Materials and their Applications

By

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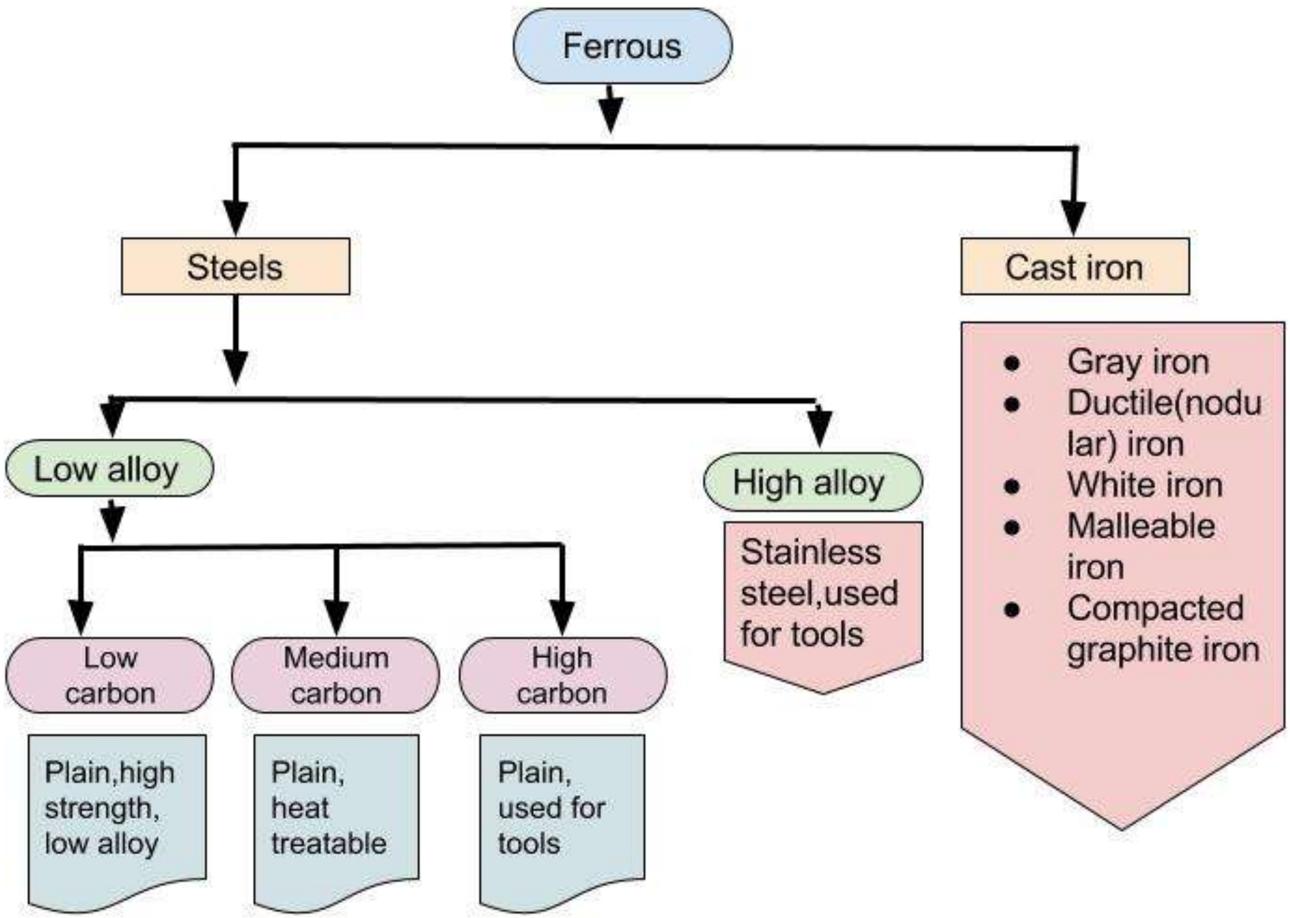
TYPES & APPLICATIONS OF METAL ALLOYS

CLASSIFICATION OF METAL ALLOYS

- Metallic materials are broadly of two kinds **– ferrous** and **non-ferrous materials.** Ferrous materials are those in which iron (Fe) is the principle constituent. All other materials are categorized as non-ferrous materials.
- **Non-ferrous alloys** are, literally, materials that are not iron-based. Non-ferrous alloys are copper-based. In general, these materials deliver high strength, and excellent wear and corrosion resistance. They are often found in marine applications and also bushing, bearing, and gear environments.

FERROUS ALLOYS TYPES



Various types of ferrous metals and alloys are available in the market:

•. Carbon steels are ferrous alloys that contain carbon and small levels of other alloying elements, such as manganese or aluminum

•Alloy steels contain low to high levels of elements such as chromium, molybdenum, vanadium and nickel.

•Stainless steels are highly corrosion resistant, ferrous alloys that contain chromium and/or nickel additions.

•Cast iron, a ferrous alloy, contains high amounts of carbon. Ductile iron, gray iron and white cast iron grades are types of cast iron.

•Cast steel alloy grades are made by pouring molten iron into a mold.

•**Cast Iron Alloy** and **Iron Alloy** are two major ferrous alloys used in most industrial applications.

APPLICATIONS OF Fe ALLOYS

- STRUCTURAL: Building structures , concrete reinforcement.
- AUTOMOTIVE: Engine parts , drive train , body parts.
- MARINE: Ship hulls, structure, engines.
- DEFENCE: Tanks, weapons.
- CONSUMER PRODUCTS: Appliances, recreational vehicles, toys, utensils and tools.

NON FERROUS ALLOYS

- Generally more costly than ferrous metals, non-ferrous metals are used because of desirable properties such as low weight (e.g. aluminium), higher conductivity (e.g. copper), non-magnetic property or resistance to corrosion (e.g. zinc). Some non-ferrous materials are also used in the iron and steel industries.
- Important non-ferrous metals include aluminium,
copper, lead, nickel, tin, titanium and zinc, and alloys such as brass.

COPPER:

- Most extensively used among non ferrous materials.
- Important properties are excellent electrical conductivity and corrosion resistance.
- It occupies the second place among engineering materials
- It also very good thermal conductivity and also it can be easily machined , welded, brazed and soldered.
- Over 50% of the copper produced is used for electrical purposes like wires , switches and other articles which carry electrical current.
- These applications include water heaters , refrigerators , heat exchangers , condensors , automotive radiators etc..

ALUMINIUM:

- Aluminum occupies the third place among commercially used engineering materials.
- It has low density, low melting point and high electrical and thermal conductivities.
- It has low strength and hardness but high ductility and malleability.
- On exposure to atmosphere it forms a strong film of aluminium oxide on its surface, which prevents further oxidation and corrosion.

- It is employed for lightly loaded structures and for electrical cables and similar items.
- The main drawback is its low strength and hardness.
- By cold working , tensile strength of aluminium can be increased by two times due to strain hardening.

TITANIUM:

- Titanium has two allotropic forms.
- It is a strong, ductile and light weight metal, density of pure Ti is 60% of steel.
- High corrosion resistance and high strength at elevated temperatures and widely used as a structural material.
- Suitable for cold and hot working and has good weldability.
- Machinability is much inferior to steel.

- Used for aerospace structures and turbines due to high specific strength , corrosion resistance at elevated temperature.
- Titanium is used in construction of leaching and purification plants for cobalt production.
- Due to higher corrosion resistance titanium is also used in various chemical processing equipments, valves and tanks.

SUPER ALLOY

- A **superalloy**, or **high-performance alloy**, is an alloy that exhibits several key characteristics: excellent mechanical strength, resistance to thermal creep deformation, good surface stability, and resistance to corrosion or oxidation.
- Examples of such alloys are Hastelloy, Waspaloy, Rene alloys, Incoloy.

- **Hastelloy:** Nickel based alloy in flat product form such as sheet, coil, plate form. It is corrosion resistant, high temperature alloy for aerospace, chemical processing & industrial gas turbine industries.
- **Waspaloy:** Ni based superalloy. Used in high temperature applications particularly in gas turbines.
- **Rene alloy:** Ni based alloy, retains high strength in 649/982C temp range. Used in jet engines & missile components & other applications that require high strength at extreme temperature.

- **Incoloy:** Incoloy refers to a range of superalloys produced by the Special Metals Corporation group of companies. They are mostly nickel-based, and designed for excellent corrosion resistance as well as strength at high temperatures; there are specific alloys for resistance to particular chemical attacks (e.g. alloy **020** is designed to be resistant to sulphuric acid, **DS** to be used in heat-treating furnaces with reactive atmospheres and many heat cycles)
- **Incoloy MA956** is made by a mechanical alloying rather than a bulk-melting process; it was studied for space reactor components in the JIMO project. It is difficult to weld and needs to be heated to 200C for forming processes.

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TYPES AND APPLICATIONS OF CERAMICS

What is a Ceramic???

Ceramics are inorganic ,nonmetallic , solids , crystalline , amorphous(eg: Glass), hard , brittle, stable to high temperatures, less dense than metals and have very high melting.

Classification of Ceramics

Ceramic Materials

- **Glasses**
  - -optical
  - -composite reinforce
  - -containers/ household
- **Clay products**
  - -whiteware
  - -structural
- **Refractories**
  - -bricks for high *T* (furnaces)
- **Abrasives**
  - -sandpaper
  - -cutting
  - -polishing
- **Cements**
  - -composites
  - -structural
- **Advanced ceramics**
  - -engine rotors valves bearings
  - -sensors

Adapted from Fig. 13.1 and discussion in Section 13.2-8, *Callister & Rethwisch 8e.*

GLASSES

Glass is an amorphous material and can be formed through several methods most commonly involving heating of raw materials into molten liquid and rapidly cooling the liquid.

MOST COMMERCIALLY USED GLASS MATERIALS

GLASS TYPE	COMPOSITION	THERMAL/SHOCK RESISTANT	APPLICATIONS
BOROSILI-CATE	$SiO2,B2O3$	Average-High	•Industrial equipment •Exterior lighting •Laboratory and kitchen galssware
SODA-LIME SILICATE	$SiO2,Na2O,CaO$	Low	•Food and beverage containers •Windows
PHOSPHATE	$P2O5$	Low	•Optical fibers •Heat absorbers

APPLICATIONS

It is clear that **modern life would not be possible without glass!**

Glass is used in the following non-exhaustive list of products:

- Packaging (jars for food, bottles for drinks, flacon for cosmetics and pharmaceuticals)
- Tableware (drinking glasses, plate, cups, bowls)
- Housing and buildings (windows, facades, conservatory, insulation, reinforcement structures)
- Interior design and furniture's (mirrors, partitions, balustrades, tables, shelves, lighting)
- Appliances and Electronics (oven doors, cook top, TV, computer screens, smart-phones)

- Automotive and transport (windscreens, backlights, light weight but reinforced structural components of cars, aircrafts, ships, etc.)
- Fiber optic cables (phones, TV, computer: to carry information)
- Renewable energy (solar-energy glass, wind turbines)

All of this is made possible by the countless properties of the glass substance.

CLAY PRODUCTS

- Wall materials. The examples are common clay brick, perforated clay brick, porous and perforated stiff-mud brick, hollow clay dry-press brick.
- STRUCTURAL PRODUCTS : Brick for special purposes. The example are for sewage installations (underground sewer pipes) brick for road surface (clinker).
- Clay products for interior decoration. The examples are tiles for facing walls, built-in parts, large floor tiles and mosaic floor tiles.
- Sanitary clay items.

REFRACTORIES

- Refractories are ceramic materials designed to withstand the very high temperatures (in excess of 1,000°F [538°C]) encountered in modern manufacturing. More heat-resistant than metals.
- Refractories come in all shapes and sizes. They can be pressed or molded for use in floors and walls, produced in interlocking shapes and wedges, or curved to fit the insides of boilers some refractory parts are small and possess a complex and delicate geometry; others are massive and may weigh several tons.

- Refractory materials are used in furnaces, kilns(a type
  of oven), incinerators, and reactors.
- Refractories are also used to
  make crucibles and moulds for casting glass and metals and for surfacing flame deflector systems for rocket launch structures . Today,
  the iron- and steel-industry and metal casting sectors use approximately 70% of all refractories produced.

COMMON CERAMIC REFRACTORY MATERIALS

Based on chemical composition:

- **Acidic refractories**:

Acidic refractories consist of mostly acidic materials like alumina (Al_2O_3) and silica (SiO_2). They are generally not attacked or affected by acidic materials, but easily affected by basic materials. They include substances such as silica, alumina, and fire clay brick refractories. Notable reagents that can attack both alumina and silica are hydrofluoric acid, phosphoric acid, and fluorinated gases (e.g. HF, F_2). At high temperatures, acidic refractories may also react with limes and basic oxides.

- **Neutral refractories**:

These are used in areas where slags and atmosphere are either acidic or basic and are chemically stable to both acids and bases. The main raw materials belong to, but are not confined to, the R_2O_3 group. Common examples of these materials are alumina (Al_2O_3), chromia (Cr_2O_3) and carbon.

- **Basic refractories**:

These are used in areas where slags and atmosphere are basic; they are stable to alkaline materials but could react with acids. The main raw materials belong to the RO group to which magnesia (MgO) is a very common example. Other examples include dolomite and chrome-magnesia. For the first half of the twentieth century, the steel making process used artificial periclase (roasted magnesite) as a lining material for the furnace.

SPECIAL REFRACTORIES:

- Zirconia refractories: In zirconia refractories, main constituent of the refractory is zirconium oxide (ZrO_2). Zirconia refractories are useful as high temperature construction materials. They tend to be used in applications where temperatures are above 1900 deg C such as casting nozzles and gates, crucibles, furnace liners and kilns. The thermal conductivity of zirconium dioxide is found to be much lower than that of most other refractories and the material is therefore used as a high temperature insulating refractory. Since Zirconia shows very low thermal losses and does not react readily with liquid metals, it is mainly useful for making refractory crucibles and other vessels for metallurgical purposes.
- Alumina refractories: Alumina refractories are also having basic constituents of Al_2O_3 and SiO_2 but these refractories have a minimum of 50 % Al_2O_3. Alumina refractories are divided into seven different classes by percent alumina. These classes are (i) 50 % Al_2O_3, (ii) 60 % Al_2O_3, (iii) 70 % Al_2O_3, (iv) 80 % Al_2O_3, (v) 85 % Al_2O_3, (vi) 90 % Al_2O_3, and (vii) 99 % Al_2O_3.

ABRASIVES

- What are Abrasives????

An **abrasive** is a material, often a mineral, that is used to shape or finish a workpiece through rubbing which leads to part of the workpiece being worn away by friction. While finishing a material often means polishing it to gain a smooth, reflective surface , matte or beaded finishes. In short, the ceramics which are used to cut, grind and polish other softer materials are known as abrasives.

Common applications for abrasives include the following:

- Buffing.
- Honing.
- Drilling.
- Grinding.
- Sanding.
- Polishing.
- Cutting.
- Sharpening.

CEMENTS

A **cement** is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together.

- Cements used in construction are usually inorganic, often lime or calcium silicate based, and can be characterized as either **hydraulic** or **non-hydraulic**, depending on the ability of the cement to set in the presence of water.
- **Non-hydraulic cement** does not set in wet conditions or under water. Rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.
- **Hydraulic cements** (e.g., Portland cement) set and become adhesive due to a chemical reaction between the dry ingredients and water.

PREPARATION OF CEMENT

1. Extraction

Materials are extracted / quarried / recovered and transported to the cement plant.

2 .Crushing and milling

The raw materials, limestone, shale, silica and iron oxice are crushed and milled into fine powders.

3 .Mixing and preheating

The powders are blended (the 'raw meal') and preheated to around 900° C using the hot gases from the kiln. The preheating burns off the impurities.

4 .Heating

Next the material is burned in a large rotary kiln at 1500° C. Heating starts the de-carbonation where CO2 is driven from the limestone. The partially fused resulting is known as clinker. A modern kiln can produce around 6000 tons of clinker a day.

$CaCO_3$ (limestone) + heat -> CaO (lime) + CO_2

5 .Cooling and final grinding

The clinker is then cooled and ground to a fine powder in a tube or ball mill. A ball mill is a rotating drum filled with steel balls of different sizes (depending on the desired fineness of the cement) that crush and grind the clinker. Gypsum is added during the grinding process to provide means for controlling the setting of the cement.

SETTING PROCESS OF CEMENT

When water is added to cement a reaction takes place to form a paste. In its original form, the finely ground cement is very sensitive to water. Out of the four main ingredients C3A, C3S and C2S quickly react with water which finally produces a jelly-like paste that starts solidifying. The activity of changing from a fluid state to a solid state is known as *setting*. Setting is divided into two different categories: Initial setting time & Final setting time.

INITIAL SETTING TIME:

Initial setting time can be defined as the time when the cement paste starts losing its plasticity. The minimum initial setting time is 30 minutes for ordinary portland cement and 60 minutes for low heat cement.

FINAL SETTING TIME:

The final setting is defined as the time taken to reach the cement paste to become into a hardened mass. The maximum final setting time for all type of cement is 10 hours.

CLASSIFICATION OF CEMENT

Types of Cement:

Following are the different types of cement used in construction works.

1. Rapid Hardening Cement:

Rapid hardening cement is very similar to ordinary portland cement (OPC). It contains higher C3S content and finer grinding. Therefore it gives greater strength development at an early stage than OPC. The strength of this cement at the age of 3 days is almost same as the 7 days strength of OPC with the same water-cement ratio.

The main advantage of using rapid hardening cement is that the formwork can be removed earlier and reused in other areas which save the cost of formwork. This cement can be used in prefabricated concrete construction, road works, etc.

2. Low Heat Cement:

Low heat cement is manufactured by increasing the proportion of C2S and by decreasing the C3S and C3A content. This cement is less reactive and its initial setting time is greater than OPC. This cement is mostly used in mass concrete construction.

3. Sulfate Resisting Cement:

Sulfate resisting cement is made by reducing C3A and C4AF content. Cement with such composition has excellent resistance to sulfate attack. This type of cement is used in the construction of foundation in soil where subsoil contains very high proportions of sulfate .

4. White Cement:

White cement is a type of ordinary Portland Cement which is pure white in color and has practically the same composition and same strength as OPC. To obtain the white color the iron oxide content is considerably reduced. The raw materials used in this cement are limestone and china clay.

This cement, due to its white color, is mainly used for interior and exterior decorative work like external renderings of buildings, facing slabs, floorings, ornamental concrete products, paths of gardens, swimming pools etc.

5. Portland Pozzolana Cement:

Portland pozzolana cement is produced either by grinding together, Portland cement clinkers and pozzolana with the addition of gypsum or calcium sulfate or by intimately and uniformly blending Portland cement and fine pozzolana.

It has greater resistance to attack of chemical agencies than OPC. Concrete made with PPC is thus considered particularly suitable for construction in sea water, hydraulic works and for mass concrete works.

6. Hydrophobic Cement:

Hydrophobic cement is manufactured by adding water repellant chemicals to ordinary portland cement in the process of grinding. Hence the cement stored does not spoiled even during monsoon. This cement is claimed to remain unaffected when transported during rains also. Hydrophobic cement is mainly used for the construction of water structures such dams, water tanks, spillways, water retaining structures etc.

7. Colored Cement:

This Cement is produced by adding 5- 10% mineral pigments with Portland cement during the time of grinding. Due to the various color combinations this cement is mainly used for interior and exterior decorative works

Example:

Iron Oxide – Red colour

Chromium Oxide – Green Colour

Cobalt Oxide – Blue Colour

8. Waterproof Portland Cement:

Waterproof cement is prepared by mixing with ordinary or rapid hardening cement, a small percentage of some metal stearates (Ca, Al, etc) at the time of grinding. This cement is used for the construction of water-retaining structure like tanks, reservoirs, retaining walls, swimming pools, dams, bridges, piers etc.

9. Portland Blast Furnace Cement:

In this case, the normal cement clinkers are mixed with up to 65% of the blast furnace slag for the final grinding. This type of cement can be used with advantage in mass concrete work such as dams, foundations , construction in sea water.

10. Air Entraining Cement:

It is produced by air entraining agents such as resins, glues, sodium salts of sulfate with ordinary portland cement.

11. High Alumina Cement:

High alumina cement (HAC) is a special cement, manufactured by mixing of bauxite (aluminum ore) and lime at a certain temperature. This cement is also known as calcium aluminum cement (CAC). The compressive strength of this cement is very high and more workable than ordinary portland cement.

12. Expansive Cement:

The cement which does not shrink during and after the time of hardening but expands slightly with time is called expansive cement.

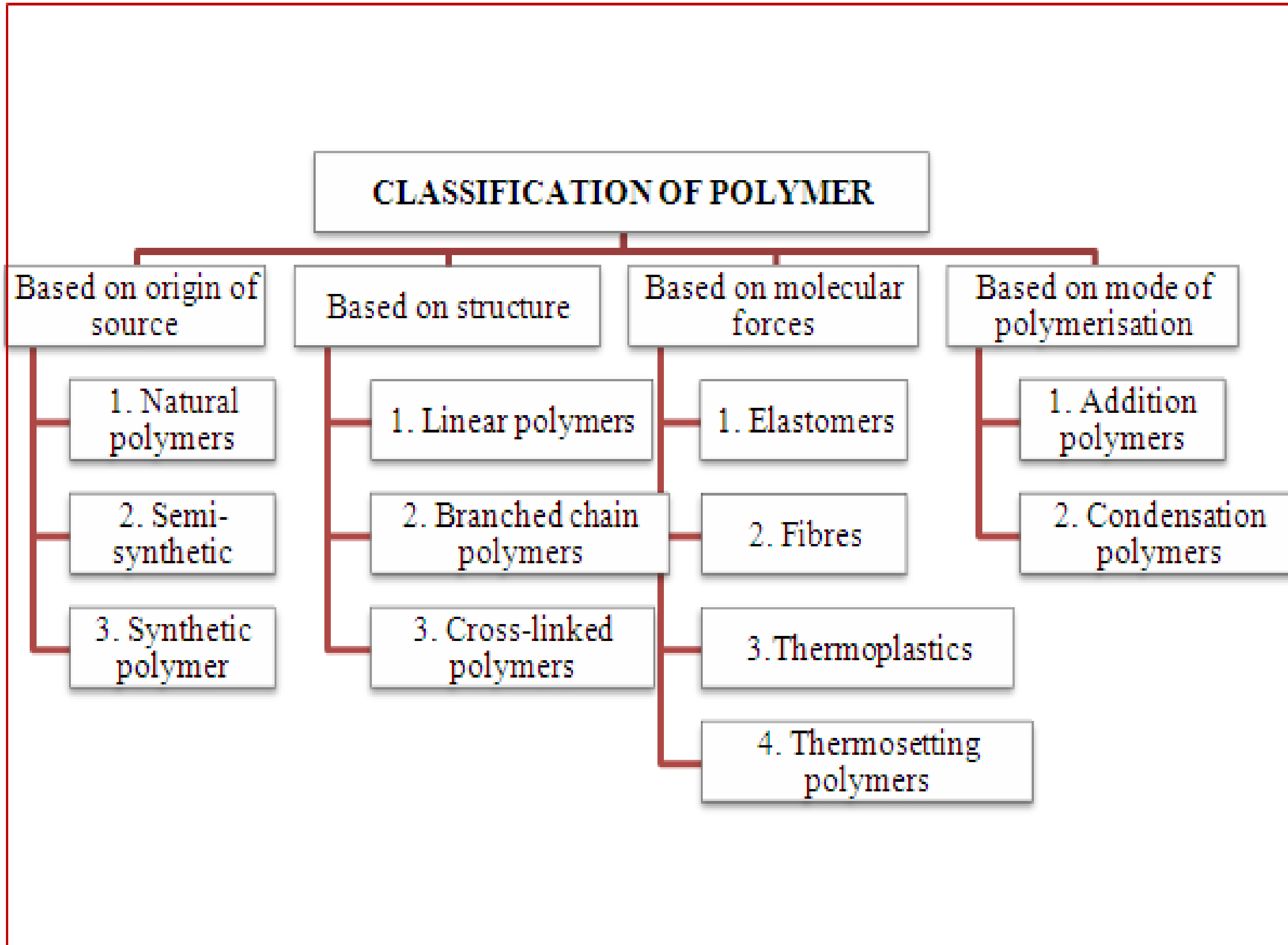
ADVANCED CERAMICS

What are advanced ceramics????

Advanced ceramics are materials which are synthetically produced using high temperatures or chemical reactions. These are very strong , can withstand high temperatures , very good chemical resistance and very stable. Advanced ceramics enhance our lives by their constant usefulness.

- Electronics: Capacitors , insulators.
- Automotive industry: in engines and heat resistant ceramic parts like valve components , for water and fuel pumps.
- Energy and environment: Reduce emissions and ensure efficient use of resources in many areas of energy supply and environmental technology.
- Aerospace: In engines(shielding a hot running air plane from damage). Rocket nozzles, shielding the missile internals from heat.

POLYMERS AND APPLICATIONS



CLASSIFICATION OF POLYMERIC MATERIALS BASED ON APPLICATIONS

- Coatings
- Adhesives
- Films
- Foams

COATINGS

Polymeric coatings are coatings or paint made with polymers that provide superior adherence and protection from corrosion.
Polymer coatings can be applied to metals, ceramics as well as synthetic materials. They are temperature-resistant up to approx. 535°F (280°C)

e.g. Teflon coating, PTFE.

ADHESIVES

Polymer dispersion adhesives are often based on polyvinyl acetate (PVAc). They are used extensively in the woodworking and packaging industries. They are also used with fabrics and fabric-based components, and in engineered products such as loudspeaker cones. Polymer adhesives have found their place in numerous electronics' applications.
Major uses include commercial/consumer products; computers; automotive, medical, and wireless communications.

FILMS

Plastic film is a thin continuous polymeric material. Thicker plastic material is often called a "sheet". These thin plastic membranes are used to separate areas or volumes, to hold items, to act as barriers, or as printable surfaces.

Plastic films are used in a wide variety of applications. These include: packaging, plastic bags, labels, building construction, landscaping, electrical fabrication, photographic film, film stock for movies, video tape, etc.

FOAMS

- A **polymeric foam** is a foam, in liquid or solidified form, formed from polymers.

Examples include:

Ethylene-vinyl acetate (EVA) foam, the copolymers of ethylene and vinyl acetate; also referred to as polyethylene-vinyl acetate (PEVA)

- Silicone foam
- Microcellular foam

ADVANCED MATERIALS

Materials that are utilized in high-technology applications are termed as **Advanced materials .**

These advanced materials are typically traditional materials whose properties have been enhanced, and also newly developed, high-performance materials. Furthermore, they may be of all material types (e.g., metals, ceramics, polymers), and are normally expensive.

Types of advanced materials

- Semi conductors.
- Bio- compatible materials.
- Smart materials.
- Advanced polymeric materials.
- Nano engineered materials.

- **Semi conductors:**

A semiconductor material has an electrical conductivity value falling between that of a conductor, like copper, gold, etc. and an insulator, such as glass.

- **Smart materials:**

Smart materials are designed materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields, light, or chemical compounds.

There are a number of types of smart material, of which are already common. Some examples are as following:

- Piezoelectric materials are materials that produce a voltage when stress is applied.
- Shape-memory alloys and shape-memory polymers are materials in which large deformation can be induced and recovered through temperature changes or stress changes.
- Photovoltaic materials or optoelectronics convert light to electrical current.
- Electroactive polymers (EAPs) change their volume by voltage or electric fields.
- Magnetostrictive materials exhibit a change in shape under the influence of magnetic field.
- pH-sensitive polymers are materials that change in volume when the pH of the surrounding medium changes.
- Halochromic materials are commonly used materials that change their color as a result of changing acidity.

- **Advanced polymeric materials:**

Advanced polymer matrix composites. These are high strength fibres with high stiffness, elasticity characteristics, compared to other materials, while bound together by weaker matrices.

Advanced composites exhibit desirable physical and chemical properties that include light weight coupled with high stiffness (elasticity), and strength along the direction of the reinforcing fiber, dimensional stability, temperature and chemical resistance and relatively easy processing. Advanced composites are replacing metal components in many uses, particularly in the aerospace industry.

- **Nano engineered materials:**

Materials composed of one or more engineered nano -components. A nano -component has at least one of its dimensions between 1nm and 100nm. These nano -components or their interactions are engineered to impart the unique properties of these materials. Examples include nanotubes, nanoparticles, nanostructured materials, and designer molecules.

- **Bio compatible material:**

A biocompatible material is a synthetic or natural material used to replace part of a living system or to function in intimate contact with living tissue. Biocompatible materials are intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body.

Artificial hips, vascular stents, artificial pacemakers, and catheters are all made from different biomaterials and comprise different medical devices.

Bio materials

- Biomaterials relates to the study of biocompatible materials used for biomedical applications.
- Materials that are used for biomedical or clinical applications are known as biomaterials. They are bioactive and biocompatible in nature. Currently, many types of metals and alloys (stainless steel, titanium, nickel, magnesium, Co–Cr alloys, Ti alloys), ceramics (zirconia, bioglass, alumina, hydro xyapatite) and polymers (acrylic, nylon, silicone, polyurethane, polycaprolactone, polyanhydrides) .
- This includes dental replacement and bone joining or replacement for medical and clinical application.

Metals and alloys used in bone and joint replacement

Joints in the body may be replaced by metal alloys, ceramics and polymers.

Metals have the mechanical strength and stiffness necessary for load bearing.

Metals used in orthopedic implants include surgical grade **stainless** steel (commonly 316L) temporarily, **cobalt-chromium** (**Co-Cr**) **alloys** and pure commercial **titanium** (Ti) or **titanium alloys are commonly used**.

Filling and restoration materials

Teeth can be filled with gold; porcelain; silver amalgam (which consists of mercury mixed with silver, tin, zinc, and copper); or tooth-colored, plastic, and materials called composite resin fillings.

- **DENTAL CEMENTS:**

GIC – Glass Ionomer cement

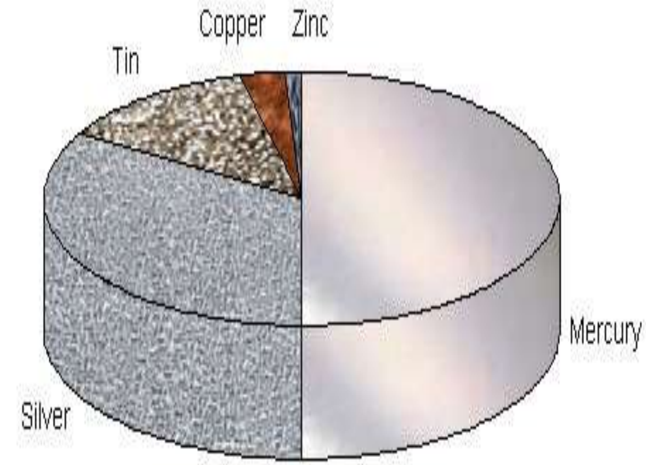
Zinc Polycarboxylate cement

Zinc Oxide Eugenol cement

- **Dental Amalgam :**

Dental amalgam is a liquid mercury and metal alloy mixture used to fill cavities caused by tooth decay.

Low-copper amalgam commonly consists of mercury (50%), silver (~22–32%), tin (~14%), copper (~8%) and other trace metals.



- **Dental adhesisves :**

Dental bonding is a dental procedure in which a dentist applies a tooth-colored resin material (durable plastic material) and cures it with visible, blue light. This ultimately "bonds" the material to the tooth and improves the overall appearance of teeth.