 0.5 Ni, 0.75 Ti	Annealed	380	205	20	Automotive exhaust components, tanks for agricultural sprays
446	S44600	0.20 C, 25 Cr, 1.5 Mn	Annealed	515	275	20	Valves (high temperature), glass molds, combustion chambers
				Austenitic			
304	S30400	0.08 C, 19 Cr, 9.0 Ni, 2.0 Mn	Annealed	515	205	40	Chemical and food processing equipments, cryogenic vessels
316L	S31603	0.03 C, 17 Cr, 12 Ni, 2.5 Mo, 2.0 Mn	Annealed	485	170	40	Welding construction
				Martensitic			
410	S41000	0.15 C, 12.5 Cr, 1.0 Mn	Annealed Q & T	485 825	275 620	20 12	Rifle barrels, cutlery, jet engine parts
440A	S44002	0.70 C, 17 Cr, 0.75 Mo, 1.0 Mn	Annealed Q & T	725 1790	415 1650	20 5	Cutlery, bearings, surgical tools
				Precipitation Hardenable			
17-7PH	S17700	0.09 C, 17 Cr, 7 Ni, 1.0 Al, 1.0 Mn	Precipitation hardened	1450	1310	1 - 6	Springs, knives, pressure vessels

Applications of Stainless steels

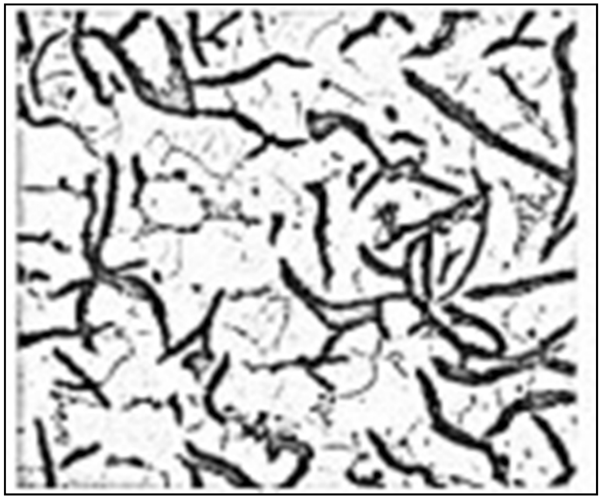


Cast Irons

- Carbon 2.1- 4.5 wt% and Si (normally 1-3 wt%).
- Lower melting point (about 300 °C lower than pure iron) due to presence of eutectic point at 1153 °C and 4.2 wt% C.
- Low shrinkage and good fluidity and casting ability.
- Types of cast iron: grey, white, nodular, malleable and compacted graphite.

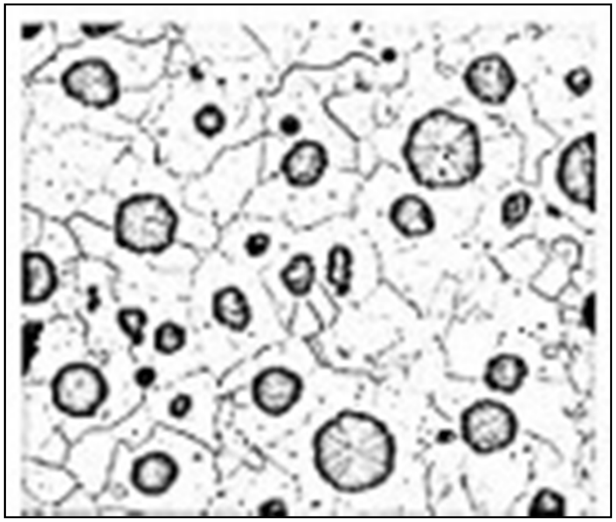
Grey Cast Iron

- Grey cast iron contains graphite in the form of flakes. Named after its grey fractured surface. C:3.0 – 4.0 wt%, Si: 1.0 – 3.0 %
- Microstructure: graphite flakes in a ferrite or pearlite matrix
- Weak & brittle in tension (the graphite flake tips act as stress concentration sites).Stronger in compression,
- Excellent damping capacity, wear resistance.
- Microstructure modification by varying silicon content and cooling rate
- Casting shrinkage is low



Nodular or Ductile Iron

- Addition of Mg and/or Cerium to grey iron converts the graphite flakes to nodules.
- Normally a pearlite matrix.
- Castings are stronger and much more ductile than grey iron as the stress concentration points existing at the flake tips are eliminated.



White Cast Iron

- White cast iron – C: 2.5 – 3 wt.%, Si: 0.5 – 1.5%. Most of the carbon is in the form of cementite. Named after its white fracture surface.
- Results from faster cooling. Contains pearlite + cementite, not graphite. Thickness variation may result in nonuniform microstructure from variable cooling
- Very hard and brittle
- Used as intermediate to produce malleable cast iron.

Malleable Cast Iron

❖Malleable cast iron – Carbon: 2.3 – 2.7 wt%, Si: 1.0 – 1.75 %

❖Obtained by heat treating white iron for a prolonged period that causes decomposition of cementite into graphite.

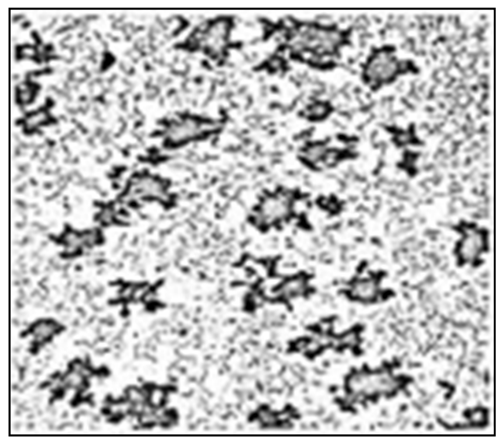
❖Heat treatment : Two stages – Isothermal holding at 950 °C and then holding at 720 °C.

❖graphite forms in the form of rosettes in a ferrite or pearlite matrix.

❖Reasonable strength and improved ductility (malleable)

White iron

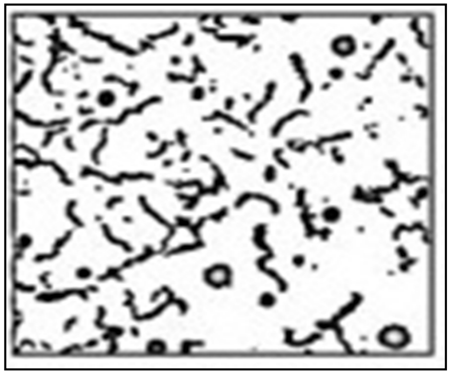
Heat treatment →



Malleable

Compact Graphite Iron (CGI)

- CGI graphite occurs as blunt flakes or with a worm-like shape (vermicular). Carbon: 3.1 – 4.0 wt%, Silicon: 1.7 – 3.0 wt %. Microstructure and properties are between gray and ductile iron.
- Alloying addition may be needed to minimize the sharp edges and formation of spheroidal graphite. Matrix varies with alloy additions or heat treatment.
- As castable as grey iron, but has a higher tensile strength and some ductility.
- Relatively high thermal conductivity, good resistance to thermal shock, lower oxidation at elevated temperatures.



Applications of Cast iron

- Cast irons are used in wide variety of application owing to the properties like good fluidity, ease of casting, low shrinkage, excellent machinability, wear resistance and damping capacity.
- Applications –
  - Car parts – cylinder heads, blocks and gearbox cases.
  - Pipes, lids (manhole lids)
  - Foundation for big machines (good damping property)
  - Bridges, buildings
  - Cook wares – Excellent heat retention

Nonferrous Metals

Nonferrous

- Cu Alloys

Brass: Cu-Zn alloy. Corrosion resistant. Used in costume jewelry, coins

Bronze : Cu – with Sn, Al, Si, Ni

Cu-Be: precipitation hardened (bushings, landing gear)

- Al Alloys

-low ρ: 2.7 g/cm^3
-Cu, Mg, Si, Mn, Zn additions
-solid solution or precipitation strengthened (structural aircraft parts & packaging)

- Mg Alloys

-very low ρ: 1.7g/cm^3
-ignites easily
-aircraft, missiles

- Ti Alloys

relatively low ρ: 4.5 g/cc
reactive at high *T's*
space and biomedical application

Noble metals
- Ag, Au, Pt
oxidation/corrosion resistant

- Refractory metals

-high melting *T's*
-Nb, Mo, W, Ta

Copper

- Copper is one of the earliest metals discovered by man.
- The boilers on early steamboats were made from copper.
- The copper tubing used in water plumbing in Pyramids was found in serviceable condition after more than 5,000 years.
- Cu is a ductile metal. Pure Cu is soft and malleable, difficult to machine.
- Very high electrical conductivity – second only to silver.
- Copper is refined to high purity for many electrical applications.
- Excellent thermal conductivity – Copper cookware most highly regarded – fast and uniform heating.
- Electrical and construction industries are the largest users of Cu.

Copper

- The second largest use of Cu is probably in coins.
- The U.S. nickel is actually 75% copper. The dime, quarter, and half dollar coins contain 91.67% copper and the Susan B Anthony dollar is 87.5% copper.
- The various Euro coins are made of Cu-Ni, Cu-Zn-Ni or Cu-Al-Zn-Sn alloys.

Copper Alloys

- Brasses and Bronzes are most commonly used alloys of Cu. Brass is an alloy with Zn. Bronzes contain tin, aluminum, silicon or beryllium.
- Other copper alloy families include copper-nickels and nickel silvers. More than 400 copper-base alloys are recognized.

Family of Cu Alloys		
Alloy	**Alloying element**	**UNS numbers**
Brass	Zinc (Zn)	C1xxxx–C4xxxx,C66400–C69800
Phosphor bronze	Tin (Sn)	C5xxxx
Aluminium bronzes	Aluminium (Al)	C60600–C64200
Silicon bronzes	Silicon (Si)	C64700–C66100
Copper nickel, nickel silvers	Nickel (Ni)	C7xxxx

Copper Alloys - Brass

- Brass is the most common alloy of Cu – It's an alloy with Zn
- Brass has higher ductility than copper or zinc.
- Easy to cast - Relatively low melting point and high fluidity
- Properties can be tailored by varying Zn content.
- Some of the common brasses are yellow, naval and cartridge.
- Brass is frequently used to make musical instruments (good ductility and acoustic properties).

Bronze

❖ Copper alloys containing tin, lead, aluminum, silicon and nickel are classified as bronzes.

❖ Cu-Sn Bronze is one of the earliest alloy to be discovered as Cu ores invariably contain Sn.

❖ Stronger than brasses with good corrosion and tensile properties; can be cast, hot worked and cold worked.

❖ Wide range of applications: ancient Chinese cast artifacts, skateboard ball bearings, surgical and dental instruments.

Bronze bearing

Beryllium copper

- Cu-Be alloys are heat treatable. Max solubility of Be in Cu is 2.7% at 866 °C. Decreasing solubility at lower temp. imparts precipitation hardening ability.
- Cast alloys - higher Be. Wrought alloys – lower Be and some Co
- Cu-Be is ductile, weldable and machinable. Also resistant to non-oxidizing acids (HCl or H_2CO_3), abrasive wear and galling.
- Thermal conductivity is between steels and aluminum.

Applications

- Used in springs, load cells and other parts subjected to repeated loading. Low-current contacts for batteries and electrical connectors. Cast alloys are used in injection molds. Other applications include jet aircraft landing gear bearings and bushings and percussion instruments.

Compositions, Properties and Application of some Cu Alloys

Name	UNS No.	Compos. (wt.%)	Condition	YS (MPa)	UTS (MPa)	%El	Applications
Eletrolytic Copper	C11000	0.04 O	Annealed	69	220	45	Electrical wires, roofing, nails, rivets
Cartridge brass	C26000	30.0 Zn	Cold-rolled	435	525	8	Automotive radiator core, lamp fixture, ammunition.
Phosphor bronze	C51000	5.0 Sn, 0.25 P	Annealed	130	325	64	Bellows, clutch disk, diaphragm, fuse clips, springs
Yellow bras (Leaded)	C85400	29 Zn, 3.0 Pb, 1 Sn	As cast	83	234	35	Furniture, radiator fittings, battery clamps, light fixtures
Al bronze	C95400	11 Al, 4 Fe	As cast	241	586	18	Bearings, bushings, valve seats and guards
Beryllium copper	C17200	1.9 Be 0.2 Co	Precipita. hardened	965	1140	10	Electrical, valves, pumps
Cu - Ni	C71500	30 Ni	Annealed	125	380	36	Condenser, heat-exchanger, piping, valves
Tin bronze	C90500	10 Sn, 2 Zn	As cast	152	310	25	Bearings, bushing, piston rings, gears

Aluminum

- Aluminum is a light metal (ρ = 2.7 g/cc); is easily machinable; has wide variety of surface finishes; good electrical and thermal conductivities; highly reflective to heat and light.
- Versatile metal - can be cast, rolled, stamped, drawn, spun, roll-formed, hammered, extruded and forged into many shapes.
- Aluminum can be riveted, welded, brazed, or resin bonded.
- Corrosion resistant - no protective coating needed, however it is often anodized to improve surface finish, appearance.
- Al and its alloys - **high strength-to-weight ratio** (high specific strength) owing to low density.
- Such materials are widely used in aerospace and automotive applications where weight savings are needed for better fuel efficiency and performance.
- Al-Li alloys are lightest among all Al alloys and find wide applications in the aerospace industry.

Aluminum Alloys

❖Aluminum alloys are classified into two categories – Cast and Wrought alloys.

❖Wrought alloys can be either heat-treatable or non-heat treatable.

❖Alloys are designated by a 4 digit number. Wrought – the 1st digit indicates the major alloying element. Cast – The last digit after the decimal indicates product from(casting - 0 or ingot -1)

Wrought

Alloy Series	***Principal Alloying Element***
1xxx	Minimum 99.00% Aluminum
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc
8xxx	Other Elements

As Cast

Alloy Series	***Principal Alloying Element***
1xx.x	Aluminum, 99.00% or greater
2xx.x	Copper
3xx.x	Silicon with Copper and/or Magnesium
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused Series
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other Elements

Temper Designations

- **F** As fabricated - products in which no thermal treatments or strain-hardening.
- **H** Strain-hardened (wrought products) – strain hardened with or without additional thermal treatment.
- **H1** Strain-hardened only - strain-hardened without thermal treatment.
- **O** Annealed, recrystallized
- **T** Thermally treated with or without strain-hardening to produce stable tempers other than F, O or H.
- **T3** Solution heat-treated and then cold worked.

Solution heat treatment – heating to the single phase region and isothermal holding.

Compositions, Properties and Application of some Al Alloys

Al Ass. No	Composition (wt.%)	Condition	YS (MPa)	UTS (MPa)	%El	Applications
1100	0.12 Cu	Annealed (O)	35	90	45	Food/chemical handling equipment, heat exchangers light reflectors
3003	0.12 Cu,1.2 Mn, 0.1 Zn	Annealed	40	110	30	Utensils, pressure vessels and piping
5052	2.5 Mg, 0.25 Cr	Strain-hardn. (H32)	195	230	14	Bellows, clutch disk, diaphragm, fuse clips, springs
2024	4.4 Cu, 1.5 Mg, 0.6 Mn	Heat treated (T4)	325	470	20	Aircraft structure, rivets, truck wheels, screw
6061	1 Mg, 0.6 Si, 0.3 Cu, 0.2 Cr	T4	145	240	22	Trucks, canoes, railroad cars, furniture, pipelines
7075	5.6 Zn, 2.5 Mg, 1.6 Cu, 0.23 Cr	Peak-aged (T6)	505	570	11	Aircraft structures and other highly loaded applications
359.0	7 Si, 0.3 Mg	T6	164	228	4	Aircraft pump parts, automotive transmission cases, cylinder blocks
8090	2.0 Li. 1.3 Cu, 0.95 Mg, 0.12 Zr	Heat treated cold-worked (T651)	360	465	-	Damage tolerant aircraft structures

Titanium

❖Pure titanium melts at 1670 ^{o}C and has a low density of 4.51 g/cc (40% lighter than steel and 60% heavier than aluminum).

❖Titanium has high affinity to oxygen – strong deoxidiser. Can catch fire and cause severe damage

❖Ti is stronger than Al - high strength and low weight makes titanium very useful as a structural metal.

❖Excellent corrosion resistance due to a presence of a protective thin oxide surface film. Can be used as biomaterial.

❖Can be used in elevated temperature components.

❖Limitation of pure Ti is its lower strength. Alloying is done to improve strength.

Titanium

❖Oxygen, nitrogen, and hydrogen can cause titanium to become more brittle. Care should be taken during processing.

❖Titanium can also be cast using a vacuum furnace.

❖Because of its high strength to weight ratio and excellent corrosion resistance, titanium is used in a variety of applications:

❖Aircraft – Body structure, Engine parts

❖sporting equipment, chemical processing, desalination, turbine engine parts, valve and pump parts, marine hardware

❖Medical implants - prosthetic devices.

❖Recently use of Ti in bikes and automotives is increasing

Titanium alloys

❖Pure Ti exhibits two phases – Hexagonal α-phase at room temperature and BCC β-phase above 882 °C.

❖Strength of Titanium is improved by alloying. Alloying elements are either α or β stabilizer.

❖Elements with electron/atoms ratio < 4 – α stabilizer (Al, O, Ga), = 4 – neutral (Sn, Zr) and > 4 – β stabilizer (V, Mo,Ta, W).

❖(α + β) two-phase alloys can be obtained with right proportions of alloying elements.

❖α alloys have low density, moderate strength, reasonable ductility and good creep resistance.

❖Metastable β alloys are heavier, stronger and less ductile than α alloys. Creep strength reduces with increasing β content

❖ (α + β) alloys show a good strength-ductility combination

Compositions, Properties and Application of some Ti Alloys

Alloy type	Comp . wt.% (UNS No)	Condition	YS (MPa)	UTS (MPa)	%El	Applications
CP Ti	99.1Ti (R50500)	Annealed	414	484	45	Airframe skins, marine and chemical processing equipments
α	Ti-5Al-2.5Sn (R54520)	Annealed	784	826	16	Gas turbine engine casing and rings, chemical processing equipment
Near-α	Ti-8Al-1Mo-1V (R54810)	Annealed	890	950	15	Forged jet engine components – compressor disc, plate, hubs
α-β	Ti-6Al-4V (R56400)	Annealed	877	947	14	Prosthetic implants, airframe components
α-β	Ti-6Al-6V -2Sn (R56620)	Annealed	985	1050	14	Rocket engine case, airframe structure
β	Ti-10V -2Fe-3Al	Heat treated (aging)	1150	1223	10	High-strength airframe components, parts requiring uniform tensile stresses

Nickel

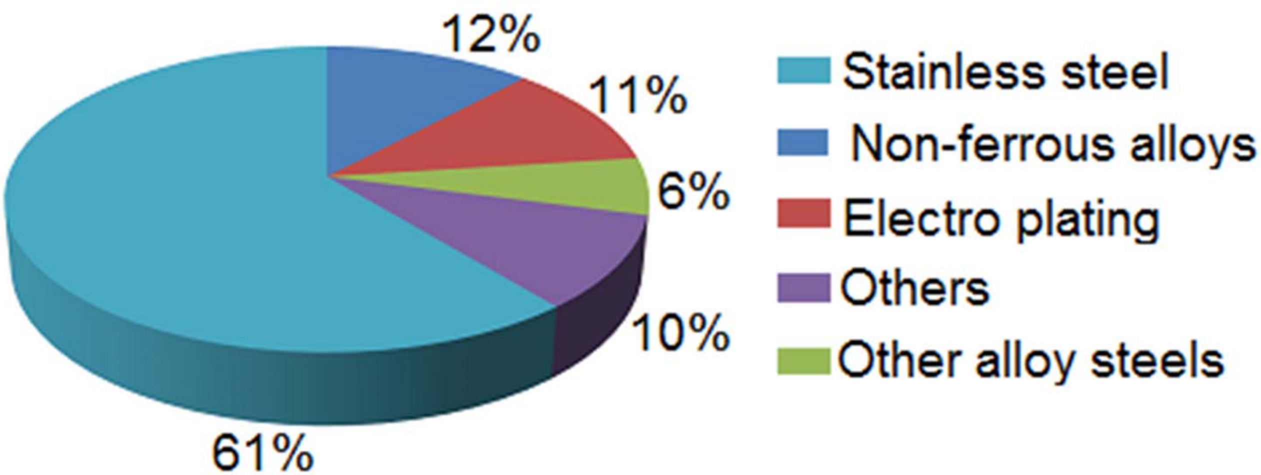
- Nickel is a high-density, high-strength metal with good ductility and excellent corrosion resistance and high temperature properties.
- Ni has may unique properties including its excellent catalytic property. Nickel Catalyst for Fuel Cells: Nickel-cobalt is seen as a low-cost substitute for platinum catalysts.
- Two-thirds of all nickel produced goes into stainless steel production. Also used extensively in electroplating various parts in variety of applications.
- Ni-base super alloys are a unique class of materials having exceptionally good high temperature strength, creep and oxidation resistance. Used in many high temperature applications like turbine engines.

Nickel

- Shape Memory Alloys: Ni base (Ni-Ti) and Ni containing (Cu-Al-Ni) shape memory alloys that can go back to original form, are an important class of engineering materials finding widespread use in many applications.

- Nickel-containing materials are used in buildings and infrastructure, chemical production, communications, energy (batteries: Ni-Cd, Ni-metal hydrides), environmental protection, food preparation, water treatment and transportation.

Applications of Nickel



Turbine engine

Electroplating

Batteries

Magnesium

- Magnesium - Lightest among commonly used metals (ρ 1.7 g/cm^3). Melting point is 650 °C and it has HCP structure.
- Is very reactive and readily combustible in air. Can be used as igniter or firestarter.
- Thermal conductivity is less than Al while their CTE is almost same.
- Pure Mg has adequate atmospheric resistance and moderate strength.
- Properties of Mg can be improved substantially by alloying.
- Favorable atomic size - Can be alloyed with many elements. Most widely used alloying elements are Al, Zn, Mn and Zr.
- Mg Alloys – Cast, Wrought
- Wrought alloys are available in rod, bar, sheet, plate, forgings and extrusions.

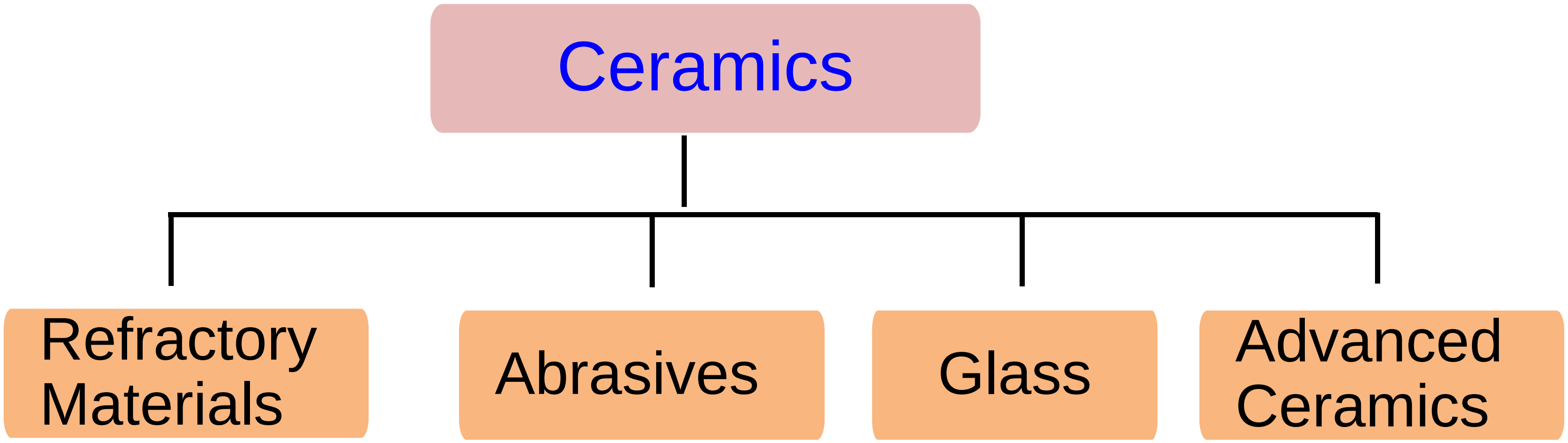
Magnesium Alloys

- Mg alloys: Impact and dent resistant, have good damping capacity - effective for high-speed applications.
- Due to its light weight, superior machinability and ease of casting, Mg and its alloys are used in many applications:– Auto parts, sporting goods, power tools, aerospace equipment, fixtures, electronic gadgets, and material handling equipment.
- Automotive applications include gearboxes, valve covers, alloy wheels, clutch housings, and brake pedal brackets.

Compositions, Properties and Application of some Mg Alloys

ASTM No	Compos. (wt.%)	Condition	YS (MPa)	UTS (MPa)	%El	Applications
			Wrought Alloys			
AZ31B	3.0 Al, 1.0Zn, 0.2 Mn	Extruded	200	262	15	Structure and tubing, cathodic protection
HK31A	3.0Th, 0.6Zr	Strain hard. Annealed	200	255	9	High temp applications (high strength to 315 °C)
ZK60A	5.5 Zn, 0.45Zr	Aged	285	350	11	Forging of max strength for aircrafts
			Cast Alloys			
AZ91D	9.0Al, 0.15 Mn, 0.7 Zn	As cast	150	230	3	Die-cast parts for automobile, luggage and electronic devices
AM60A	9.0Al, 0.13Mn,	As cast	130	220	6	Automotive wheels
AS41A	4.3Al, 1.0 Si, 0.35Mn	As cast	140	210	6	Die-cast parts requiring good creep strength

Ceramics Materials



Refractory Materials

- **Refractory** - retains its strength at high temperatures > 500°C.
- Must be chemically and physically stable at high temperatures. Need to be resistant to thermal shock, should be chemically inert, and have specific ranges of thermal conductivity and thermal expansion.
- Are used in linings for furnaces, kilns, incinerators, crucibles and reactors.
- Aluminium oxide (alumina), silicon oxide (silica), calcium oxide (lime) magnesium oxide (magnesia) and fireclays are used to manufacture refractory materials.
- Zirconia - extremely high temperatures.
- SiC and Carbon – also used in some very severe temperature conditions, but cannot be used in oxygen environment, as they will oxidize and burn.

Composition of some common refractory materials

	Composition (wt%)							
Refractory	*Al_2O_3*	*SiO_2*	*MgO*	*Cr_2O_3*	*Fe_2O_3*	*CaO*	*TiO_2*	***%Porosity***
Fireclay	25-45	50-70	0-1		0-1	0-1	1-2	10-25
High-alumina fireclay	90-50	10-45	0-1		0-1	0-1	1-4	18-25
Silica	0.2	96.3	0.6			2.2		25
Periclase	1.0	3.0	90	0.3	3.0	2.5		22
Periclase - chrome ore	9.0	5.0	73	8.2	2.0	2.2		21

Advanced Ceramics: Automobile Engine parts

Advantages:

Operate at high temperatures – high efficiencies; Low frictional losses; Operate without a cooling system; Lower weights than current engines

Disadvantages:

Ceramic materials are brittle; Difficult to remove internal voids (that weaken structures); Ceramic parts are difficult to form and machine

Potential materials: Si_3N_4 (engine valves, ball bearings), SiC (MESFETS), & ZrO_2 (sensors),

Possible engine parts: engine block & piston coatings

Microelectromechanical systems (MEMS)

- MEMS – These micron-sized structures such as beams, cantilevers, diaphragms, valves, plates and switches that can function as tiny sensors and actuators.
- Fabricated by integrated circuit (IC) manufacturing processes: bulk and surface micromachining.
- Thousands of micromachines can be fabricated on a single silicon wafer with supporting circuits integrated on the chip. Can be mass-produced in the millions at low prices.
- Low-cost, commercial MEMS devices developed for: Corrosion detectors and monitors; Instrumentation for automotive and aerospace; Biological and medical devices; Chemical and environmental sensors; Manufacturing and process control devices ;Virtual reality systems

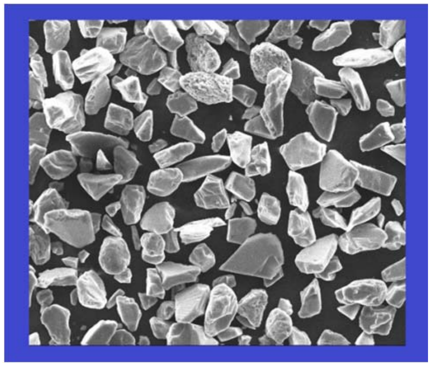
Abrasive Ceramics

❖Abrasives are used in cutting and grinding tools.

❖Diamonds - natural and synthetic, are used as abrasives, though relatively expensive. Industrial diamonds are hard and thermally conductive. Diamonds unsuitable as gemstone are used as industrial diamond

❖Common abrasives – SiC, WC, Al_2O_3 (corundum) and silica sand.

❖Either bonded to a grinding wheel or made into a powder and used with a cloth or paper.



Silicon carbide

Glass

- Glass - inorganic, non-crystalline (amorphous) material.
- Range - soda-lime silicate glass for soda bottles to the extremely high purity silica glass for optical fibers.
- Widely used for windows, bottles, glasses for drinking, transfer piping and receptacles for highly corrosive liquids, optical glasses, windows for nuclear applications.
- The main constituent of glass is silica (SiO_2). The most common form of silica used in glass is sand.
- Sand fusion temp to produce glass - 1700 °C. Adding other chemicals to sand can considerably reduce the fusion temperature.
- Sodium carbonate (Na_2CO_3) or soda ash, (75% SiO_2 + 25% Na_2O) will reduce the fusion temperature to 800 °C.
- Other chemicals like Calcia (CaO) and magnesia (MgO) are used for stability. Limestone ($CaCO_3$) and dolomite ($MgCO_3$) are used for this purpose as source of CaO and MgO.

Key Properties of Glass

- Glass-ceramic materials should have:
  - Relatively high mechanical strengths
  - Low coefficients of thermal expansion
  - Relatively high temperature capabilities
  - Good dielectric properties
  - Good biological compatibility
  - Thermal shock resistance

Compositions and Characteristics of some common Glasses

Glass type	***Composition (wt%)***						***Comments***
	SiO_2	*Na_2O*	*CaO*	*Al_2O_3*	*B_2O_3*	*Other*	
Fused silica	>99.5						High MP, low CTE, thermal shock resistant
96%Silica	96				4		Thermal shock and chemically resistant - laboratory ware
Borosilicate	81	3.5		2.5	13		Thermal shock and chemically resistant - Oven ware
Container	74	16	5	1		4MgO	Low MP, formable, and durable
Fiberglass	55		16	15	10	4MgO	Ease of drawing – used in FRP
Optical flint	54	1				37PbO, $8K_2O$	High density, high refractive index – optical lenses
Glass ceramic	43.5	14		30	5.5	$6.5TiO_2$, $0.5As_2O_3$	Strong, thermal shock resistant – Oven ware

Polymers

- Polymers – Chain of H-C molecules. Each repeat unit of H-C is a monomer e.g. ethylene (C_2H_4), Polyethylene – $(–CH_2 – CH_2)_n$
- Polymers: Thermosets – Soften when heated and harden on cooling – totally reversible. Thermoplasts – Do not soften on heating
- Plastics – moldable into many shape and have sufficient structural rigidity. Are one of the most commonly used class of materials.
- Are used in clothing, housing, automobiles, aircraft, packaging, electronics, signs, recreation items, and medical implants.
- Natural plastics – hellac, rubber, asphalt, and cellulose.

Characteristics and Applications of some common Thermoplastics

Material	Characteristics	Applications
Polyethylene	Chemically resistant, tough, low friction coeff., low strength	Flexible bottles, toys, battery parts, ice trays, film wrapping materials
Polyamide (Nylon)	Good strength and toughness, abrasion resistant, liquid absorber, low friction coeff.	Bearings, gears, cams, bushings and jacketing for wires and cables
Fluorocarbon (Teflon)	Chemically inert, excellent electrical properties, relatively weak	Anticorrosive seals, chemical pipes and valves, bearings, anti-adhesive coatings, high temp electronic parts
Polyester (PET)	Tough plastic film, excellent fatigue and tear strength, corrosion resistant	Recording tapes, clothing, automotive tyre cords, beverage containers
Vinyl	Low-cost general purpose material, rigid, can be made flexible	Floor coverings, pipe, electric al wire insulation, garden hose, phonograph records
Polystyrene	Excellent electrical prop and optical clarity, good thermal and dimensional stability	Wall tile, battery cases, toys, lighting panels, housing appliances

Characteristics and Applications of some common Thermosetting Polymers

Material	Characteristics	Applications
Epoxy (Araldite)	Excellent mechanical properties and corrosion resistance, good electrical prop., good adhesion and dimensional stability	Electrical moldings, sinks, adhesives, protective coatings, fiber reinforced plastic (FRP), laminates
Phenolic (Bakelite)	Excellent thermal stability (>150°C), inexpensive, can be compounded with many resins	Motor housings, telephones, auto distributors, electrical fixtures
Polyester (Aropol)	Excellent electrical properties, low cost, can formulated for room or high temperature, often fiber reinforced	Helmets, fiberglass boats, auto body components, chair fans

Elastomers

❖**Elastomer** – a polymer with rubber-like elasticity.

❖Each of the monomers that link to form the polymer is usually made of carbon, hydrogen, oxygen and/or silicon.

❖Cross-linking in the monomers provides the flexibility.

❖Glass transition temperature, T_g, is the temperature at which transition from rubbery to rigid state takes place in polymers.

❖Elastomers are amorphous polymers existing above their T_g. Hence, considerable segmental motion exists in them.

❖Their primary uses are in seals, adhesives and molded flexible parts.

Characteristics and Applications of some commercial Elastomers

Material	Characteristics	Applications
Natural rubber (NR)	Useful temp. range : - 60 – 120°Cgood resistance to cutting abrasion, resistant to oil, ozone, elng. 500- 700%	Pneumatic tyres and tubes, heels and soles, gaskets
Styrene-butadiene copolymer (SBR))	Temp. range: - 60 – 120° C, Good physical properties, elongation 450 – 500%	Same as natural rubber
Acrylonitrile-butadiene copolymer (NBR)	Temp. range: - 50 – 150° C. Excellent resistance to oils, elongation 400 – 600%	Gasoline, chemicals and oil hose, seals and O-rings, soles and heels
Chloroprene (CR)	Temp. range: - 50 – 105° C. Excellent resistance to high and low temp. excellent electrical prop. Elng. 100 – 800%	High and low temp. insulation, seals, diaphragm, tubing for food and medical uses

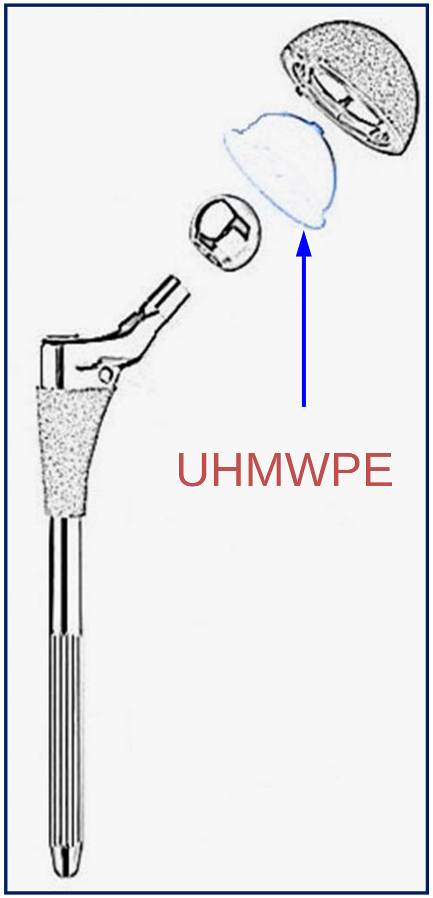
Liquid Crystal Polymers (LCP)

- LCPs are a group of chemically complex structure having unique properties. Primarily used in LCDs (liquid crystal displays) on watches, flat panel computer monitors, televisions and clocks.
- Advantages - LCDs are thinner and lighter and consume much less power than cathode ray tubes (CRTs).
- The name "liquid crystal" arises out of their characteristics. It takes a fair amount of heat to change a suitable substance from a solid into a liquid crystal, and it only takes a little more heat to turn the liquid crystal into a real liquid.
- LCDs use these liquid crystals because they react predictably to electric current in such a way as to control light passage.
- A particular sort of nematic liquid crystal, called twisted nematics (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the applied electrical potential.

Advanced Polymers

Ultrahigh Molecular Weight Polyethylene (UHMWPE)

- **Molecular weight ca. 4 x 10^6 g/mol**
- **Outstanding properties**
  - **high impact strength**
  - **resistance to wear/abrasion**
  - **low coefficient of friction**
  - **self-lubricating surface**
- **Important applications**
  - **bullet-proof vests**
  - **golf ball covers**
  - **hip implants (acetabular cup)**



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Key words: Application of materials, Ferrous and Noferrous alloys, Stainless steel, Cast iron, aluminium alloys, temper designation, titanium, nickel, magnesium, ceramics, polymers

Quiz

1. Classify materials. Classify metals.
2. What are the typical grades of steel? What is the effect of different alloying elements in steel?
3. Why are tool steels hard? What is HSLA steel?
4. What are the major alloying elements in stainless steels? Why are stainless steels resistant to corrosion?
5. What is 17-7PH steel? What is the source of high strength in these steels?
6. What should be minimum carbon content in a cast iron?
7. Why is grey cast iron so brittle? Why is it resistant to wear?
8. How can the ductility of cast irons be increased?
9. What is the shape of graphite in malleable cast iron?
10. What are the useful properties of cast iron?
11. Why is copper used extensively in electrical and thermal applications?

Quiz

12. What is Brass? What are typical alloying elements in bronze?
13. Which is the heat treatable alloy of copper?
14. How are Alumium alloys classified and designated?
15. What are the different temper designation of aluminum alloys?
16. Why is titanium resistant to corrosion?
17. What are the typical phases in Ti alloys? What is α and β stabilizer?
18. Why Ti alloys are preferred for high temperature applications?
19. What are the different categories of ceramic materials?
20. What are the main constituents in refractory ceramics? What are the main constituents of glass?
21. What are the key properties of glass-ceramics?

Quiz

22. What are thermosets and thermoplasts?
23. Why do plastics find widespread applications?
24. What is elastomer? What are their typical characteristics and applications?
25. What is glass transition temperature?
26. What is UHMWPE polymer?
27. What is LCP?
28. Why are LCPs used in LCD displays?
29. What is twisted nematics?
30. Name some natural plastics.