Nano Materials

Nanomaterials are cornerstones of nanoscience and nanotechnology. Nanostructure science and Technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years.

Nano scale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers. A nanometer is one millionth of a millimeter - approximately 100,000 times smaller than the diameter of a human hair. Nano materials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, and other fields.

Some nanomaterials occur naturally, but of particular interest are engineered nanomaterials (EN), which are designed for, and already being used in many commercial products and processes. They can be found in such things as sunscreens, cosmetics, sporting goods, stain resistant clothing, tires, electronics, as well as many other everyday items, and are used in medicine for purposes of diagnosis, imaging and drug delivery.

Methods for creating nanostructures:

There are many different ways of creating nanostructures: macromolecules or nanoparticles or buckyballs or nanotubes and so on can be synthesized artificially for certain specific materials. They can also be arranged by methods based on equilibrium or near equilibrium thermo dynamics such as methods of self-organization and self-assembly (sometimes also called bio-mimetic processes). Using these methods, synthesized materials can be arranged into useful shapes so that finally the material can be applied to a certain application.

Applications

Automotive (fuel cells and filters, bedding protection, nano products for HVAC etc.)

Health Care (targeted drug delivery, artificial joints, tissue replacement, tissue engineering)

Chemical Industry (nanotubes, nanocomposites, cosmetic creams, UV protection)

Environment (filtration, biodegradation, removal of impurities, marking of food, desalinisation)

Electronics (storage devices, spintronics, bioelectronics, quantum electronics)

Military (respirators, fabrics providing biological or chemical protection, haemostatic pads)

Textile Industry (novel apparels, sports clothing, hydrophobic and non-soiling fabrics)

Bio- materials

A **biomaterial** is any substance that has been engineered to interact with biological systems for a medical purpose - either a therapeutic (treat, augment, repair or replace a tissue function of the body) or a diagnostic one. Biomaterials can be derived either from nature or synthesized in the laboratory using a variety of chemical approaches utilizing metallic components, polymers, ceramics or composite materials. They are often used and/or adapted for a medical application, and thus comprises whole or part of a living structure or biomedical device which performs, augments, or replaces a natural function. Such functions may be relatively passive, like being used for a heart valve, or may be bioactive with a more interactive functionality such as hydroxy-apatite coated hip implants. Biomaterials are also used every day in dental applications, surgery, and drug delivery. For example, a construct with impregnated pharmaceutical products can be placed into the body, which permits the prolonged release of a drug over an extended period of time. A biomaterial may also be an autograft, allograft or xenograft used as a transplant material.

Biomaterials must be compatible with the body, and there are often issues of biocompatibility which must be resolved before a product can be placed on the market and used in a clinical setting. Because of this, biomaterials are usually subjected to the same requirements as those undergone by new drug therapies.

Biomaterials are used in:

- Joint replacements
- Bone plates
- Intraocular lenses (IOLs) for eye surgery
- Bone cement
- Artificial ligaments and tendons
- Dental implants for tooth fixation
- Blood vessel prostheses
- Heart valves
- Skin repair devices (artificial tissue)
- Cochlear replacements
- Contact lenses
- Breast implants

- Drug delivery mechanisms
- Sustainable materials
- Vascular grafts
- Stents
- Nerve conduits
- Surgical sutures, clips, and staples for wound closure
- Pins and screws for fracture stabilisation
- Surgical mesh

Non-ferrous metals

Non-ferrous metals are those which do not contain significant quantity of iron or iron as base metal. These metals possess low strength at high temperatures, generally suffer from hot shortness and have more shrinkage than ferrous metals.

They are utilized in industry due to following advantages:

- High corrosion resistance
- Easy to fabricate, i.e., machining, casting, welding, forging and rolling
- Possess very good thermal and electrical conductivity
- Attractive colour and low density

But these metal are expensive than ferrous metals as they are not abundantly available

However different materials have distinct characteristics, and are used for specific purposes.

The various non-metals used in industry are: copper, aluminium, tin, lead, zinc, and nickel, etc., and their alloys.

Aluminium

Aluminium is white metal which is produced by electrical processes from clayey mineral known as bauxite. However, this aluminium ore bauxite is available in India in plenty and we have a thriving aluminium industry.

Properties:

- These are characterized by low density, high thermal & electrical conductivities,
- good corrosion resistant characteristics because of formation of Al_2O_3 protective layer.
- As Al has FCC crystal structure, these alloys are ductile even at low temperatures and can be formed easily.
- However, the great limitation of these alloys is their low melting point (660 ^{0} C), which restricts their use at elevated temperatures.

Applications:

Aerospace: The absolute requirement for light structures, make aluminium and its alloys now more than ever the number one material in the sky.

Automotive: Chassis, bodies, engine blocks, radiators, hubcaps etc. because of its lightweight and corrosion resistance

Marine: Marine transport is increasing its use of aluminium by capitalizing on its two leading qualities: lightness and corrosion resistance. Advanced alloys have enabled the design of high-speed ships, by lightening hulls by 40% to 50% over steel.

Rail: Lighter structures, resistance and durability have made aluminium crucial to rail transport applications.

Packaging: Its lightness saves both on the material and the energy it takes to produce it. It is complete recyclability makes it reusable in the economic cycle.

Energy distribution: Aluminium’s low density combined with its excellent electrical conductivity make it a crucial material in the distribution of electricity.

Sports and leisure: sports equipment (hang gliders, ski poles, golf clubs, off-road bikes, scooters) and leisure products (trailers, camping, diving and mountaineering equipment).

Alloys of Aluminium

Aluminium may be alloyed with one or more alloying elements such as copper, manganese, magnesium, silicon and nickel.

The addition of small quantities of alloying elements converts the soft and weak aluminium into hard and strong metal, while it retains its light weight.

The main alloys of aluminium are:

- Duralumin
- Y-alloy
- Magnalium
- Hindalium

Duralumin

Composition:

- This is a famous alloy of aluminium containing *4% copper, 0.5% manganese, 0.5% magnesium* and a trace of iron with remainder as aluminium is known as duralumin.

Properties:

- It possesses high strength comparable with mild steel and low specific gravity.
- However, its corrosion resistance is much lower as compared with pure aluminium.
- The strength of this alloy increases significantly when heat treated and allowed to age for 3 to 4 weeks, it will be hardened.
- To improve upon the corrosion resistance of it, a thin film of aluminium is rolled on the duralumin sheets.

Applications:

- These aluminium rolled sheets are known as *Alclad* by trade name and are widely used in aircraft industry.
- Due to lightweight and high strength this alloy may be used in automobile industry.

Y-Alloy

It is also known as *copper-aluminium* alloy.

Composition:

- The addition of copper to pure aluminium improves its strength and machinability.
- Y-alloy contains *93% aluminium, 2% copper, 1% nickel and magnesium.*

Properties:

- This alloy is heat treated as well as age hardened just like duralumin.
- A heat treatment of Y-alloy castings, consisting of quenching in boiling water from 510°C and then aging for 5 days develops very good mechanical characteristics in them.

Applications:

- Since Y-alloy has better strength at elevated temperature than duralumin therefore it is much used in aircraft cylinder heads and piston.
- It is also used in strip and sheet form.

Magnalium

- It is produced by melting the aluminium and 2 to 10% magnesium in a vacuum and then cooling it in vacuum or under a pressure of 100 to 200 atmospheres.
- About 1.75% copper is also added to it.

Applications:

- Due to its light weight and good mechanical characteristics, it is mainly used for aircraft and automobile components.

Hindalium

- It is an alloy of *aluminium and magnesium* with *small quantity of chromium*.
- It is manufactured as rolled product in 16 gauge mainly used in manufacture of *anodized utensils*.

Copper and its alloys

The crude form of copper extracted from its ores through series of processes contains 68% purity known as Blister copper. By electrolytic refining process, highly pure (99.9%) copper which is remelted and casted into suitable shapes.

Copper is a corrosion resistant metal of an attractive reddish brown colour.

Properties and Uses:

- *High Thermal Conductivity:* Used in heat exchangers, heating vessels and appliances, etc.
- *High Electrical Conductivity:* Used as electrical conductor in various shapes and forms for various applications.
- *Good Corrosion Resistance:* Used for providing coating on steel prior to nickel and chromium plating
- *High Ductility:* Can be easily cold worked, folded and spun. Requires annealing after cold working as it loses its ductility.

Alloys of Copper

Most copper alloys cannot be hardened or strengthened by heat-treating procedures. consequently, cold working and/or solid-solution alloying must be utilized to improve these mechanical properties.

- Copper alloys are among the best conductors of heat and electricity and they have good corrosion resistance.

The common types of copper alloys are brasses and bronzes

Brass

All brasses are basically alloys of *copper and zinc*.

Commercially there are two main varieties of brasses:

1. Alpha brass:
   - Contains up to 36% Zn and rest copper for *cold working*.
2. Alpha-Beta brass:
   - Contains 36 to 45% Zn and remainder is copper for *hot working*.

Effect of Zinc on Copper:

- The tensile strength and ductility of brass both increase with increase in content of Zn up to 30% zinc.
- With further increase in zinc content beyond 30%, the tensile strength continues to increase up to 45% of Zn, but ductility of brasses drops significantly.
- β- phase is less ductile than α-phase but it is harder and stronger.

There are various types of brasses depending upon proportion of copper and zinc.

- Fundamentally brass is a binary alloy of copper with as much as 50% zinc.
- Various classes of brasses such as cartridge brass, Muntz Metal leaded brass, Admiralty brass, naval brass and nickel brass depending upon the proportion of copper and zinc plus third alloying metal are available for various uses.

Applications:

- Brasses possess very good corrosion resistance and can be easily soldered.
- Costume jewelry, cartridge casings, automotive radiators, musical instruments, electronic packaging, and coins.

Bronze

The alloy of *copper and tin* are usually termed bronzes.

- The useful range of composition is 75 to 95% copper and remainder tin.
- In general, it possesses superior mechanical properties and corrosion resistance to brass.

Properties:

- The alloy can be easily cold rolled into wire, rods and sheets.
- With increase in tin content, the strength of this alloy and its corrosion resistance increases. It is then known as hot working bronze.

Applications:

- Bronze is generally utilized in hydraulic fittings, bearings, bushes, utensils, sheets, rods and many other stamped and drawn products.

The properties of bronzes are modified with different alloying elements as below

Phosphor bronze

When bronze contains phosphorus, it is known as phosphor bronze.

Properties:

- The composition of the alloy varies according to whether it is to be forged, wrought or cast.

A common type of phosphor bronze has the following composition as per Indian standards.

- Copper is 93.6%, tin is 9%, and phosphorus is 0.1 to 0.3%.
- The alloy possesses good wearing qualities and high elasticity.
- The alloy is resistant to saltwater corrosion.

Applications:

- Cast phosphor bronze is utilized for production of bearings and gears.
- Bearings of bronze contain 10% tin and small addition of lead.

- This is also used in making gears, nuts, for machine lead screws, springs, pump parts, linings and many other such applications.

Gun metal

Composition:

- Gun metal contains *2% zinc, 10% tin and 88% copper.*

Properties:

- Sometimes very small amount of lead is also added to improve castability and machinability.
- The presence of zinc improve its fluidity.

Applications:

- This bronze is used for bearing bushes, glands, pump valves and boiler fittings, etc.

Silicon bronze

Composition:

- Silicon bronze has an average composition of 3% silicon, 1% manganese and rest copper.

Properties:

- It possesses good general corrosion resistance of copper with higher strength and toughness.
- It can be cast rolled, stamped, forged and pressed either hot or cold and can be welded by all the usual methods.

Applications:

- Silicon bronze is widely utilized for parts of boilers, tanks, stoves or where high strength as well as corrosion resistance is required.

Bell metal

Composition:

- This alloy contains *20 to 21% tin* and rest copper.

Properties:

- It is hard and resistant to surface wear.
- It can be readily cast

Applications:

- generally utilized for casting bells, gongs and utensils, etc.

Manganese Bronze

Composition:

It contains 55 to 60% copper, 40% zinc, with 3.5% manganese.

Properties:

- This alloy is highly resistant to corrosion.
- It is stronger and harder than phosphor bronze. It has poor response to cold working but can be easily hot worked.

Applications:

- It is generally utilized for producing bushes, plungers, feed pumps and rods, etc.
- Worm gears are frequently made of manganese bronze.

Muntz Metal

Composition:

- 60% copper and 40% zinc.
- Sometimes a small quantity of lead is also added.

Properties:

- This alloy is stronger, harder and more ductile than normal brass.
- While hot working between 700°C to 750, it responds excellently for process but does not respond to cold working.

Applications:

- This alloy is utilized for a wide variety of small components of machines, bolts, rods, tubes, electrical equipment as well as ordnance works.
- It is widely employed in producing such articles which are required to resist wear.

<u>Titanium and its alloys</u>

Titanium is widely distributed throughout the whole universe such as stars and interstellar dust. After Al, Fe and Mg, titanium is the fourth most abundant of structural metals and is the ninth most abundant element on the earth.

Titanium exists in most minerals such as **ilmenite** ($FeTiO_3$); **rutile** (TiO_2); **arizonite** ($Fe_2Ti_3O_9$); **perovskite** ($CaTiO_3$) and **titanite** ($CaTiSiO_5$).

Titanium offers a unique property spectrum owing to the combination of **high strength, stiffness, toughness, low density, and good corrosion resistance**. These properties are enabled by a wide variety of titanium alloys ranging from applications at very low to elevated temperatures. This spectrum enables weight savings in multiple key **aerospace applications** and other high-performance applications in the medical, chemcial and car industry.

The atomic weight of titanium is 47.88. Titanium is elastically stiff (around **115 GPa Young's modulus**), intrinsically strong, lightweight, corrosion resistant and highly abundant in nature. Titanium and its alloys possess tensile strengths ranging between 210-1380 MPa, which approaches the strengths found in many complex steels.

Titanium is a low-density element (approximately 60% of the density of iron) that can be strengthened by solute alloying, second phase hardening, and plastic deformation. Titanium is nonmagnetic and has good heat-transfer properties. Its coefficient of thermal expansion is somewhat lower than that of steels and less than half that of aluminum.

One of its important properties is its high melting point of 1725°C, i.e. nearly 200°C above that of steel and more than 1000°C above that of aluminum.

Titanium can be passivated, and thereby its alloys exhibit a high degree of immunity to attack by most mineral acids and chlorides. Titanium is nontoxic and generally biologically compatible with human tissues, minerals and bones. The excellent corrosion resistance and biocompatibility coupled with excellent strength make titanium and its alloys useful in chemical and petrochemical applications, marine environments, and biomaterial applications.

Alloying of Titanium

Ti-alloys are hence classified into three types, namely, α-alloys, β -alloys and α - β -alloys. These alloys are stabilized by solute elements that have strong effect on the transformation temperature. Elements increasing the transformation temperature are referred to as α -stabilizers, while elements that decrease it, thereby increasing the β- phase region, are referred as the β -stabilizers. The most common α -stabilizers are Al, O, C and N, whereas many heavy and high melting transition elements such as particularly Fe, Cr, Nb, Mo, Ta, V, and W are β -stabilizers. For β -stabilizers, a minimum concentration β is required to fully stabilize the β -phase following a quench from the high temperature.

Most titanium alloys used in structural applications in the aerospace, energy and chemical industries consist of two-phase mixtures of α and β phases combined in different morphologies and relative volume fractions. Two-phase α + β alloys offer a wide range of combinations of strength, toughness and high temperature properties up to ~600°C. Solid state phase transformations are the main factors determining the functional characteristics of these alloys. Manipulation of the mechanical properties depends on the effect of alloying additions and thermo-mechanical processing on the stability and physical and mechanical behavior of the two phases, both individually and in a variety of microstructural combinations.

Applications of Titanium Alloys

Aerospace applications

By combining light weight with high strength, titanium helps to reinforce airframes and enable higher performance in jet engines. In the case of the space shuttle, titanium is used for many critical parts, including the exterior paneling of the fuel tank and wing parts.

Aircraft and Jet Engines

Aircraft use a large amount of titanium alloy because it is light and extremely strong at high temperatures. Titanium is used to strengthen the frame structure and contributes towards the technical advancement of jet engines.

Space craft

Titanium alloy, which has high corrosion resistance, high specific strength, and good heat resistance, is used for different spacecraft parts including outer fuel tank sheathing and wings.

Chemical Industrial Production Plants

LNG plants
Seawater desalination plants
Petroleum refineries
Nuclear power plants

Recognized for total cost merits provided by its durability over an extended period, the adoption of titanium for plant structural and equipment materials is on the rise.

Tanker Trucks

Tanker trucks that carry sodium hypochlorite and sodium chromate use titanium because it is light, resistant to corrosion, and extremely strong.

Heat Exchangers

Titanium is a safe and economical material that is perfect for heat exchangers, which are used in extreme high-temperature and high-pressure conditions.

Biomedical applications

The main benefits of Titanium, enabling it as a primary implant material are:

+ Strength
+ Lightweight
+ Corrosion Resistant
+ Cost-efficient
+ Non-toxic
+ Biocompatible (non-toxic AND not rejected by the body)
+ Long-lasting
+ Non-ferromagnetic
+ Osseointegrated (the joining of bone with artificial implant)
+ Long range availability
+ Flexibility and elasticity rivals that of human bone