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Materials Science for Engineers – ME232TB
Unit III

Prepared by

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Syllabus – Unit III

Materials and their Applications ------10 Hrs

Semiconductors, dielectrics, optoelectronics, structural materials, ferrous alloys, nonferrous alloys, cement, concrete, ceramic, and glasses. Polymers: thermosets and thermoplastics, composites: fibre reinforced, aggregated composites, electronic packaging materials, biomaterials, processing of structural materials.

Semiconductors

Semiconductors are materials with electrical conductivity between that of conductors (such as metals) and insulators. Electrical properties of semiconductors are unique and extremely sensitive to very small concentration of impurities.

Silicon is one of the most commonly used semiconductor materials.

Two kinds of semiconductors –**intrinsic** and **extrinsic**.

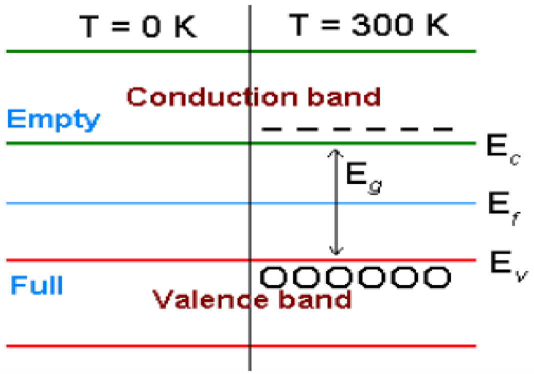
Intrinsic semiconductors - electrical behavior is based on inherent electronic structure of the pure material.

Extrinsic semiconductors - electrical behavior is dominated by impurities

In semiconductors, the valence and conduction bands do not overlap as in metals, but they possess enough electrons in the valence band those can be promoted to the conduction band at a certain temperature.

Semiconductors

Intrinsic semiconductors – Electrical conduction is due to promoted electrons and charged hole left behind by these electrons. This occurs at elevated temperatures. The concentration of thermally excited electrons in the conduction band becomes so high that the semiconductor behaves like a metal. Examples : Si, Ge, Sn, Pb etc.



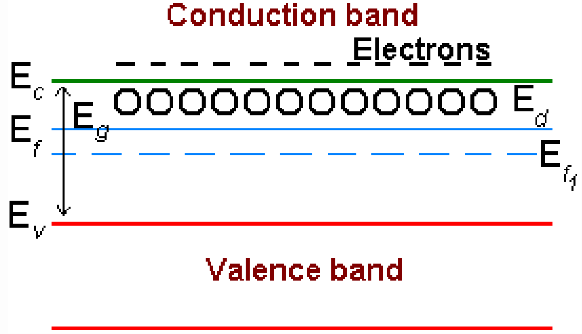
Intrinsic semiconductors

Extrinsic semiconductors – The charge carrier density increased by adding impurities, known as doping. Impurity atoms are known as donor atoms.

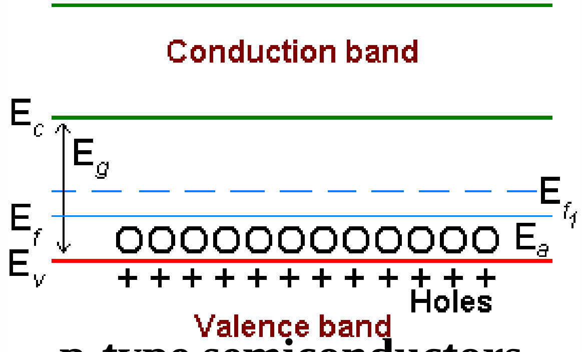
Donor atoms increases number of charge carriers in form of negatively charged electrons (n-type) or positively charged holes (p-type). Pentavalent substitutional atoms like P, As, or Sb are used as donors.

n-type semiconductors – higher valence elements used as donors

p-type semiconductors – lower valence elements used as donors. Trivalent substitutional atoms like B, Al, Ga, In, Th are used as donors.



n-type semiconductors



p-type semiconductors

Applications of semiconductors

Integrated Circuits (ICs) and Microprocessors : Microprocessors, the "brains" of computers, use semiconductors extensively.

Memory Devices - Semiconductor-based memory devices, such as RAM (Random Access Memory) and ROM (Read-Only Memory), are used in computers and other electronic devices for temporary and permanent data storage.

Transistors - Transistors are fundamental semiconductor devices that act as amplifiers or switches. They are crucial in electronic circuits, serving roles from signal amplification in audio devices to forming the basis of digital logic circuits in computers.

Diodes - Semiconductor diodes, such as light-emitting diodes (LEDs) and rectifiers, are used in a wide range of applications. LEDs are employed for lighting, displays, and indicators, while rectifiers convert alternating current (AC) to direct current (DC) in power supplies.

Solar Cells - Photovoltaic cells or solar cells use semiconductors to convert sunlight into electrical energy.

Semiconductor Lasers: - Used in optical communication (fiber optics), laser printers, barcode scanners, and medical equipment. They offer a compact and efficient way to produce coherent light.

Applications of semiconductors

Sensors - Semiconductor sensors play a crucial role in detecting and measuring physical quantities. For instance, temperature sensors, pressure sensors, and light sensors in cameras and smartphones often use semiconductor technology.

Radio Frequency (RF) Devices -Semiconductors are essential in the design of RF devices used in communication systems, such as mobile phones, radios, and wireless networking equipment.

Power Electronics - Semiconductor devices like power transistors and diodes are critical in power electronics applications, including inverters, converters, and motor control systems.

Digital and Analog Electronics - Semiconductors are used in both digital and analog circuits. Digital circuits process information in discrete binary states (0s and 1s), while analog circuits handle continuous signals. Applications include signal processing, amplification, and signal conversion.

Microcontrollers - Microcontrollers are compact integrated circuits that contain a processor, memory, and input/output peripherals. They are widely used in embedded systems, including appliances, automotive electronics, and industrial control systems.

Dielectric Materials

A dielectric material is a poor conductor of electricity but an efficient supporter of electrostatic fields. It can store electrical charges, have a high specific resistance and a negative temperature coefficient of resistance

They are characterized by their ability to store and support the transmission of electric charge without conducting it.

Dielectric vs. Insulators

Dielectrics	Insulators
Can develop an internal electric field, which nullifies the externally applied voltage. Dielectrics are easily polarized and can store charges.	Do not develop an internal field. Actively obstruct electricity
Contain relatively weak bonds with atoms. Mainly used in capacitors, power cables, transformers and resonator oscillator Ex. porcelain (ceramic), mica, glass, plastic many metal oxides	Contain strong covalent bonds Used in high voltage line systems and electrical appliances to prevent electric shocks. Ex. glass, air, wood, plastic and rubber

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Dielectric Materials - Applications

Capacitors: Capacitors are electronic components that store and release electrical energy. Dielectrics are used between the capacitor plates to insulate them, allowing the capacitor to store charge. Ceramics, tantalum, aluminum oxide, and polyester.

Insulation in Electrical Systems : Oil-impregnated paper, polyethylene, polypropylene, and others.

used as insulation in electrical systems, including power cables, transformers, and electrical equipment, to prevent the flow of electric current.

Dielectric Resonators : Dielectric resonators are used in microwave circuits and antennas to tune and control the frequency response. Ceramics, quartz, and other high-permittivity materials.

Microwave Devices : used in microwave components such as circulators, isolators, and filters for telecommunications and radar systems. Ferrites, barium titanate, and certain ceramics.

Dielectric Heating: used in microwave ovens to heat food. The dielectric material (food) absorbs microwaves and gets heated. Water, certain polymers, and other materials with high dielectric loss.

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Dielectric Materials - Applications

Dielectric Elastomers : Dielectric elastomers can deform when an electric field is applied. They are used in soft robotics, artificial muscles, and haptic feedback systems. Silicone, acrylic elastomers.

Dielectric Coatings : Dielectric coatings are applied to electronic components and devices to provide electrical insulation and protect against environmental factors. Polyurethane, epoxy, and other insulating coatings

Dielectric Mirrors : Dielectric mirrors are used in optics to reflect specific wavelengths of light while allowing others to pass through, commonly employed in lasers and optical instruments. Multilayer coatings of dielectric materials

Dielectric Fluids : Dielectric fluids are used in transformers and high-voltage equipment to provide electrical insulation and dissipate heat. Mineral oil, silicone oil, and synthetic esters.

Dielectric Resonator : The dielectric resonator is a ceramic or composite material with a high permittivity (relative dielectric constant). Its shape and dimensions determine the resonant frequency of the antenna.

Optoelectronics

Optoelectronics is the communication between optics and electronics which includes the study, design and manufacture of a hardware device that converts electrical energy into light and light into energy through semiconductors.

This device is made from solid crystalline materials which are lighter than metals and heavier than insulators.

Optoelectronics device is basically an electronic device involving light. This device can be found in many optoelectronics applications like military services, telecommunications, automatic access control systems and medical equipments.

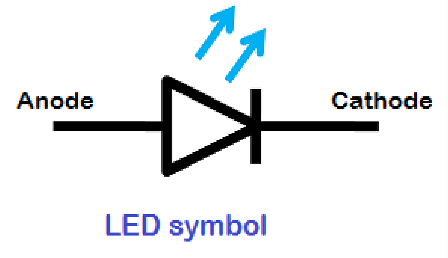
Applications : This academic field covers a wide range of devices including LEDs and elements, image pick up devices, information displays, optical communication systems, optical storages and remote sensing systems, etc.

Examples of optoelectronic devices include telecommunication laser, blue laser, optical fiber, LED traffic lights, photo diodes and solar cells.

Majority of the optoelectronic devices (direct conversion between electrons and photons) are LEDs, laser diodes, photo diodes and solar cells.

Categories of Optoelectronics Devices

- Light Emitters
- Light Receivers
- Optocouplers



Light Emitters - Capable of emitting light belong to the category of the diodes

- LED (Light emitting Diodes)
- Laser Diode

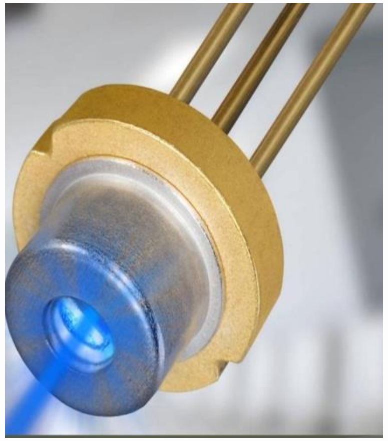
LED - A light-emitting diode (LED) is a P-N semiconductor diode which acts as a light source that emits light when current flows through it. Electrons in the semiconductor recombine with holes, releasing energy in the form of photons. The colour of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor. White light is obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device.

Applications of LED : Burglar alarms systems, calculators, traffic signals, digital computers, multimeters, microprocessors, digital watches, automotive heat lamps, camera flashes, aviation lighting etc.

Laser Diode – Light Amplification by Stimulated Emission of Radiation (LASER) is an electrical pumped semiconductor laser in which the active laser medium is formed by a p-n junction of a semiconductor diode similar to a LED

Its advantages over LED
- Light emission in only one direction
- Light emission is monochromatic

Applications :
- Data communications in fiber optics
- Optical interconnections between integrated circuits
- Laser printers
- Scanners and digitizers
- Sensors
- Dental laser treatments



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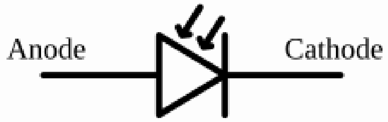
Light Receivers (Detectors) - is a device which absorbs light and converts the optical energy to measurable electric current. Detectors are classified as Thermal detectors and Photon detectors. Light detecting devices of light Sensors Photocells, LDR, Photodiodes, Phototransistors, Photovoltaic Cells and Light Dependent Resistor

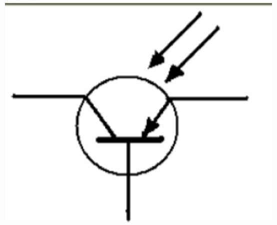
A **photodiode** The photodiode is a type of semiconductor diode with a p-n junction and an intrinsic layer between p and n layers which **converts the light into the electric current** by generating electron – hole pairs. This type of diode is also called photo-detector or light sensor. It works on both the reversed and forward biasing. The small leakage current flows in the reversed direction, even when no light incident on it. The current constitutes in the diode are directly proportional to the intensity of light absorbed by it.

Applications : Cameras, medical devices, safety equipment, optical communication devices, position Sensors, bar-code scanners, automotive devices



Optoelectronics

Phototransistors resemble normal transistor except the fact that the base terminal is not present in case of the phototransistor. Phototransistors **convert the incident light into photocurrent**. Instead of providing the base current for triggering the transistor, the light rays are used to illuminate the base region.



Sensitivity of a phototransistors are higher than a photodiode.

Applications : Punch-card readers, security systems, electric controls, computer logic circuits, relays, lighting control, level indication, counting systems

Optoelectronics

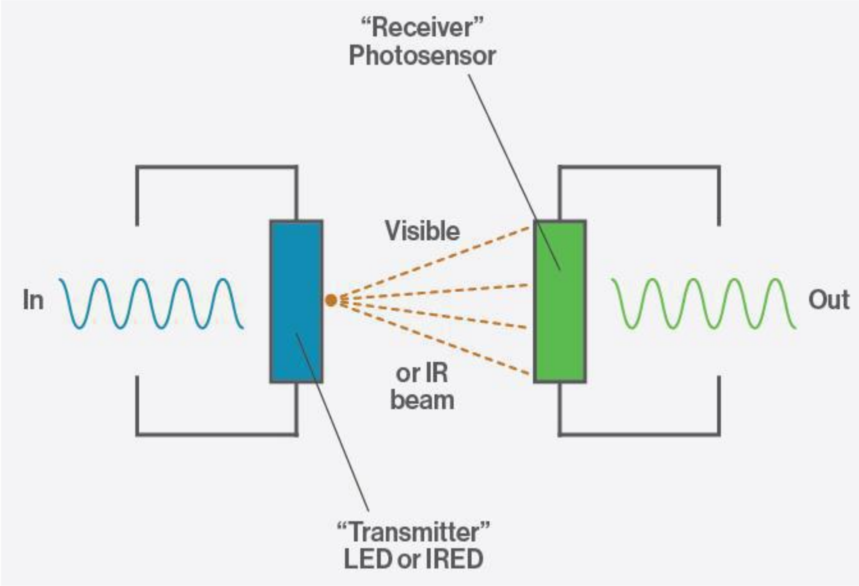
A **photoresistor** (acronymed LDR for Light Decreasing Resistance, or light-dependent resistor, or photo-conductive cell) is a passive component that **decreases resistance with respect to receiving luminosity (light)** on the component's sensitive surface. The resistance of a photoresistor decreases with increase in incident light intensity; in other words, it exhibits photoconductivity.

Light-dependent resistors are simple and low-cost devices. ... These resistors are used as light sensors and the **applications of LDR** mainly include alarm clocks, street lights, light intensity meters,

o burglar alarm circuits.
o LDRs are used in Light Sensors
o LDR is also used in some cameras to detect the presence of the light.
o LDRs are used Ligh Intensity measurement meters.
o In the manufacturing industry, LDR is used as a sensor for the counting of the packets moving on a conveyor belt.
o LDRs are also used in Light Activated Control Circuits.
o LDRs are used in Street Lights which are automatically turn ON in the night time.

Optoelectronics

Optocouplers – is a transmission and reception device that works as a switch activated by light emitted by a LED, which saturate an optoelectronic component.



When an electric current is applied to the LED, infrared light is produced and passes through the material inside the optoisolator

The beam travels across a transparent gap and is picked by the receiver, which converts it into an electrical signal

Applications : Presence detecting applications. tape-position detection, smoke or fog detection etc.

Structural Materials

Structural materials are those used to construct various elements of buildings, infrastructure, and other engineering projects. The selection of these materials is crucial for ensuring the structural integrity, durability, and safety of the constructed components.

- **Steel:** Widely used in construction for beams, columns, and structural frames. Also used in bridges, automotive structures, and industrial machinery.
- **Concrete:** Used in construction for foundations, pillars, beams, and slabs. Also employed in bridges, dams, and other infrastructure projects.
- **Wood:** Used in residential construction for framing, flooring, and siding. Also used in the construction of bridges, decks, and other outdoor structures.
- **Aluminum:** Used in the aerospace industry for aircraft frames and components. Also used in the construction of lightweight structures, such as curtain walls and architectural features.

Structural Materials

- **Masonry (Brick and Stone):**Used in the construction of walls, facades, and partitions. Stone is used for decorative and structural purposes in buildings and monuments.
- **Reinforced Concrete:** Combines concrete with reinforcing materials (usually steel) to enhance tensile strength. Commonly used in high-rise buildings, bridges, and infrastructure projects.
- **Fiber-Reinforced Polymers (FRP):** Used as a substitute for steel in some applications, such as strengthening of concrete structures, and in the construction of lightweight and corrosion-resistant components.
- **Glass:** Used in buildings for windows, facades, and decorative features. Also employed in the construction of certain bridges and as a structural material in the form of laminated glass.
- **Composites:** Materials like fiberglass, carbon fiber, and aramid fibers are used in the construction of lightweight and high-strength components in aerospace, automotive, and marine industries.

Structural Materials

- **Pre-stressed Concrete:** Concrete in which internal stresses are introduced before loading to improve its ability to resist tension. Used in bridges, parking structures, and buildings with large spans.
- **Engineered Wood Products:** Includes materials like laminated veneer lumber (LVL), particleboard, and plywood, used in construction for beams, columns, and sheathing.
- **Titanium:** Used in the aerospace industry for aircraft components, as well as in medical implants and certain high-performance structures.
- **Ceramics:** Used in specialized applications such as the construction of heat-resistant components, refractory linings, and certain structural elements in electronic devices.
- **Geosynthetics:** Materials like geotextiles, geogrids, and geomembranes used in civil engineering for soil stabilization, erosion control, and reinforcement of slopes and embankments.
- **Bamboo:** Used in traditional construction and increasingly in modern building for its sustainability and strength-to-weight ratio.

Metals

- **Ferrous Metals**
  - Cast irons
  - Steels
- **Super alloys**
  - Iron-based
  - Nickel-based
  - Cobalt-based
- **Non-ferrous metals**
  - Aluminum and its alloys
  - Copper and its alloys
  - Magnesium and its alloys
  - Nickel and its alloys
  - Titanium and its alloys
  - Zinc and its alloys
  - Lead & Tin
  - Refractory metals
  - Precious metals

Ferrous Alloys

Ferrous Alloys are metals that are primarily made of iron (Fe) and other elements

Composition: Ferrous alloys are made up of iron and other elements like silicon, manganese, chromium, aluminum, or titanium.

Properties: Ferrous alloys are known for their high **strength, durability, and magnetic** properties. They are widely used due to inexpensive and abundant supply of iron ore.

Limitations

1) Relatively high densities
2) Relatively low electrical conductivities
3) Generally poor corrosion resistance

Examples: Steel and cast iron are two well-known ferrous alloys

Cast Iron (CI)

- Iron (Fe) with greater than 2 wt.% Carbon
- Relatively low melting temperature and liquid phase viscosities, undergo moderate shrinkage during solidification
- Inferior mechanical properties compared to steels less uniform microstructure with porosity

Properties :

Strength: Cast iron has a high strength, it can withstand high force without breaking.

Brittleness: Cast iron is brittle and fractures under excessive tensile loading. Cast iron is nonmalleable, meaning it cannot be bent, stretched, or hammered into shape.

Wear resistance: Cast iron is resistant to wear.

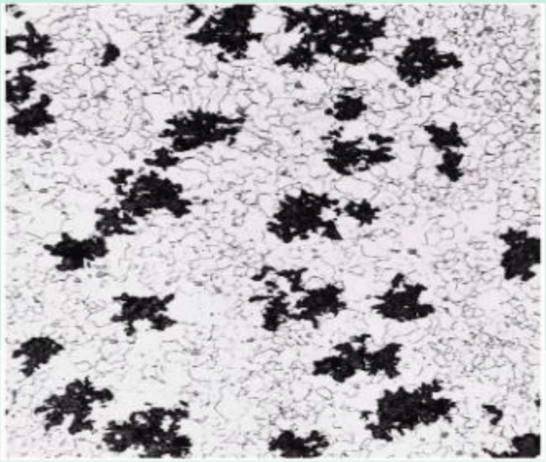
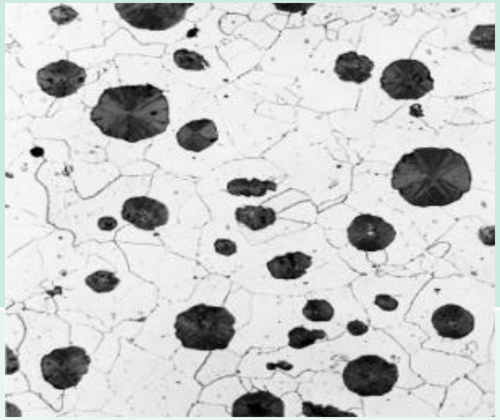
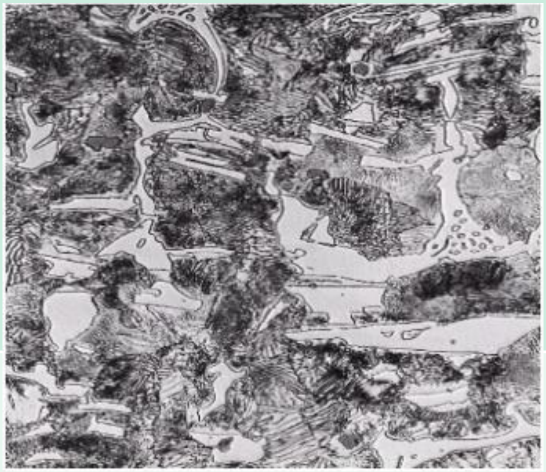
Vibration damping: Cast iron has a good vibration damping capacity.

Hardness: Cast iron is hard due to its high carbon content, which is usually 2–4%. .

Types : Gray cast iron, Ductile cast iron, Malleable cast iron, White cast iron

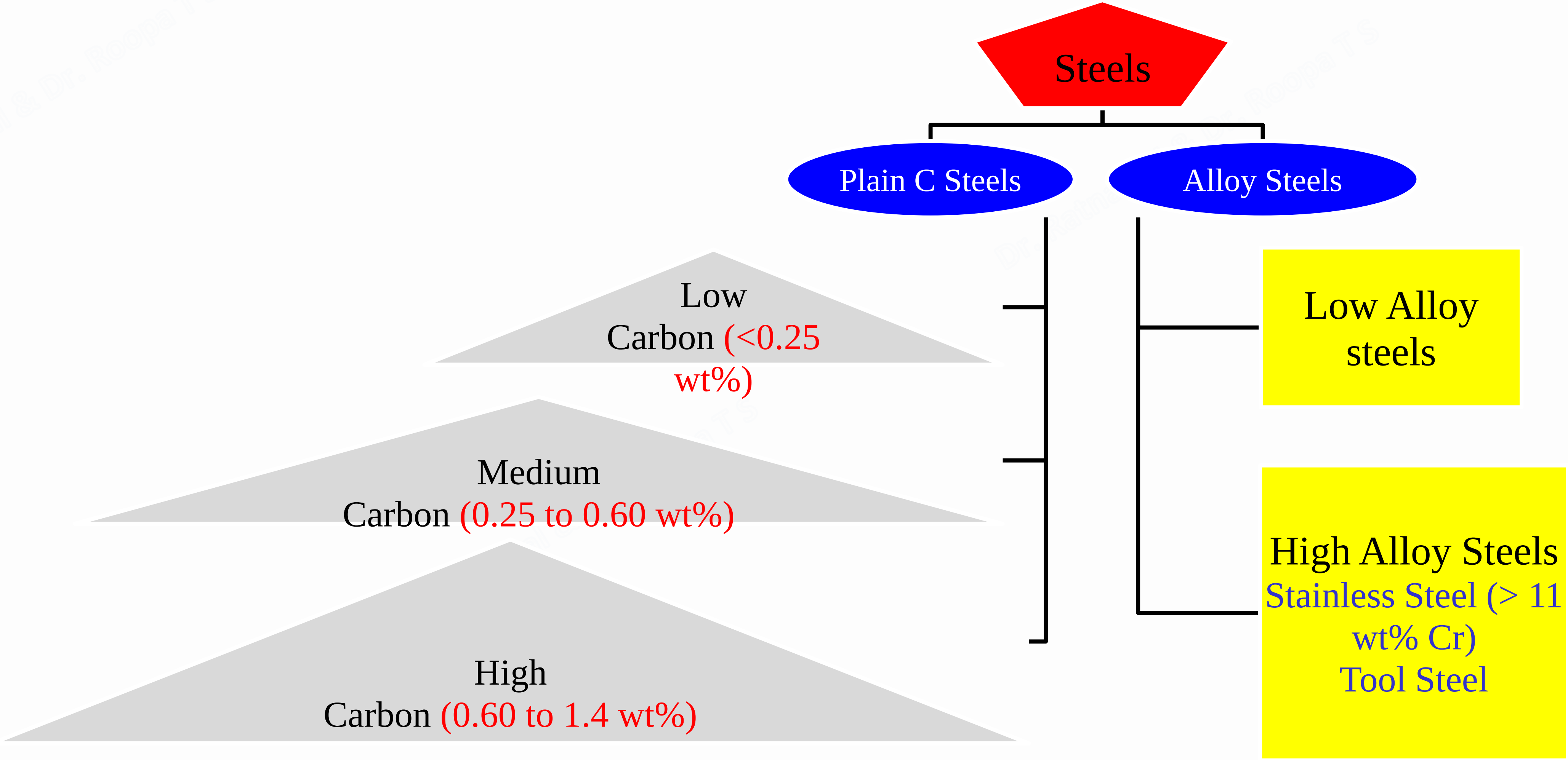
Cast Iron (CI)

Grey Cast Iron	Malleable Cast Iron	Ductile Cast Iron	White Cast Iron
Flakes of graphite in pearlite/ferrite matrix leading to grey sooty appearance	Obtained by heat treatment of white cast iron. Contains carbon as irregular round particles known as temper carbon	Also called nodular cast iron- graphite exists as round particles/spheroid form in ferrite/pearlite matrix	Freshly broken surface shows a bright white fracture
Composition: 2.5- 3.8 % C; 1.1 – 2.8% Si; 0.15%P; 0.4 – 1% Mn;0.1%S	**Composition**: 2- 3%C; 0.6 – 1.3% Si; 0.15%P; 0.2 – 0.6% Mn;0.1%S	**Composition**: 3.5- 3.8%C; 1.1 – 3.5% Si; 0.08%P; 0.3 – 0.8% Mn;0.2%S	**Composition**: 1.8 – 3.6%C; 0.5 – 2% Si; 0.18%P; 0.2 – 0.8% Mn;0.1%S
Lowest melting point- 1200ºC, High fluidity, Better machinability, High resistant to wear, Good damping capacity, High compressive strength	High tensile strength, good machinability, high toughness, high wear resistance and damping capacity	High tensile strength, high machinability, high wear and corrosion resistance and good thermal shock resistance	Brittle-not machinable under normal conditions, excellent abrasive wear resistance

Grey Cast Iron	Malleable Cast Iron	Ductile Cast Iron	White Cast Iron
			
Applications: Machine tool structures, under ground gas/water pipes, machine covers, IC engine cylinder block heads, Piston rings furnace parts Frames of electric motors	**Applications:** Automobile industry, agricultural implements, electrical line hardware, conveyor chain links, machine parts, hand tools	**Applications:** Paper industries machinery, IC engines and automobiles, power transmission equipment, farm implements and tractors, earth moving machinery, pumps compressors and pipes	**Applications:** for producing malleable iron castings, hard and abrasion resistance requirements

Ferrous Materials → Steels

Steels are iron-carbon alloys that may contain other alloying elements.



Plain Carbon Steel

- Relatively low strength
- Very high ductility and relatively low cost – this is why the automotive industry likes it for auto body parts such as the panels for doors, roofs, hoods, etc.
- •It cannot be strengthened above ~690 Mpa (150,000 psi) without substantial loss in ductility and impact strength.
- •It has low resistance to corrosion and oxidation, so coatings such as Zn, Sn and paints are used for protection.
- •It has poor resistance to impact at low temperatures, having a BCC structure.
- •There's difficulty in evenly heat treating large pieces, which creates a variability in properties.

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Plain Carbon Steels --Contd

- Low-carbon steels have carbon less than 0.25% carbon
- Have good formability.
- Used for making bolts, nuts sheet plates wired rod, thin sheets, tubes, corrugated sheets, automobile stampings, boiler plates, draw forgings etc.

- Medium-carbon steels have carbon between 0.25% and 0.60% carbon
- Best balance of properties
- High toughness and ductility are good with respect to the levels of strength and hardness.
- Used for machine parts, automotive and agricultural equipments.

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Plain Carbon Steels --Contd

- High-carbon steels have more than 0.60% carbon
- Toughness and formability are low, but hardness and wear resistance are high.
- Used for hard wearing rails, springs, cutlery, blades, cutting tools (hammers, chisels, milling cutters) ball bearings, files, lathe tools

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- Steels containing alloys in specifiable amounts
  - 1.65% or more manganese
  - 0.60% silicon
  - 0.60% copper
- Most common alloying elements are chromium, nickel, molybdenum, vanadium, tungsten, cobalt, boron and copper
- Low alloy steels contain less than 8% alloy additions
- High alloy steels contain more than 8% alloy additions

Alloy steels

- Tool steels (HSS)
- Stainless steels
- Structural steels (HSLA, Maraging)
- High temperature steels

Tool steels: Used in machining and forming operations Capable to work in high temperature.

Properties: High strength and toughness, high wear and abrasion resistance, high dimensional and thermal stability.

- High Speed Steels (HSS):

▪Hot worked ▪Cold worked ▪Water hardening ▪Shock resisting	▪ HSS-Mb based ▪ HSS-W based

HSS – High Speed Steels

	HSS-Mb based	HSS-W based
Composition	0.7-1%C, 9%Mo, 5%W	0.7-1 %C, 18%W, 4%Cr, 1%V
Properties	High strength and toughness, high resistance to wear and abrasion, high dimensional and thermal stability	High strength and toughness, high resistance to wear and abrasion
Applications	Cutting tools, drill bits, reamers, dies, Shear blades, concrete drills, Blacksmith tools, wood working tools	High temperature dies, tools for hard materials, embossing dies, lathe and planer tools, drills, saws

Stainless steels

Stainless steels are used because of their excellent corrosion resistance.

- It contain at least 12% Cr.
- Corrosion resistance is because of the thin adherent, stable chromium oxide (Cr2O3) layer
- The Cr2O3 in the steel is very stable against attack by a number of chemicals and electrolytic corrosion actions. It is self healing if damaged.
- Based on microstructure it is classified as
  - Austenitic
  - Ferritic
  - Martensitic

Stainless steels

Austenitic Stainless Steels	***Ferritic***	***Martensitic***
18%Cr, 8%Ni, <0.1% C	18 - 30%Cr, No Nickel	12 - 17%Cr, No Ni
Non-magnetic FCC structure Temperature resistant (Ni stabilises austenitic structure) Can be hardened by cold working High resistant to corrosion It can undergo intergranular corrosion Strong, more ductile, have better fabrication characteristics.	Magnetic BCC structure Can be hardened by cold working but cannot be hardened by heat treatment Less corrosion resistance compared to austenitic steels It can undergo intergranular corrosion Strong, more ductile, have better fabrication characteristics.	Magnetic Have Body centered tetragonal structure Can be hardened by heat treatment Corrosion resistance under mild conditions usually used in a hardened and tempered condition.
Relatively low yield stress	have relatively low yield strength	characterised by high strength. Strength

Properties of stainless steels

- High corrosion resistance
- Resistance to oxidation and sulfidation
- Good strength and ductility at service temperature
- High Toughness
- Resistance to abrasion, erosion, galling, and seizing
- Product availability
- Excellent cryogenic properties and good high temperature strength.
- Non-hardenable by heat treatments.
- High work hardening rates.
- Prone to the problem of sensitization and highly prone to stress corrosion cracking.
- Non magnetic alloys.

Applications of stainless steels

- **Automotive and transportation** - exhaust systems, grills, and trims, structural components, shipping containers, road tankers and refuse vehicles.
- **Medical technology** - wide range of medical equipment, including surgical and dental instruments, operation tables, kidney dishes, MRI scanners, cannulas, and steam sterilizers, replacement joints and artificial hips are made from stainless steel, as well as some joining equipment like stainless steel pins and plates to repair broken bones.
- **Aircraft construction** - frames of aeroplanes and jet engines, landing gear.
- **Food and the catering industry** - kitchen accessories, cookware, and cutlery. Utensils such as knives are made using less ductile grades of stainless steel. The more ductile grades are used to make grills, cookers, saucepans, and sinks.
- **Tanker manufacture**
- **Vessel manufacture**

High temperature steels

- Designed to resist oxidation and corrosion
- Have good mechanical properties and strength
- Have good ductility and formability
- Have excellent impact toughness, even at cryogenic temperatures
- Are good to work with and weld

Ex: 1. Mo and V alloys: up to 450 and up to 550ºC with 2% Cr

2. Austenitic steels: up to 900ºC

3. Ferritic steels: up to 800ºC

4. Martensitic steels: up to 650ºC

5. Super alloys (Ni and Co based): up to 1000ºC

Applications:
Pressure vessels,
Super heater tubes,

aircraft parts,
Furnace linings,

Exhaust systems

Structural steels

	High strength low alloy steels (HSLA UTS - 600-1000MPa)	Ultra-high strength low alloy steel [Maraging steel – (martensitic + aging) UTS- >1000 MPa]
Composition	0.15-0.25%C, 1.25%Mn, 0.3%Si, 0.02%V	0.03%C, 18-25% Ni, 8%Co
Properties	Yield strength: 600MPa Tensile strength: 750MPa high ductility (% elongation 25%)	Extremely high yield strength 2000MPa and high toughness with high ductility (% elongation 12%)
Applications	Automobiles, bridges, trains and buildings	Used in aircraft, with applications including landing gear, helicopter undercarriages, slat tracks and rocket motor cases

Effects of Alloying Elements on Steel

- Manganese contributes to **strength and hardness**; dependent upon the carbon content. Increasing the manganese content decreases ductility and weldability. Manganese has a significant effect on the hardenability of steel.
- Phosphorus **increases strength and hardness and decreases ductility** and notch impact toughness of steel. The adverse effects on ductility and toughness are greater in quenched and tempered higher-carbon steels.
- Sulfur **decreases ductility** and notch impact toughness especially in the transverse direction. Weldability decreases with increasing sulfur content. Sulfur is found primarily in the form of sulfide inclusions.
- Silicon is one of the principal **deoxidizers** used in steelmaking. Silicon is less effective than manganese in increasing as-rolled strength and hardness. In low-carbon steels, silicon is generally detrimental to surface quality.
- Copper in significant amounts is detrimental to hot-working steels. Copper can be detrimental to surface quality. Copper is beneficial to **atmospheric corrosion resistance** when present in amounts exceeding 0.20%.
- Nickel is a ferrite strengthener. Nickel does not form carbides in steel. It remains in solution in ferrite, strengthening and toughening the ferrite phase. Nickel increases the hardenability and impact strength of steels.
- Molybdenum increases the hardenability of steel. It enhances the creep strength of low-alloy steels at elevated temperatures.

Nonferrous Metals

Drawbacks of Ferrous metals and alloys

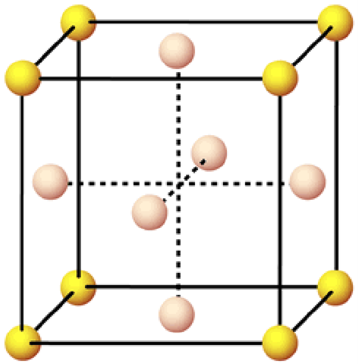
- Relatively high density
- Comparatively low electrical conductivity
- An inherent susceptibility to corrosion in some common environments.

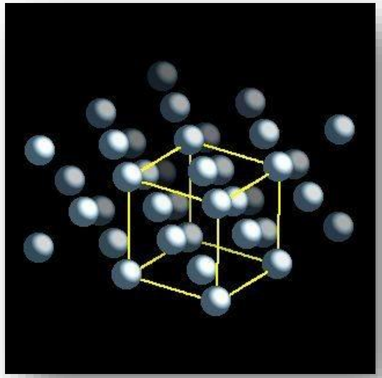
Advantages of Non Ferrous metals and alloys

- **Corrosion resistance**: Non-ferrous metals are resistant to corrosion and oxidation, making them ideal for use in aggressive environments.
- **Thermal and electrical conductivity**: Non-ferrous metals like copper and aluminum have high thermal and electrical conductivity, which is useful in the electronics and aerospace industries.
- **Lightweight**: Non-ferrous metals are usually lighter than ferrous metals, making them a good choice for industries where weight reduction is important, such as aerospace, automotive, and transportation.
- **Recyclable**: Most non-ferrous metals are completely recyclable through smelting.
- **Malleable**: Non-ferrous metals are malleable, making them good for precision casting.
- **Non-magnetic**: Non-ferrous metals are non-magnetic
- **Easy to fabricate**: Non-ferrous metals are easy to fabricate through machining, casting, and welding

Aluminium and its Alloys

- Aluminium alloy surfaces are apparently shiny in a dry environment due to the formation of a clear, protective layer of aluminium oxide.
- Aluminium and its alloys are characterized by a relatively low density (2.1g/cm3 as compared to 7.9g/cm3 for steel)
- High electrical conductivity and thermal conductivities.
- Resistance to corrosion in some common environments
- Alloys are easily formed by virtue of high ductility: this is evidenced by the thin aluminium foil sheet into which the relatively pure material may be rolled.
- Aluminium has an FCC crystal structure, its ductility is retained even at very low temperatures.
- The mechanical strength of aluminium may be enhanced by cold work and by alloying; however, both processes tend to diminish resistance to corrosion.





Aluminium Alloys – Grades and Applications

Wrought Aluminium Alloys– Aluminum Association designation system

Major Alloying Elements	Series
Commercially pure aluminium (99% min)	1000
Copper (0.2%-1.8%)	2000
Manganese(.4%-1.5%)	3000
Silicon(4.5%-6%)	4000
Magnesium(2.2%-5.5%)	5000
Magnesium and silicon	6000
Zinc(1%-7.3%)	7000
Other elements(mainly lithium)	8000

Applications :

Sheet metal work, fin stock, Pressure Vessels, Bus. Truck and marine uses, Aircraft Structres, Truck and marine structres, Pump housings, Crankcases, Transmission cases, truck axle, Automotive pistons, Large intricate castings

Copper and its Alloys

Along with strength, fatigue resistance, and ability to take a good finish, the primary selection criteria for copper and copper alloys are:

- Corrosion resistance
- Electrical conductivity
- Thermal conductivity
- Colour
- Ease of fabrication

Compositions - There are as many as 400 different copper and copper-alloy compositions

- Copper
- High copper alloy
- Brasses (Cu-Zn)
- Bronzes (Cu-Sn-Al-Si-Ni)
- Copper nickels (Cu-Ni)
- Copper–nickel–zinc (Cu-Ni-Ag))
- Copper- Beryllium (Cu-Be)
- Leaded copper (Cu-Pb)
- special alloys

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Copper and its Alloys

Applications :

Electrical: Copper alloys are used in electrical wiring, cables, busbars, and power transmission lines. Copper's high conductivity makes it ideal for electrical applications.

Construction: Copper alloys are used in architectural applications such as roofs, spires, shingles, statues, and doors.

Plumbing: Copper alloys are used in plumbing, fire sprinklers, and natural gas piping systems.

Renewable energy: Copper alloys are used in solar, hydro, thermal, and wind energy systems.

Automotive: Copper alloys are used in many of the latest design elements in today's cars.

Marine: Copper's unique properties make it ideal for many applications in the harsh environments of marine.

Electronics: Copper alloys are an essential material in a vast number of industries including electronics.

Bearings, gears, and valve guides: Copper alloys are used for bearings, gears, and valve guides.

Radiators and hydraulic tubing: Copper alloys are used for radiators and hydraulic tubing.

•**Fasteners**: Copper alloys are used for fasteners.

Magnesium and its Alloys

- ✓ Perhaps the most outstanding characteristic of magnesium is its density, 1.7 g/cm, which is the lowest of all the structural metals; therefore, its alloys are used where light weight is an important consideration (in aircraft application).
- ✓ Magnesium has an **HCP** crystal structure, is relatively soft, and has a low elastic modulus: 45 GPa (6.5 10 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. Consequently, most fabrication is by casting or hot working at temperatures between 200°C and 350°C (400F and 650F).
- ✓ 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; consequently, care should be exercised when handling it in this state.
- ✓ Due to its light weight, superior machinability and ease of casting, magnesium has many applications in auto parts (gearboxes, valve covers, wheels, clutch housings, and brake pedal brackets, sporting goods, power tools, aerospace equipment, and fixtures). Wrought alloys are available in rod, bar, sheet, plate, forgings and extrusions.

Titanium Alloys

PHYSICAL PROPERTIES

- Low density
- high strength and ductility
- lustrous
- corrosion resistant and high melting point
- low thermal & electrical conductivity
- Paramagnetic

Applications

Aerospace, power plants, sporting goods, automotive, orthopedic implants, paints, corrosion resistant tools, surgical instruments, plumbing equipments, jewellery, alloying, Engine parts such as connecting rods, wrist pins, valves, valve retainers and springs, rocker arms and camshafts, computer accessories.

Mechanical Properties

- High strength, can be strengthened through heat treatments.
- High Corrosion resistance
- High Formability
- Good weldability
- High Density
- Superior Fatigue resistance
- resistance to high temperatures
- low thermal conductivity
- low electrical conductivity
- no harm to biological tissues

Categories - Ti Alloys

The crystal structure of titanium at ambient temperature and pressure is close-packed hexagonal α phase. At about 890°C, the titanium undergoes an allotropic transformation to a body-centred cubic β phase which remains stable to the melting temperature.

Alpha alloys - which contain **neutral alloying elements** (such as tin) and/ or **alpha stabilisers** (such as Al, Ga, Ge, C, O, N). These are not heat treatable.

Alpha - Beta Alloys - which are metastable and generally include some combination of both alpha and beta stabilizers and which can be heat treated.

Beta Alloys - which are metastable and which contain sufficient beta stabilizers (such as Mo, V, Ta, Nb, Mn, Fe, Cr, Co, Ni, Cu and Si) to allow them to maintain the beta phase when quenched, and which can also be solution treated and aged to improve strength

Nickel

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

Nickel Catalyst for Fuel Cells: Nickel-cobalt is a low-cost substitute for platinum catalysts.

Shape Memory Alloys: NiTiNol is the commonly used metal foe SMA

Production of stainless steels : Promotes a stable, ductile, austenitic structure as well as contribute to corrosion resistance.

Superalloys : Ni-based superalloys are used in aerospace gas turbine engines, space vehicle rocket engines, nuclear reactors, petrochemical equipments, high temperature fasteners, hot working tools and dies, submarines, turbines

Key attributes : high melting point of 1453°C , forms an adherent oxide film resists corrosion by alkalis forms alloys readily, both as solute and solvent readily deposited by electroplating.

Refractory Metals

Refractory metals are a group of metals with high melting points and resistance to heat and wear. They are used in many industrial applications that require strength, durability, and temperature resistance. Some examples of refractory metals include:

- Tungsten: The most abundant refractory metal, tungsten is known for its use in light bulb filaments. It has the highest melting point of any metal, at 3410 °C.
- Molybdenum: Used as a high-temperature lubricant and electrical contact material.
- Tantalum: Used in electronic components and surgical implants.
- Niobium: Used in the aerospace and nuclear industries.
- Other refractory metals include:
- rhenium, vanadium, hafnium, titanium, zirconium, ruthenium, osmium, rhodium, and iridium

Noble Metals

Noble metals are metallic elements that are resistant to corrosion and oxidation, and are usually found in nature in their raw form:

- Examples: Gold, platinum, silver, ruthenium, rhodium, palladium, osmium, and iridium
- Characteristics: They are resistant to oxidation, even at high temperatures. They are also generally unreactive with air, water, acids, and bases.
- Uses: They are used in jewelry, and are also used in the petroleum, chemical, electronic, electrical, marine, and aviation industries.
- Abundance: They are relatively rare, and are therefore considered precious.
- Economic value: Gold and silver are sometimes seen as defensive assets against inflation and economic downturn.
- Medicinal uses: Noble metals are used in the pharmacological field as anticancer agents, anti-inflammatory, antibacterial, antirheumatic, and antimalarial drugs.
- Other names: The platinum group metals are ruthenium, rhodium, palladium, osmium, and iridium. Silver and gold, along with copper, are sometimes called the coinage metals.

Cements

Cement is a binder, a substance that sets and hardens and can bind other materials together.

Cement has the property of setting and hardening in the presence of water. So, it is called as hydraulic cement. The essential constituents of cement used for constructional purposes are compounds of calcium (calcareous) and Al +Si (argillaceous).

Uses:- Cement mortar for Masonry work, plaster and pointing, Concrete for laying floors, roofs and constructing lintels, beams, weather- shed, stairs, pillars, Construction of water, wells, tennis courts, septic tanks, lamp posts, telephone cabins, Making joint for joints, pipes, Manufacturing of precast pipes, garden seats, flower posts, Preparation of foundation, water tight floors, footpaths, etc.

Types of cements

Ordinary Portland Cement (OPC)
Portland Pozzolana Cement (PPC)
Rapid Hardening Cement
Quick setting cement

High Alumina Cement
White Cement
Colored cement
Air Entraining Cement

Low Heat Cement
Sulfates resisting cement
Expansive cement
Hydrographic cement

Portland cement: Portland cement is the most widely used cement. This is produced by the mixing of calcarious matter (lime containing matter) and argillacous matter (clay containing matter) and powdered with addition of 2-3% gypsum.

Concrete

Concrete is one of the most commonly used building materials. Concrete is a composite material made from several readily available constituents (aggregates, sand, cement, water). Concrete is a versatile material that can easily be mixed to meet a variety of special needs and formed to virtually any shape.

Constituents :Cement Water Fine Agg. Coarse Agg. Admixtures

Advantages

- Ability to be cast
- Economical
- Durable
- Fire resistant
- Energy efficient
- On-site fabrication

Disadvantages

- Low tensile strength
- Low ductility
- Volume instability
- Low strength to weight ratio

Uses

- Concrete is the second most used building material in the world.
- It is used for building constructions
- marine constructions
- sewers and culverts
- Large constructions like Dams, Reservoirs etc..
- Pavements, Roads and runways
- Bridges etc,..

Glass

Glass is an amorphous , hard , brittle , transparent or translucent super cooled liquid of infinite viscosity , having no definite melting point obtained by fusing a mixture of a number of metallic silicates or borates of Sodium , Potassium , Calcium and Lead.

The most familiar and historically the oldest types of manufactured glass are “Silicate glasses” based on the chemical compound silica , the primary constitute of sand.

Properties

- Amorphous Solid
- No definite melting point
- Very brittle
- Softens on heating
- Can absorb , reflect and transmit light
- Good electrical insulator
- Not affected by air , water , acid or chemical reagents

The **types** of glass used in construction :

1. Float glass
2. Shatterproof glass
3. Laminated glass
4. Extra clean glass
5. Chromatic glass
6. Tinted glass
7. Toughened glass
8. Glass blocks
9. Glass wool
10. Insulated glazed units

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Glass-Types

Float glass is made of sodium silicate and calcium silicate so, it is also called as soda lime glass. It is clear and flat so, it causes glare. These are used as shop fronts, public places etc.

Shatterproof glass is used for windows, skylights, floors etc. Some type of plastic polyvinyl butyral is added in its making process. So, it cannot form sharp edged pieces when it breaks.

Laminated glass is the combination of layers of normal glass. So, it has more weight than normal glass. It has more thickness and is UV proof and soundproof. These are used for aquariums, bridges etc.

Extra clean glass has two special properties, photocatalytic and hydrophilic. Because of these properties, it acts as stain proof and gives beautiful appearance. Maintenance is also easy.

Chromatic glass is used in ICU's, meeting rooms etc. it can control the transparent efficiency of glass and protects the interior from daylight. The chromatic glass may be photochromic which has light sensitive lamination, thermos-chromatic which has heat sensitive lamination and electrochromic which has electric lamination over it.

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Glass - Types

Tinted glass is nothing but coloured glass. A colour producing ingredients is mixed to the normal glass mix to produce coloured glass which does not affect other properties of glass

Toughened glass is strong glass which has low visibility. It is available in all thicknesses and when it is broken it forms small granular chunks which are dangerous. This is also called as tempered glass. This type of glass is used for fire resistant doors, mobile screen protectors etc.

Glass block or glass bricks are manufactured from two different halves and they are pressed and annealed together while melting process of glass. These are used as architectural purpose in the construction of walls, skylights etc. They provide aesthetic appearance when light is passed through it

Glass wool is made of fibres of glass and acts as good insulating filler. It is fire resistant glass

Insulated glazed glass units contains a glass is separated into two or three layers by air or vacuum. They cannot allow heat through it because of air between the layers and acts as good insulators. These are also called as double glazed units.

Polymers

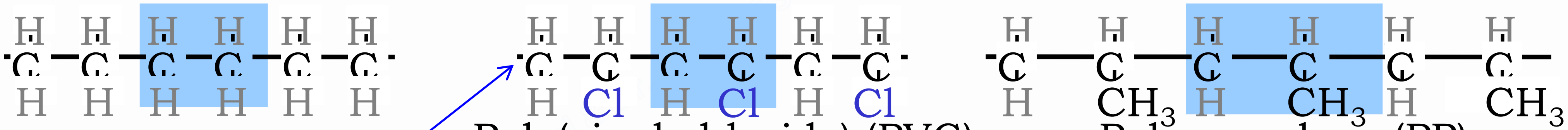
- A compound consisting of long-chain molecules, each molecule made up of repeating units connected together
- There may be thousands, even millions of units in a single polymer molecule
- The word polymer is derived from the Greek words poly, meaning many, and **meros** (reduced to mer), meaning **part**
- Most polymers are based on carbon and are therefore considered organic chemicals

Poly mer

many repeat unit (building blocks)

repeat unit

repeat unit



Polyethylene (PE) Poly(vinyl chloride) (PVC) Polypropylene (PP)

Carbon chain backbone

Classification and Properties of Polymers

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

1. Thermoplastic polymers
2. Thermosetting polymers
3. Elastomers (rubbers)

Properties

- Can be very resistant to chemicals.
- Can be both thermal and electrical insulators.
- Generally, polymers are very light in weight with significant degrees of strength.
- Can be processed in various ways.
- Are materials with a seemingly limitless range of characteristics and colors.
- Are usually made of petroleum, but not always.
- Can be used to make items that have no alternatives from other materials.

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Thermosets and Thermoplastics

Sl No.	Thermosetting Plastics	Thermoplastics
1	Three dimensional network of primary covalent bonds with cross linking between chains	Linear polymers without cross linking and branching
2	Upon heating they retain their strength and prolonged heating causes roasting of polymers and ultimately depolymerisation	Upon heating the secondary bonds between individual chains break, the polymers become soft and on cooling hard and rigid because secondary bonds re-establish themselves
3	Harder, stronger and more brittle	Strong and less brittle
5	It is difficult to fill an intricate mould with such plastics	They can fill the complicated mould quite easily
6	can not be recycled	can be recycled
7	Ex: epoxy, polyesters, silicones, Bakelite etc.	PVC, Nylons, polyethylene
8	Applications: manufacture of telephones, electrical outlets, appliance handles etc.	Applications: Plastic walls, floor tiles, reflectors, plastic lenses etc.

Applications of Polymers

Applications :

Industrial - Polymers are used in vehicles and airplanes because they are durable and lightweight, which helps save fuel. They are also used in building materials, adhesives, ceramics, fibers, clothing, and concrete.

Biomedical - Polymers are used in biomedical applications such as medical device coatings, pharmaceutical, and resorbable implants. They are also used in the development of prosthetic materials, dressings, dental materials, and other disposable supplies.

Packaging - Polymers with an amorphous structure, which means they are transparent, are used in the manufacture of packaging.

Contact lenses - Polymers with an amorphous structure are used in the manufacture of contact lenses.

Agriculture - Superabsorbent polymers, a class of hydrogels, are used in agriculture to hold moisture content in the soil.

Automotive - Polymers are used to make strong car bumpers, luggage, and elastic materials like tires

Ceramics

Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non metal.

Types : Crystalline and Amorphous (Non-crystalline)

Properties :

- -high temperature stability
- -high hardness
- -brittleness
- -high mechanical strength
- -low elongation under application of stress
- -low thermal and electrical conductivities

Examples

- **Structural clay products**: Bricks, tiles, and pipes made from silica, alumina, and other oxides
- **Whitewares**: Stoneware, china, and porcelain used for tableware, artware, and cookware
- **Cements**: Concrete and mortars used in construction, made from tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite
- **Refractory materials**: Silica, aluminum silicate, and magnesite used for thermal insulation in high-temperature furnaces

Classification - Ceramics

Based on their **engineering applications**

- Traditional ceramics–most made up of clay, silica and feldspar
- Engineering ceramics–these consist of highly purified aluminium oxide (Al2O3), silicon carbide (SiC) and silicon nitiride (Si3N4)

Based on their **specific applications** :

-Glasses
-Clay products
-Refractories
-Abrasives
-Cements
-Advanced ceramics for special applications

Based on their **composition** :

-Oxides
-Carbides
-Nitrides
-Sulfides
-Fluorides

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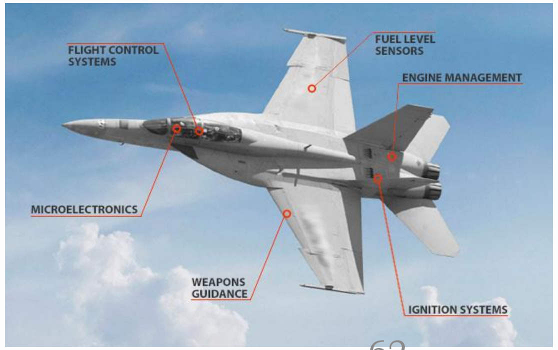
Applications of Ceramics

- **Aerospace:** space shuttle tiles, thermal barriers, high temperature glass windows, fuel cells
- **Consumer Uses:** glassware, windows, pottery, Corning¨ ware, magnets, dinnerware, ceramic tiles, lenses, home electronics, microwave transducers
- **Automotive:** catalytic converters, ceramic filters, airbag sensors, ceramic rotors, valves, spark plugs,
- **Medical (Bio ceramics):** orthopedic joint replacement, prosthesis, dental restoration, bone implants
- **Military:** structural components for ground, air and naval vehicles, missiles, sensors
- **Computers:** insulators, resistors, superconductors, capacitors, ferroelectric components, microelectronic packaging
- **Other Industries:** bricks, cement, membranes and filters, lab equipment
- **Communications:** fiber optic/laser communications, TV and radio components, microphones



Composites

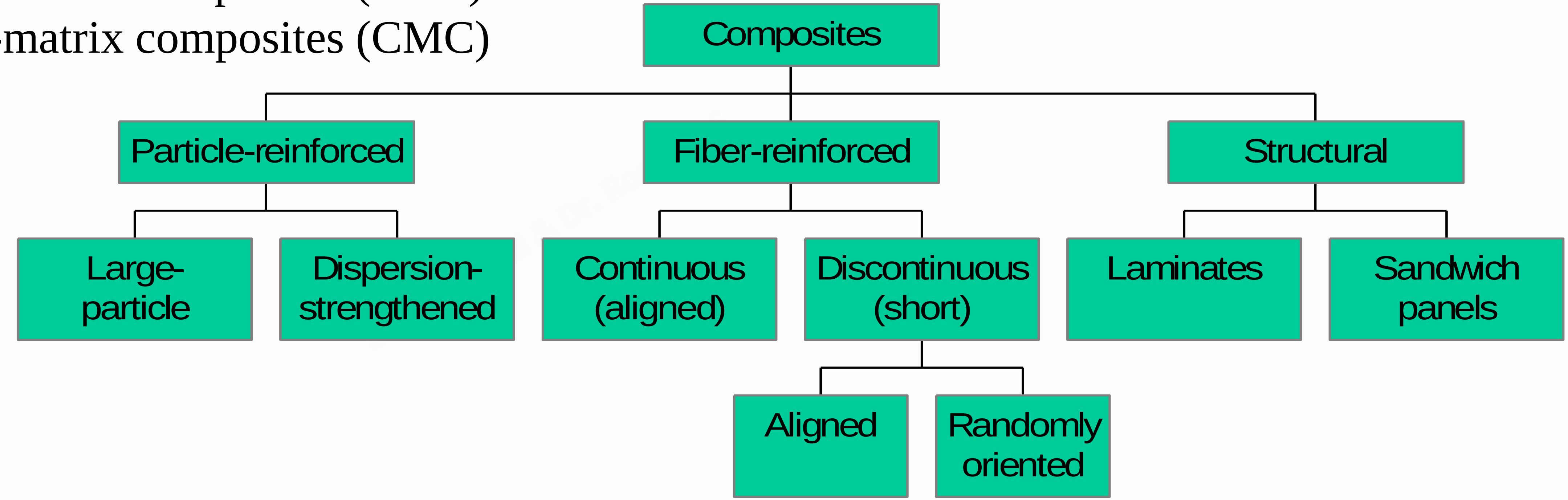
A materials system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents.

It consists of **two phases** – Matrix and Reinforcements

Classification - based on **matrix** material

- Metal-matrix composites (MMC)
- Polymer-matrix composites (PMC)
- Ceramic-matrix composites (CMC)

Classification - based on **reinforcements**



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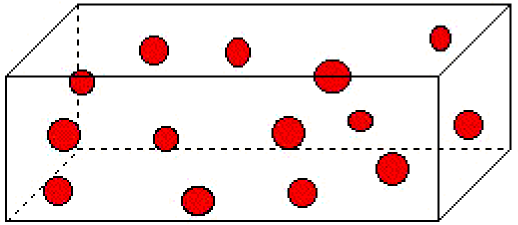
Classification of Composites

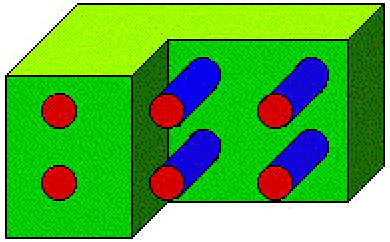
Particulate composite

materials contain a large number of randomly oriented particles. Ex: ceramic particles dispersed in a metallic matrix.



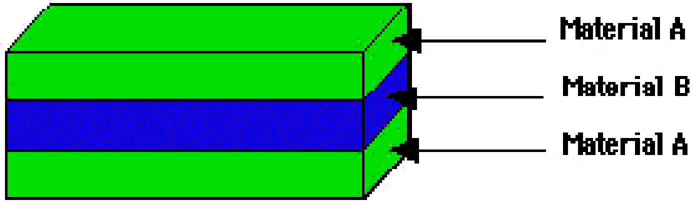
Fiber-reinforced composites

are composed of strong and stiff brittle fibers which are incorporated into a softer, more ductile matrix.

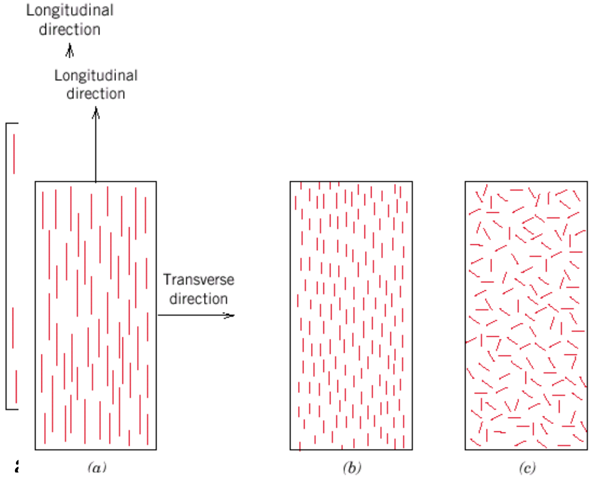


Laminar composites (Laminates)

are Composed of layers of different materials, called laminates

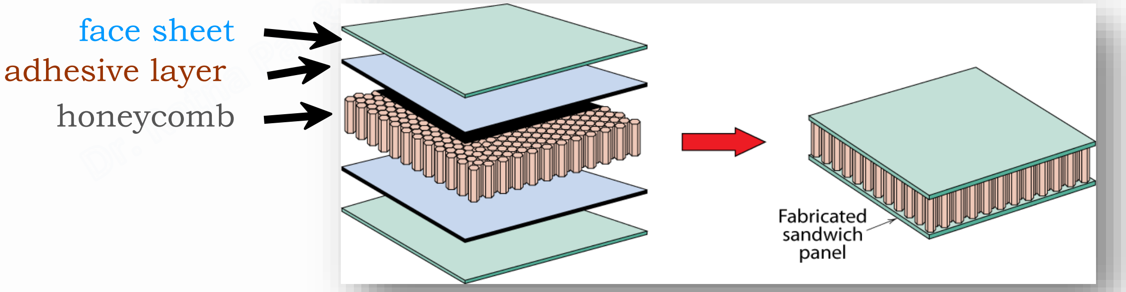


- Laminate

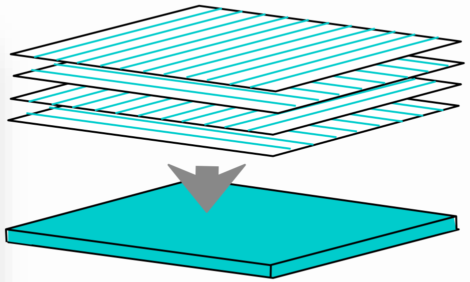


aligned continuous aligned discontinuous random

- Sandwich panels
  -- low density, honeycomb core
  -- benefit: light weight, large bending stiffness



- Stacked and bonded fiber-reinforced sheets
  -- stacking sequence: e.g., 0°/90° or 0°/45°/90°
  -- benefit: balanced, in-plane stiffness



Adapted from Fig. 16.16, *Callister 7e.*

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Composites – Contd.

Properties / Advantages

- High Strength to Weight Ratio or High specific strength
- High creep resistance
- High corrosion resistance
- High wear resistance
- High toughness
- High tensile strength at elevated temperature
- High fatigue strength
- Fire Resistance
- Better dimensional stability
- Anisotropic

Disadvantages

- High material cost
- Fabrication / manufacturing difficulties
- Repair / joining is difficult
- For PMCs low operating temperature
- Anisotropic properties design is difficult
- Inspection and testing is not standard

Function of matrix

- Provides the bulk form of the product
- Holds the imbedded phase in place, enclosing and encasing
- Sharing the load and transferring to the reinforcement ohase

Function of reinforcements

- Carry the load

Applications of Composites

- **Aerospace**

Bio-composites are used in aircraft to reduce weight and improve fuel efficiency. Composites are also used in aircraft parts like compressor blades, turbine blades, and rotor shafts.

- **Construction**

Composites are used in buildings, bridges, roofing shingles, and water piping systems.

- **Energy production and storage**

Composites are used in wind turbines to increase power output and efficiency.

- **Automotive**

Composites are used in car bodies, bumpers, door panels, dashboards, and more.

- **Sports**

Composites are used in skis, surfboards, tennis racquets, golf clubs, baseball bats, and more.

- **Dental**

Composites are used in tooth fillings, dental bridges, inlays, and veneers.

- **Consumer products**

Composites are used in luggage, smartphone cases, and kitchenware

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Applications of Composites – Contd.

Aggregate composites - commonly known as composite materials, are materials composed of two or more distinct phases (typically a matrix and reinforcement) with different properties that, when combined, produce a material with enhanced performance characteristics. Here are various applications of aggregate composites across different industries:

Concrete with Aggregate - Building Construction
Fiberglass Composite- Boat Hulls
Carbon Fiber Reinforced Polymer (CFRP) - Aerospace Components
Carbon Nanotube Reinforced Composites - Sports Equipment
Epoxy Resin Matrix Composites - Printed Circuit Boards (PCBs)
Wood-Plastic Composite (WPC) -Decking Material
Aluminum Matrix Composites - Aerospace Components
Natural Fiber Composites - Automotive Interiors
Biocomposite - Bone Implants- Medical Implants

(FRPs)

- pipes, roofing's, storage containers, industrial floorings and automotive bodies
- sports and recreational equipment's, pressure vessels and aircraft structural components.
- military aircraft components, helicopter rotor blades and in some sporting goods.
- Sic and Al2O3 fibre reinforced composites are used in tennis rackets, circuit boards and rocket cone noses.

Electronic Packaging Materials

Electronic packaging is the design and production of enclosures for electronic devices ranging from individual semiconductor devices up to complete systems such as a mainframe computer.

Packaging of an electronic system must consider protection from mechanical damage, cooling, radio frequency noise emission and electrostatic discharge.

Product safety standards may dictate particular features of a consumer product, for example, external case temperature or grounding of exposed metal parts. Prototypes and industrial equipment made in small quantities may use standardized commercially available enclosures such as card cages or prefabricated boxes.

Electronic packaging materials are crucial for the performance, reliability, and longevity of electronic devices. They serve various functions such as electrical conduction, insulation, structural support, thermal management, and protection from environmental factors like moisture, chemicals, and radiation.

Electronic Packaging Materials

Here are some common electronic packaging materials and their properties:

1. **Interconnections**: Materials like copper and aluminum are used for electrical connections due to their excellent conductivity.
2. **Printed Circuit Boards (PCBs)**: Typically made from materials like FR4 (a composite of epoxy resin and fiberglass), providing good mechanical strength and electrical insulation.
3. **Substrates**: Materials such as alumina (aluminum oxide) and silicon are used for their thermal stability and electrical properties.
4. **Encapsulants**: Epoxy resins and silicone are used to protect electronic components from environmental damage.
5. **Dielectrics**: Materials like polyimide and PTFE (Teflon) are used for their high dielectric strength and low dielectric constant.
6. **Die Attach Materials**: Silver-filled epoxies and solder are used to attach semiconductor dies to substrates.
7. **Electrical Contacts**: Gold and silver are used for their excellent conductivity and resistance to corrosion.
8. **Thermal Materials**: Materials like thermal greases and phase change materials are used to manage heat dissipation.
9. **Solders**: Lead-tin and lead-free solders are used for creating electrical and mechanical connections.

Each material is chosen based on its specific properties to meet the requirements of the electronic packaging system. If you have any specific questions or need more details on any of these materials, feel free to ask!

Biomaterials

A BIOMATERIAL, is any *synthetic material that is used to* replace or restore function to a body tissue and is continuously or intermittently in contact with body fluids

First and foremost, a biomaterial must be biocompatible — it should not elicit an adverse response from the body, and vice versa. Additionally, it should be nontoxic and noncarcinogenic. The biomaterial should possess adequate physical and mechanical properties to serve as augmentation or replacement of body tissues.

Properties

- A biocompatible chemical composition to avoid adverse tissue reactions
- Excellent resistance to degradation (e.g., corrosion resistance for metals or resistance to biological degradation in polymers)
- Acceptable strength to sustain cyclic loading endured by the joint
- A low modulus to minimize bone resorption
- High wear resistance to minimize wear debris generation

Uses of Biomaterials

Implants - Biomaterials are used to create implants that replace or substitute damaged or diseased body parts. Examples include heart valves, stents, dental implants, and artificial joints.

- **Tissue regeneration** - Biomaterials can be used to regenerate human tissues, such as bone, cartilage, and skin. For example, bone regenerating hydrogels and lab-grown human bladders are made using biomaterials.
- **Drug delivery** - Biomaterials can be used to deliver drugs to a disease target. Examples include drug-coated vascular stents and implantable chemotherapy wafers.
- **Wound healing** - Biomaterials are used in sutures, clips, and staples to close wounds.
- **Biosensors** - Biomaterials are used to detect the presence and amount of substances in the body. Examples include blood glucose monitoring devices and brain activity sensors.
- **Cancer imaging and therapy** - Biomaterials can be used to break through biological barriers to aid in cancer imaging and therapy.
- **Bioinspired robotics** - Nanomaterials and nanostructured biomaterials are used to simulate the properties of human skin or the ability of some animals to sense vibrations

Processing of Structural Materials

Processing of structural material is performed using the manufacturing processes. **Manufacturing process is the series of steps that transform raw materials into a finished product.** It can be a complex process that involves a variety of machinery, tools, and equipment

There are four basic manufacturing processes for producing desired shape of a product. These are

1. Casting
2. Forming (Metal deformation)
3. Joining (Welding, Brazing, Soldering, Fastening, etc.) and
4. Metal removal (Machining) processes.

Processing of Structural Materials – Contd.

- **Casting** process exploit the fluidity of a metal in liquid state as it takes shape and solidifies in a mould. It's the primary manufacturing process.
- **Forming** (deformation processes) exploit a remarkable property of metals, which is their ability to flow plastically in the solid state without deterioration of their properties. With the application of suitable pressures, the material is moved to obtain the desired shape with almost no wastage. The required pressures are generally high and the tools and equipment needed are quite expensive. Large production quantities are often necessary to justify the process.
- **Joining** processes permit complex shapes to be constructed from simpler components and have a wide domain of applications.
- **Machining** processes provide desired shape with good accuracy and precision but tend to waste material in the generation of removed portions

Metal Casting Process

Casting is one of the oldest manufacturing process. It is the first step in making most of the products for which it’s called basic manufacturing process

Advantages :

- Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized.
- Possible to cast both ferrous and non-ferrous materials
- Tools are very simple and expensive
- Useful for small lot production
- Weight reduction in design
- No directional property There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Turbine blades: Fully casting + last machining

Limitations :

- Accuracy and surface finish are not very good for final application.
- Difficult to remove defects due to presence of moisture.
- Metal casting is a labour intensive process.
- Automation

Applications :

Cylindrical bocks, wheels, housings, pipes, bells, pistons, piston rings,machine tool beds etc.

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Metal Casting Process – Contd.

Steps to be followed for a casting operation:

a) Making mould cavity
b) Liquefy or melt the material by properly heating it in a suitable furnace.
c) Liquid or molten metal is poured into a prepared mould cavity
d) Allowed to solidify
e) Product is taken out of the mould cavity, trimmed and made to shape.

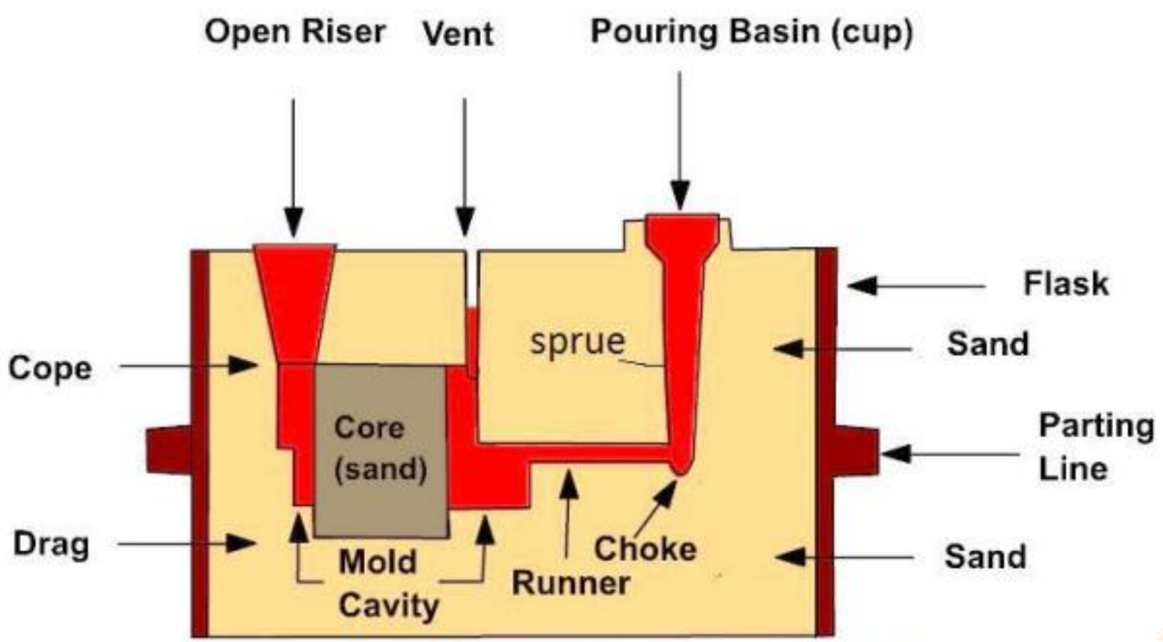

Fig: Mould Section and casting nomenclature

More attention should be given on the following for successful casting operation:

(i) Preparation of moulds of patterns
(ii) Melting and pouring of the liquefied metal
(iii) Solidification and further cooling to room temperature
(iv) Defects and inspection

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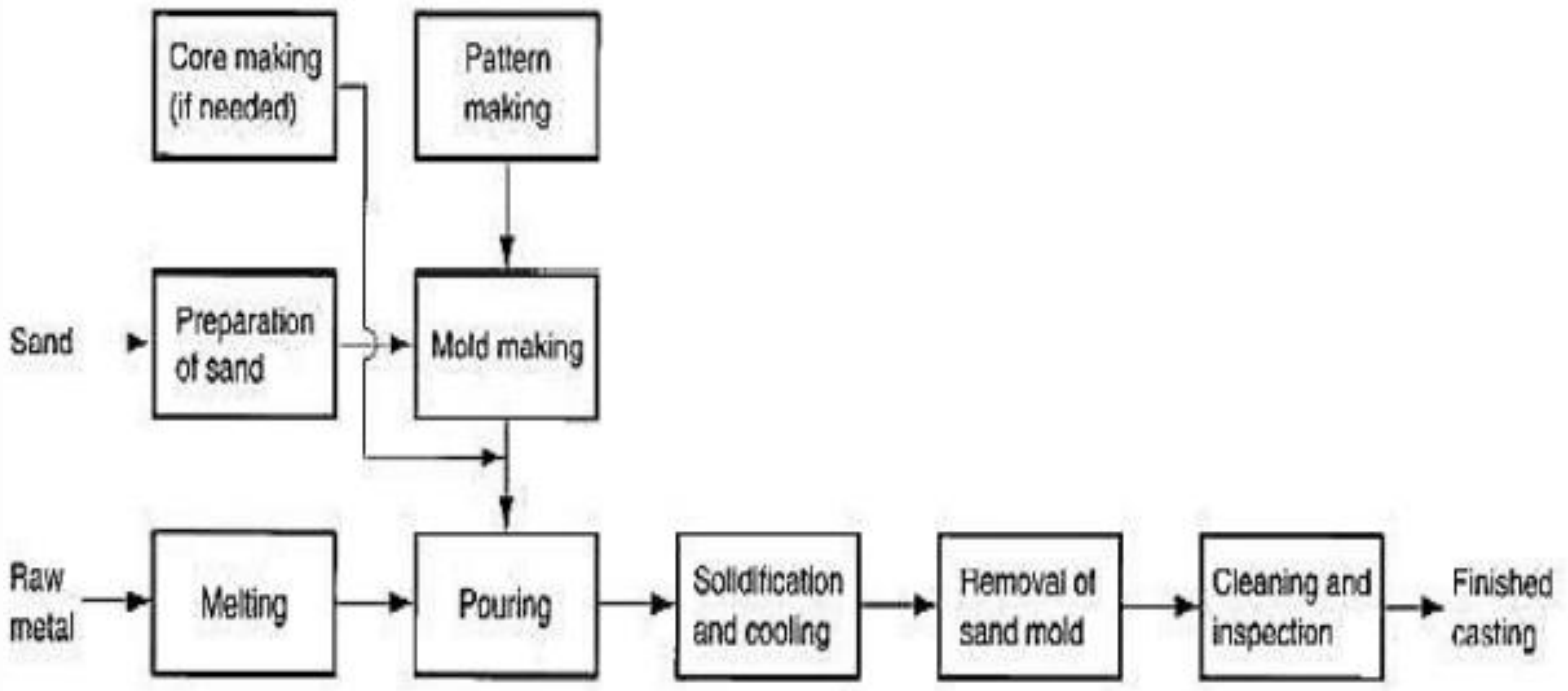
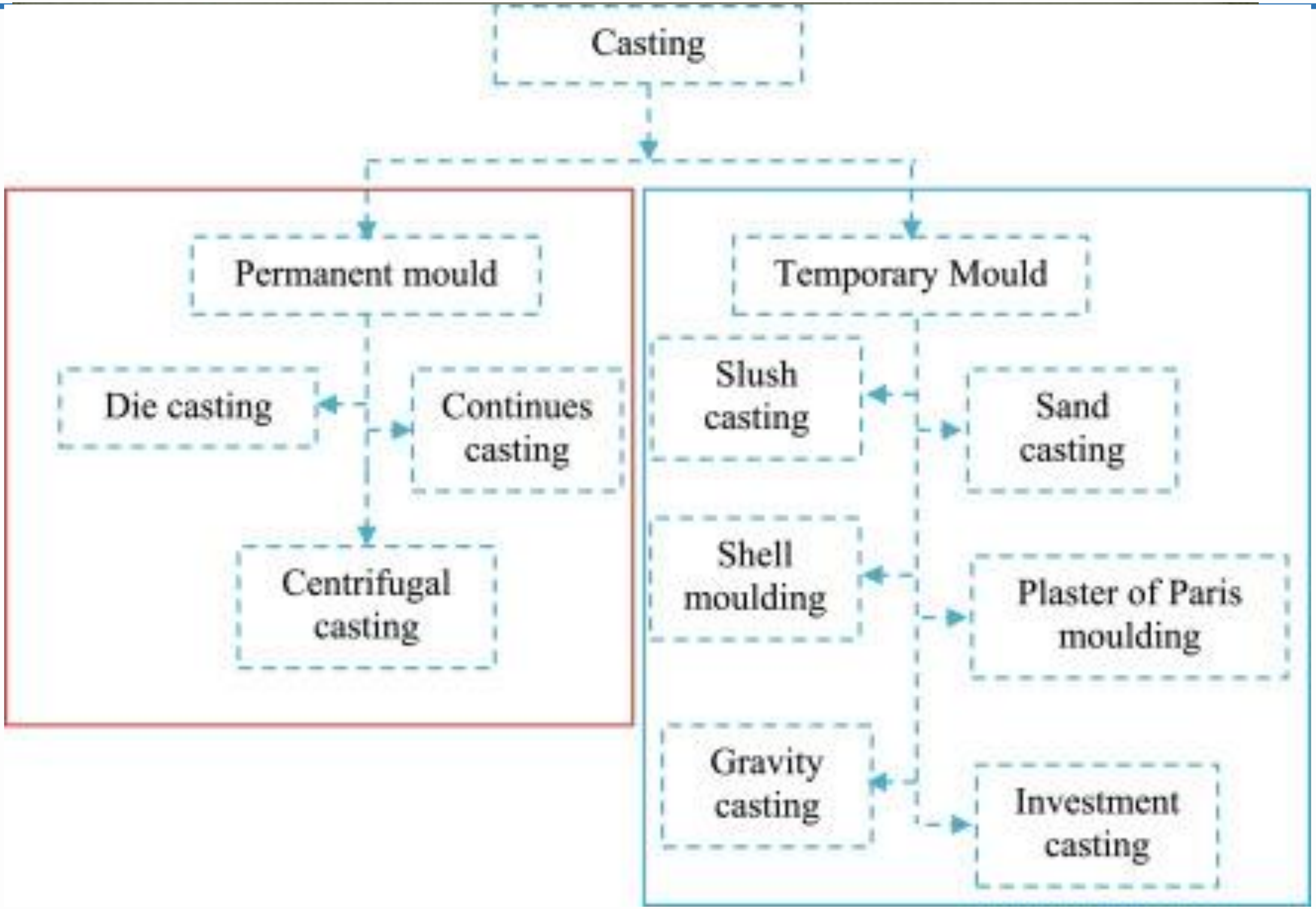
Metal Casting Process – Contd.

Steps in the production sequence of sand casting



Metal Casting Process – Contd.



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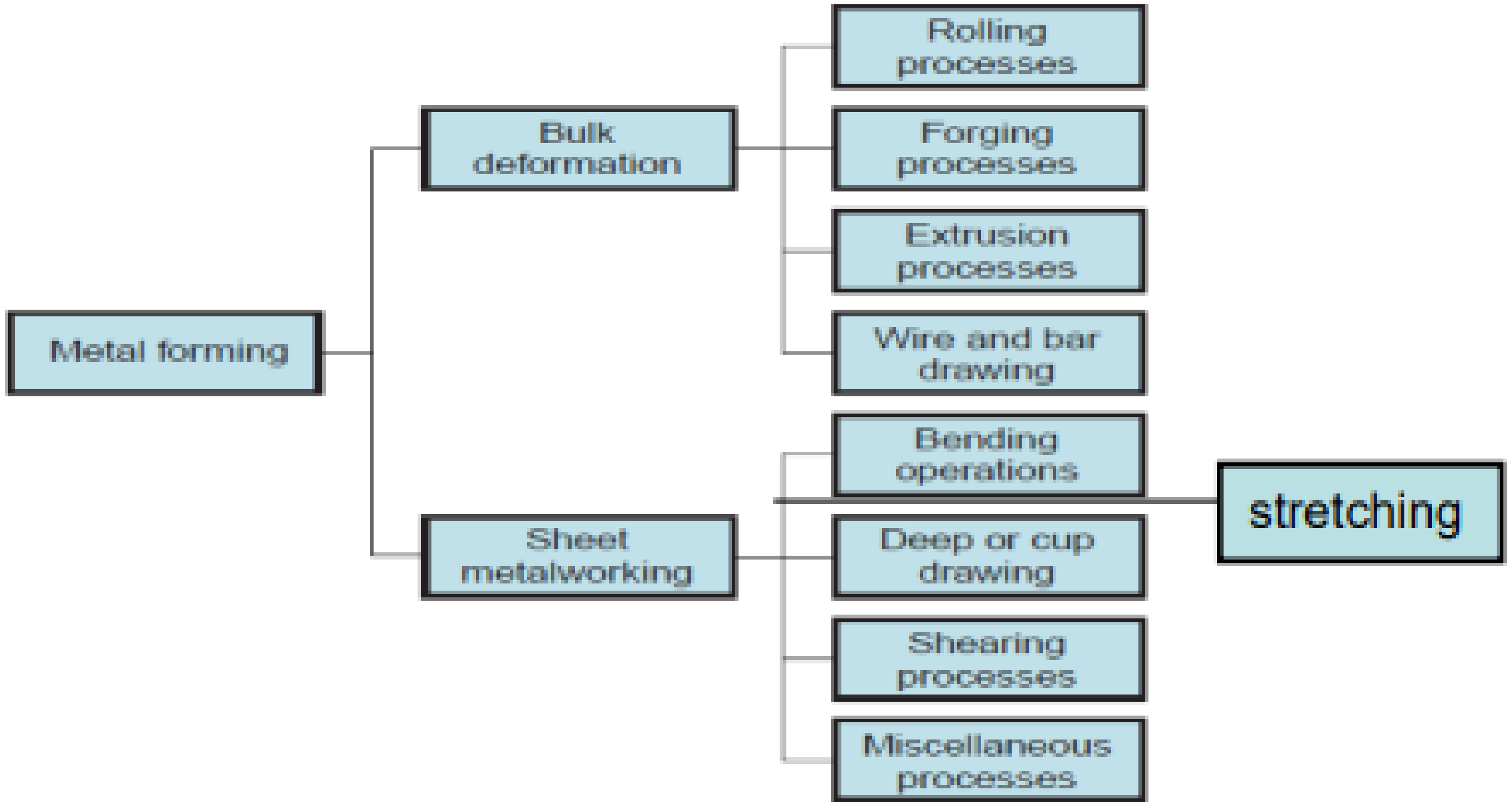
Metal Forming Process

Metal Forming - Large set of manufacturing processes in which the material is deformed plastically to take the shape of the die geometry.

The tools used for such deformation are called die, punch etc. depending on the type of process.

Plastic deformation: Stresses beyond yield strength of the workpiece material is required.

Categories: Bulk metal forming, Sheet metal forming



General classification of metal forming processes

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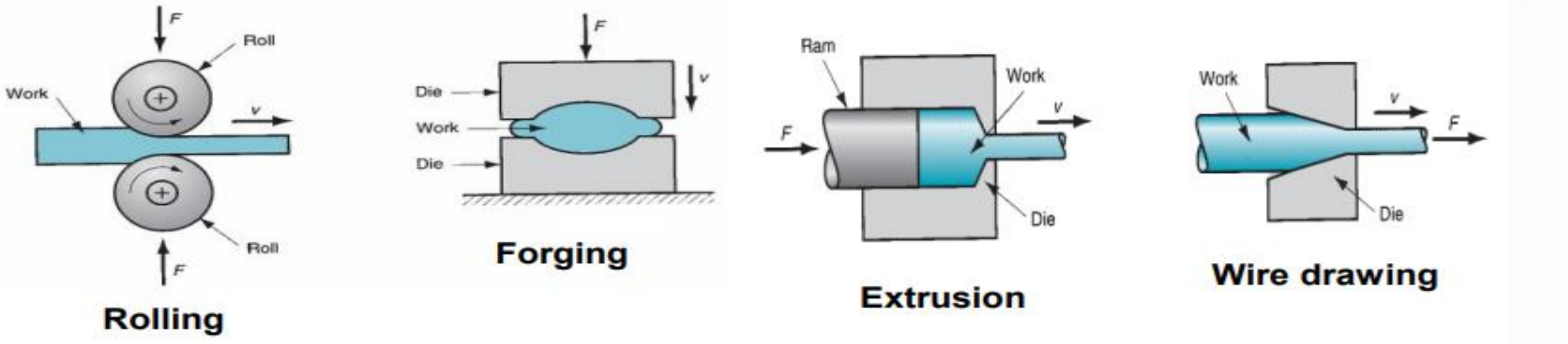
Metal Forming Process – Contd.

Bulk forming: It is a severe deformation process resulting in massive shape change. The surface area-to-volume of the work is relatively small. Mostly done in hot working conditions.



- **Rolling**: In this process, the workpiece in the form of slab or plate is compressed between two rotating rolls in the thickness direction, so that the thickness is reduced. The rotating rolls draw the slab into the gap and compresses it. The final product is in the form of sheet.
- **Forging**: The workpiece is compressed between two dies containing shaped contours. The die shapes are imparted into the final part.
- **Extrusion**: In this, the workpiece is compressed or pushed into the die opening to take the shape of the die hole as its cross section.
- **Wire or rod drawing**: similar to extrusion, except that the workpiece is pulled through the die opening to take the cross-section

Metal Forming Process - Contd.

Hot working: Involves deformation above recrystallization temperature, between 0.5Tm to 0.75Tm. **Advantages**: (1) significant plastic deformation can be given to the sample (2) significant change in workpiece shape (3) lower forces are required (4) materials with premature failure can be hot formed (5) absence of strengthening due to work hardening.

Disadvantages: (1) shorter tool life (2) poor surface finish (3) lower dimensional accuracy (4) sample surface oxidation

Cold working: Generally done at room temperature or slightly above RT.

Advantages compared to hot forming: (1) closer tolerances can be achieved (2) good surface finish (3) because of strain hardening, higher strength and hardness is seen in part (4) grain flow during deformation provides the opportunity for desirable directional properties (5) since no heating of the work is involved, furnace, fuel, electricity costs are minimized, (6) Machining requirements are minimum resulting in possibility of near net shaped forming.

Disadvantages: (1) higher forces and power are required; (2) strain hardening of the work metal limit the amount of forming that can be done, (3) the work piece is not ductile enough to be cold worked.

Metal Forming Process – Contd.

Warm working: In this case, forming is performed at temperatures just above room temperature but below the recrystallization temperature. The working temperature is taken to be 0.3 Tm where Tm is the melting point of the workpiece.

Advantages: (1) enhanced plastic deformation properties, (2) lower forces required, (3) intricate work geometries possible, (4) annealing stages can be reduced.

Metal Joining Process

The process of joining takes place by means of welding, riveting or by fastening nut and bolts.

If a joint can be disassembled then joining method is called **temporary** joining method. If the same, cannot be disassembled without breaking it then the joint is called **permanent** joint.

Examples: Welding, soldering, brazing

Normally in **welding** operation joining of metal pieces is done by raising their temperature to the fusion point so that they form a sort of pool of molten metal at the ends to the joined, sometimes, the pool is supplemented with a filler metal (wire or rod) which normally has almost same compositions as that of the work pieces. This way the pool forms a homogeneous mixture. It is allowed to get solidify to have a permanent joint. There is wide diversity in welding technology so its conventional definition can be modified as ―welding is a technique of joining similar and dissimilar metals and plastics by adopting ways which do not include adhesives and fasteners.

Types : Arc welding, Gas welding

Metal Joining Process – Contd.

Advantages of welding :

1. Permanent joint is produced, which becomes an integral part of work piece.
2. Joints can be stronger than the base metal if good quality filler metal is used.
3. Economical method of joining.
4. It is not restricted to the factory environment.

Disadvantages of welding :

1. Labour cost is high as only skilled welder can produce sound and quality weld joint.
2. It produces a permanent joint which in turn creates the problem in dissembling if of sub-component required.
3. Hazardous fumes and vapours are generated during welding. This demands proper ventilation of welding area.
4. Weld joint itself is considered as a discontinuity owing to variation in its structure, composition and mechanical properties; therefore welding is not commonly recommended for critical application where there is a danger of life.

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Applications of welding

The welding is widely used for fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications besides shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations.

Specific components need welding for fabrication includes

(a) Transport tankers for transporting oil, water, milk etc.

(b) Welding of tubes and pipes, chains, LPG cylinders and other items.

(c) Fabrication of Steel furniture, gates, doors and door frames, and body

(d) Manufacturing white goods such as refrigerators, washing machines, microwave ovens and many other items of general applications

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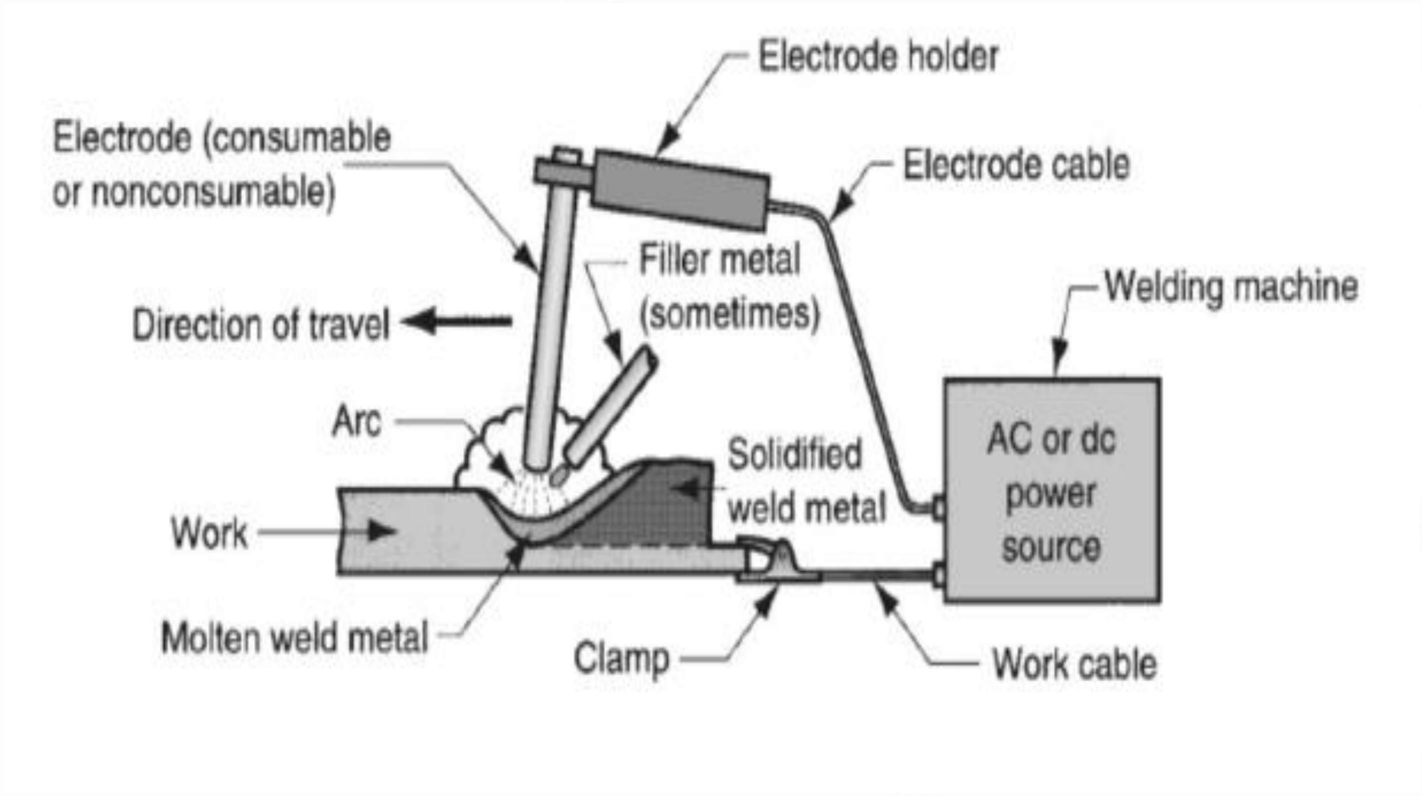
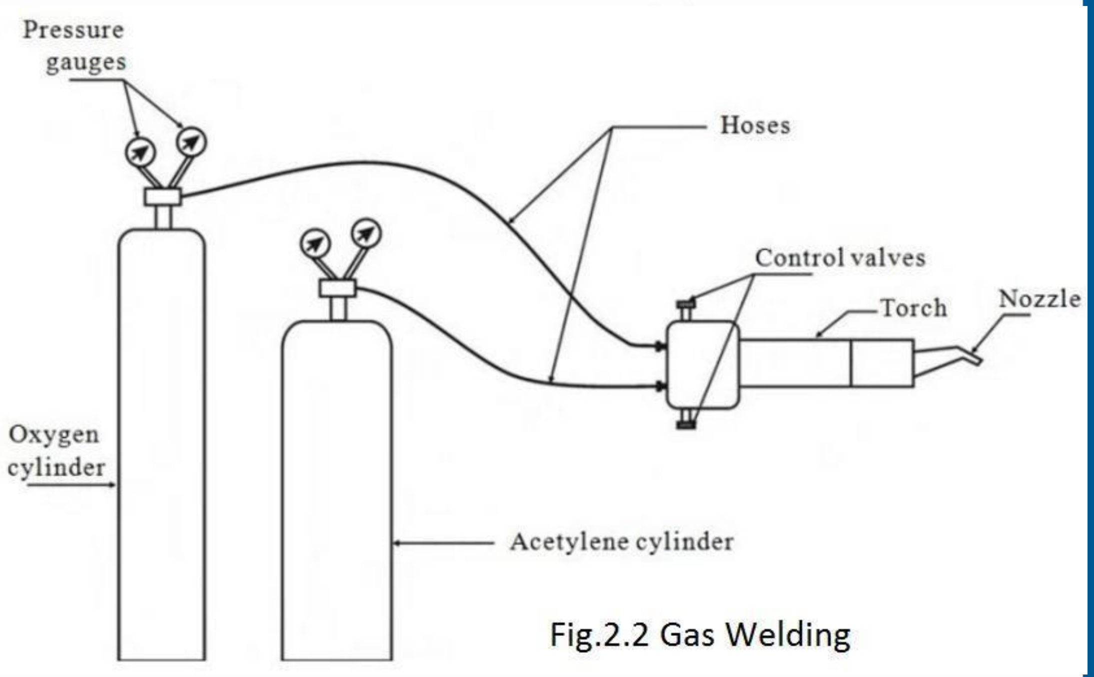
Metal Joining Process - Contd.



Electric arc welding



Gas welding

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Metal Joining Process

Brazing : It is a joining process in which a filler metal is melted and distributed by capillary action between the faying (contact) surfaces of the metal parts being joined.

Base material does not melt in brazing, only the filler melts.

In brazing, the filler metal has a melting temperature above 450°C, but below the melting point of base metals to be joined.

Applications :

Automotive (joining tubes), Pipe/Tube joining, Electrical equipment (joining wires), jewellery making

SOLDERING : Soldering is similar to brazing and can be defined as a joining process in which a filler metal with melting point not exceeding 450°C is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. Similar to brazing, no melting of the base metals occurs, but the filler metal wets and combines with the base metal to form a metallurgical bond.

Filler metal, called Solder, is added to the joint, which distributes itself between the closely fitting parts.

Solder : Alloys of Tin and Lead.

Applications

Printed circuit board (PCB) manufacturing

Pipe joining, Jewellery manufacturing,

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Metal Removal (Machining) Process

Machining Process - It is a process in which a piece of raw material is cut into a desired shape and size by means of sharp cutting tools called a Machining Process

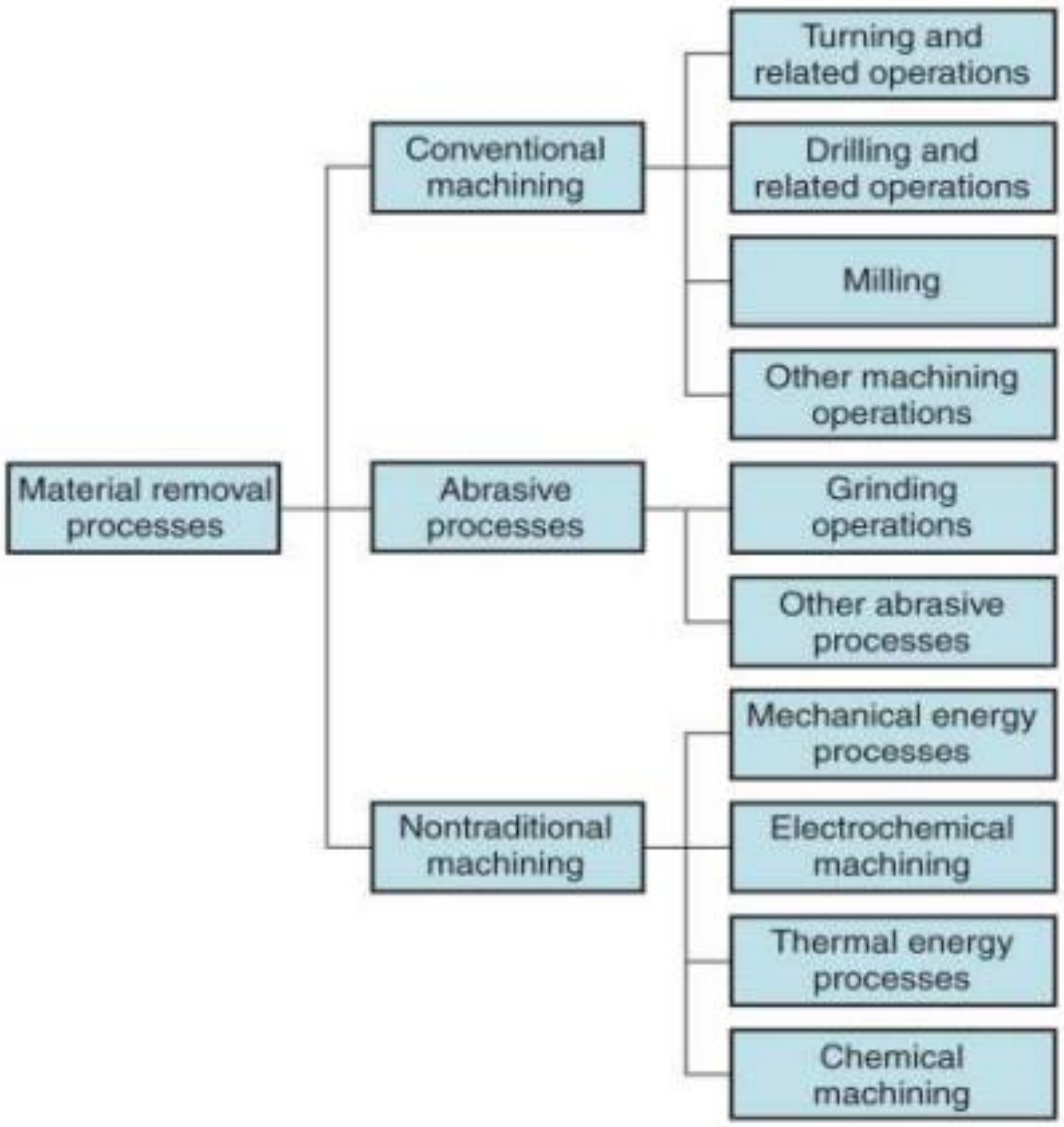
Advantages :

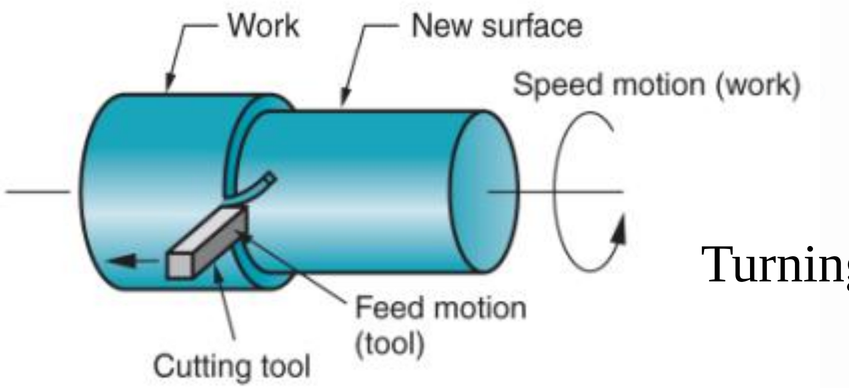
- A high surface finish can be obtained.
- Machining is not only performed on the metal but it also performs on wood, plastic, composites, and ceramics.
- Variety of geometry features are possible, such a Screw threads, Very straight edges, Accurate round holes etc.
- Good dimensional accuracy.

Limitations

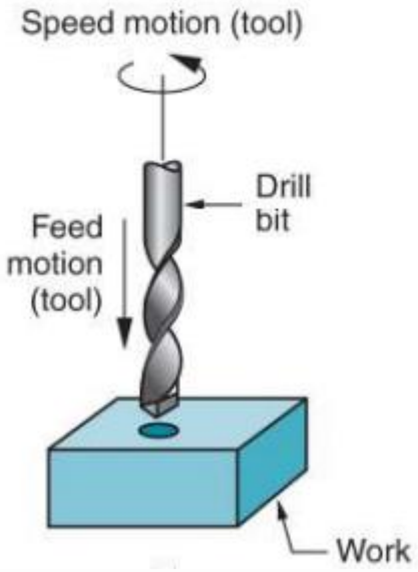
- The accuracy of the components produce is dependent on the efficiency of the operator.
- The consistency in manufacturing is not present. Hence 100% inspection of the component is required.
- Large amount of Manpower involved, the labor problem is also high.
- The complex shapes like parabolic Curvature components, Cubicle Curvature components are difficult to manufacture.
- Frequent design changes in the component cannot be incorporated into the existing layout

Metal Removal (Machining) Process

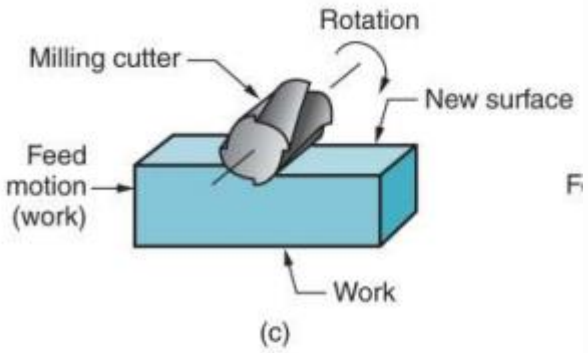




Turning



Drilling



Milling

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The End