Materials for Engineering [20ME11T]

Unit IV- NON METALLIC AND ADVANCED MATERIALS
Notes

4.1 Polymeric materials

The word "Polymer" is derived from two Greek words, 'Poly' that means many (numerous) and 'Mer' which means units. In basic terms, a polymer is a long-chain molecule that is composed of a large number of *repeating units* of identical structure. These identical structures, we understand as a unit made up of two or more molecules, join together to form a long chain.

Many common classes of polymers are composed of hydrocarbons, compounds of carbon and hydrogen. These polymers are specifically made of carbon atoms bonded together, one to the next, into long chains that are called the backbone of the polymer.

4.1.1 Characteristics of Polymers

Every polymer has very distinct characteristics, but most polymers have the following general attributes.

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

4.1.2 Types of Polymers

	Basis of Classification		Polymer Type
a)	Origin	-	Natural, Semi synthetic, Synthetic
b)	Thermal Response	-	Thermoplastic, Thermosetting
c)	Mode of formation	-	Addition, Condensation
d)	Line structure	-	Linear, Branched, Cross-linked
e)	Physical Properties	-	Rubber, Plastic, Fibers
f)	Crystallinity	-	Non – crystalline(amorphous), Semi-crystalline, Crystalline
g)	Polarity	-	Polar, Non polar
h)	Chain	-	Hetro, Homo-chain

4.1.3 Uses of Polymers

Here we will list some of the important uses of polymers in our everyday life.

a) Polypropene finds usage in a broad range of industries such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys, etc.

b) Polystyrene is one of the most common plastic, actively used in the packaging industry. Bottles, toys, containers, trays, disposable glasses and plates, tv cabinets and lids are some of the daily-used products made up of polystyrene. It is also used as an insulator.

c) The most important use of polyvinyl chloride is the manufacture of sewage pipes. It is also used as an insulator in the electric cables.

d) Polyvinyl chloride is used in clothing and furniture and has recently become popular for the construction of doors and windows as well. It is also used in vinyl flooring.

e) Urea-formaldehyde resins are used for making adhesives, moulds, laminated sheets, unbreakable containers, etc.

f) Glyptal is used for making paints, coatings, and lacquers.

g) Bakelite is used for making electrical switches, kitchen products, toys, jewellery, firearms, insulators, computer discs, etc.

4.2 Classification of Polymers on basis of Thermal behavior

All polymers can be divided into two major groups based on their thermal processing behavior.

a) Thermoplastic and b) Thermosetting plastics.

Those polymers that can be heat-softened in order to process into a desired form are called ***Thermoplastics***. e.g., polyethylene, polypropylene and poly-vinyl-chloride.

In comparison,

Thermosets are polymers whose individual chains have been chemically linked by covalent bonds during polymerization or by subsequent chemical or thermal treatment during fabrication. Once formed, these cross linked networks resist heat softening, mechanical deformation, and solvent attack, but cannot be thermally processed. e.g., epoxy, phenol–formaldehyde resins, and unsaturated polyesters

4.2.1Thermo plastics

A thermoplastic is a resin that is solid at room temperature but becomes plastic and soft upon heating

- This is due to crystal melting or by virtue of crossing the glass transition temperature (T_g). Upon processing, usually via injection-moulding or blow-moulding-like processes, thermoplastics take the shape of the mould within which they are poured as melt, and cool to solidify into the desired shape.
- The significant aspect of thermoplastics is their ***reversibility,*** the ability to undergo reheating, melt again, and change shape.
- This allows for additional processing of the same material, even after being prepared as a solid.
- Processes such as extrusion, thermoforming, and injection moulding rely on such resin behavior.
- Some common thermoplastic materials include polyethylene (PE), polycarbonate (PC), and polyvinyl chloride (PVC).

4.2.2Thermosetting plastics

A thermosetting resin, or thermosetting polymer, is generally a liquid material at room temperature which hardens irreversibly upon heating or chemical addition.

- When it is placed in a mould and heated, the thermoset solidifies into the specified shape, but this solidification process includes the formation of certain bonds, called ***cross links,*** that hold the molecules in place and change the basic nature of the material, preventing it from melting. As a result, a thermoset, as opposed to a thermoplastic, cannot return to its initial phase, rendering the process irreversible.
- Thermosets, upon heating, become **set, *fixed in a specific form***. During overheating, thermosets tend to degrade without entering a fluid phase.
- Processes such as compression moulding, resin transfer moulding, and filament winding depend on thermosetting polymer behavior.
- Some common thermosets include epoxy, polyimide, and phenolic.

4.2.3 Properties of Thermoplastics and Thermosetting plastics

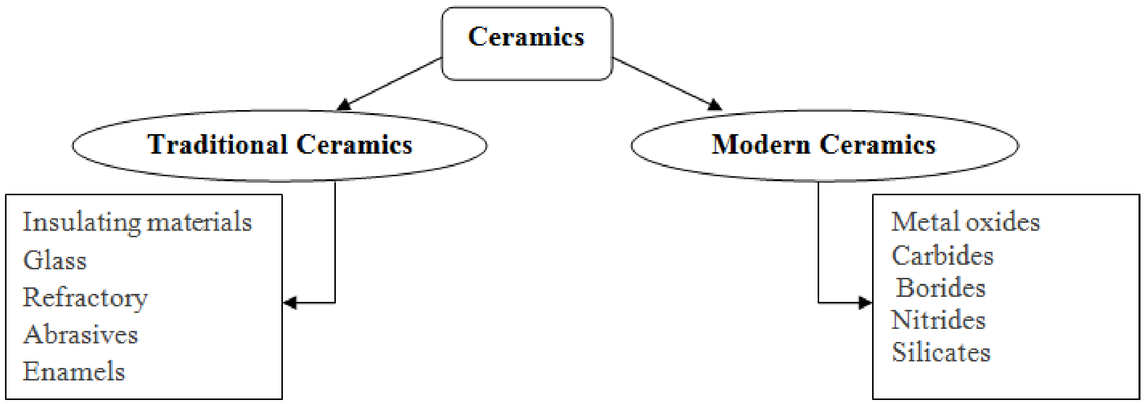
Property	Thermoplastics	Thermosets
Molecular structure	Linear polymer: weak molecular bonds in a straight-chain formation	Network polymers: high level of cross linking with strong chemical molecular bonds
Melting point	Melting point lower than the degradation temperature	Melting point higher than the degradation temperature
Mechanical	Flexible and elastic. High resistance to impact (10x more than thermosets).	Inelastic and brittle. Strong and rigid. Strength comes from cross linking.
Microstructure	Comprised of hard crystalline and elastic amorphous regions in its solid state	Comprised of thermosetting resin and reinforcing fiber in its solid state
Size	Size is expressed by molecular weight	Size is expressed by crosslink density
Recyclability	Recyclable and reusable by the application of heat and/or pressure	Non-recyclable
Chemical resistance	Highly chemical resistant	Heat and chemical resistant
Crack repair	Cracks can be repaired easily	Difficult to repair cracks
Process thermal aspect	Melting thermoplastics is endothermic	Cross linking thermosets is exothermic
Service temperature	Lower continuous use temperature (CUT) than thermosets	Higher CUT than thermoplastics
Solubility	Can dissolve in organic solvents	Do not dissolve in organic solvents

4.2.4 Difference between Thermoplastic and Thermosetting Plastic

Thermoplastic	Thermosetting Plastic
Thermoplastic can be synthesized by the process called addition polymerization.	Thermosetting plastics are synthesized by condensation polymerization.
Thermoplastic is processed by injection moulding, extrusion process, blow moulding, thermoforming process, and rotational moulding.	Thermosetting Plastic is processed by compression moulding, reaction injection moulding.
Thermoplastics have secondary bonds between molecular chains.	Thermosetting plastics have primary bonds between molecular chains and held together by strong cross-links.
Thermoplastics have low melting points and low tensile strength.	Thermosetting plastics have high melting points and tensile strength.
Thermoplastic is lower in molecular weight, compared to thermosetting plastic.	Thermosetting Plastic is high in molecular weight.
Examples for Thermoplastics are. • Polystyrene • Teflon • Acrylic • Nylon	Examples for thermosetting polymers are: • Vulcanized rubber • Bakelite • Polyurethane • Epoxy resin • Vinyl ester resin

4.3 Ceramics

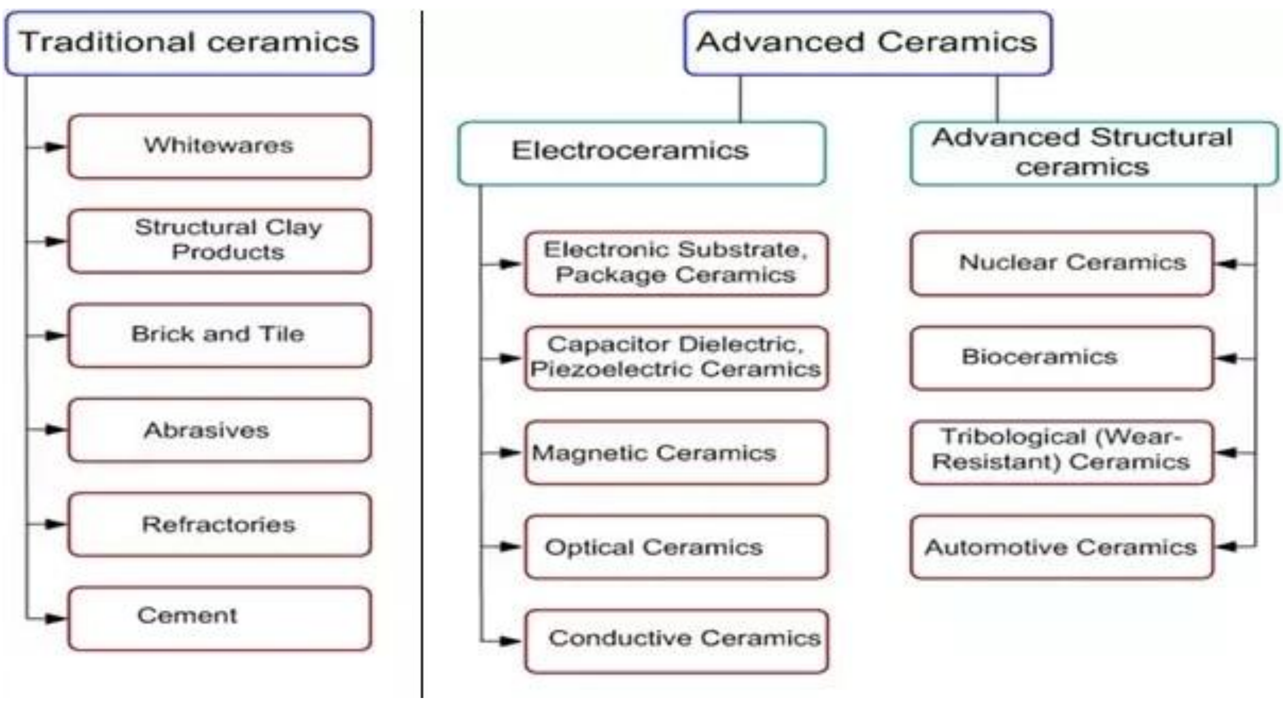
A ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures. In general, they are hard, corrosion-resistant and brittle. The word ceramics is derived from the Greek word *keramos* which means '*potter's clay*'.



Traditional ceramics include insulating materials, glass, refractoriness, abrasives and enamels.

Modern Ceramics can be defined as the compounds of metals and non-metals. They generally have ionic atomic bonding between them.

4.3.1 Types of Ceramics



Advantages of Ceramics

- Most of them have high hardness hence they are used as abrasive powder and cutting tool
- They have high melting point which makes them excellent refractory material
- They are good thermal insulators this is another reason to use them as refractory material
- They are high electric resistivity which makes them suitable to be used an insulator
- They have low mass density which results in lightweight components
- They are generally chemically inert which makes them durable

Disadvantages of Ceramics

- They are brittle in nature
- They have almost zero ductility
- They have poor tensile strength
- The show a wide range in the variation of strength, even for the identical specimens
- They are difficult to shape and machine

4.3.2 Properties of Ceramics

- High hardness
- High melting point
- Good Thermal insulator
- Highly electricity resistance
- Low mass density
- Generally, chemically inert
- Brittle in nature
- Zero ductility
- Low tensile strength

4.3.3 Applications of Ceramics

- They are used in space industry because of their low weight
- They are used as cutting tools
- They are used as refractory materials
- They are used as thermal insulator
- They are used as electrical insulator

4.4 Composite materials

A composite is structural materials that consist of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc.

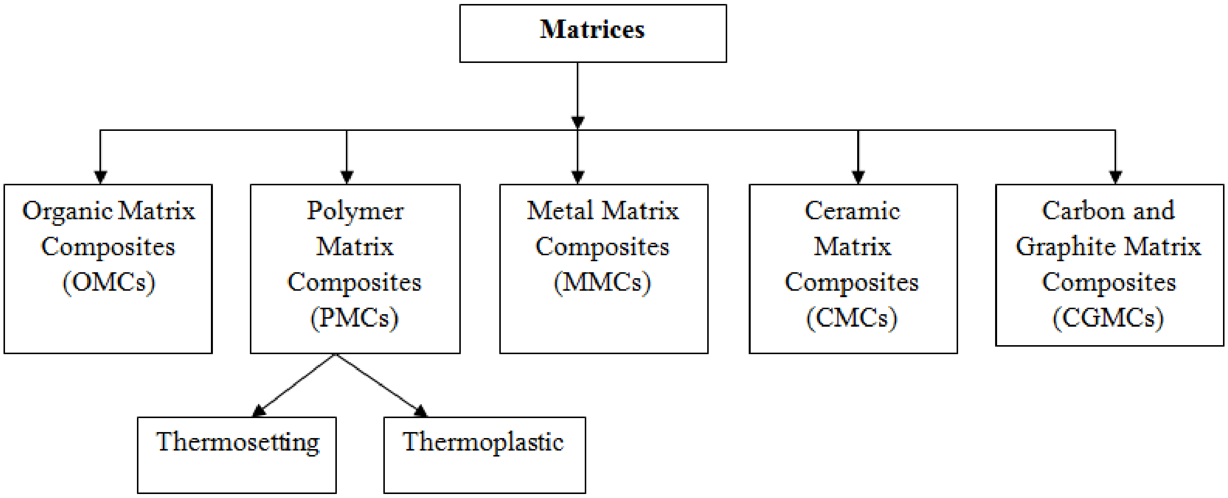
A composite material is a combination of two materials with different physical and chemical properties. When they are combined they create a material which is specialized to do a certain job. For example a material is required to be stronger, lighter or resistant to electricity. They can also improve strength and stiffness.

Some common composite materials include:

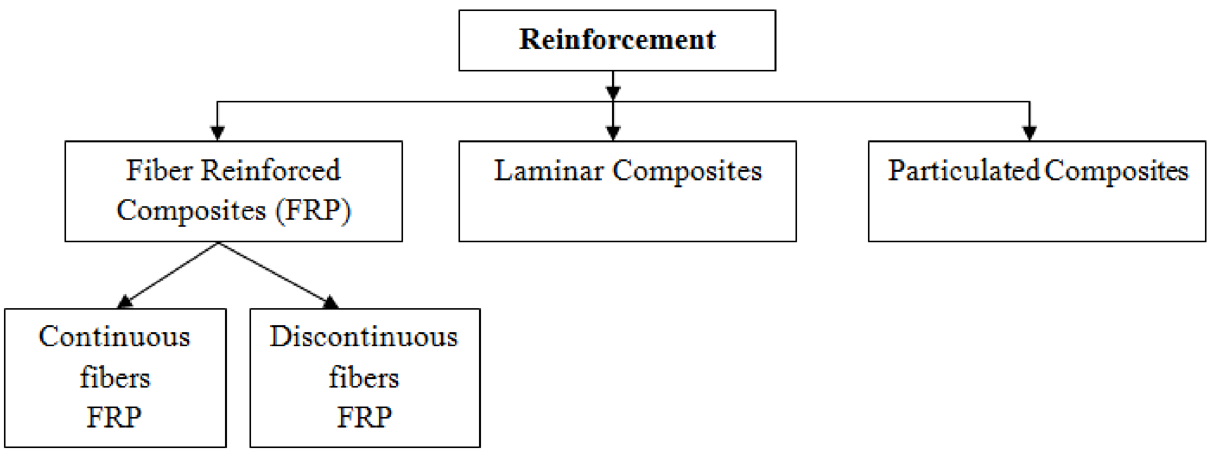
- **Ceramic matrix composite:** Ceramic spread out in a ceramic matrix. These are better than normal ceramics as they are thermal shock and fracture resistant
- **Metal matrix composite**: A metal spread throughout a matrix
- **Reinforced concrete**: Concrete strengthened by a material with high tensile strength such as steel reinforcing bars
- **Glass fiber reinforced concrete**: Concrete which is poured into a glass fiber structure with high zirconia content
- **Engineered wood** or **Plywood**: Engineered wood by gluing many thin layers of wood together at different angles
- **Fiberglass**: Glass fiber combined with a plastic which is relatively inexpensive and flexible

4.4.1 Classification of Composite Materials

a) Composite Materials Based on Matrices



b) Composite Materials Based on Reinforcement



Composite materials are commonly classified at following two distinct levels:

• The first level of classification is usually made with respect to the matrix constituent like organic, polymer, metals, ceramic, carbon and graphite.

• The second level of classification refers to the reinforcement form - fiber reinforced composites, laminar composites and particulate composites. Fiber Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibers.

• Fiber Reinforced Composites are composed of fibers embedded in matrix material. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length. On the other hand, when the length of the fiber is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fiber reinforced. Fibers are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibers must be supported to keep individual fibers from bending and buckling.

• Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

4.4.2 Properties of Composite

a) **Particle Reinforcement**

In general, particle reinforcement is strengthening the composites less than fiber reinforcement. It is used to enhance the stiffness of the composites while increasing the strength and the toughness.

b) **Continuous Fiber Reinforcement**

In general, continuous fiber reinforcement is implemented by incorporating a fiber as the strong phase into a weak phase, matrix. The reason for the popularity of fiber usage is materials with extraordinary strength can be obtained in their fiber form. Non-metallic fibers are usually showing a very high strength to density ratio compared to metal fibers because of the covalent nature of their bonds.

c) **The Effect of Fiber Orientation**

The change is in the fiber orientation can affect the mechanical properties of the fiber-reinforced composites especially the tensile strength.

d) **Fiber volume content:** The fiber volume content in composite laminates is a principal performance-dependent parameter. Taking a cross section from a unidirectional laminate specimen vertical to the fiber axis, the fiber accompanied areas are accumulated and the ratio to the total cross-sectional area under a microscope is calculated. This ratio represents the fiber volume content of the specimen.

e) **Resin volume content**: The resin volume content in laminates is of interest. Because the void content in laminates should be limited to about 1% (<2%), the sum of the resin volume content Vm plus the fiber volume content will be almost 1. Therefore, the value of the resin volume content also represents the fiber volume content in the same specimen.

f) **Void content**: The impurity or inclusion content in a laminate is the sum of entrapped air, gas, or cavities, and this is used as a composite quality control parameter. It can be determined by observing the surface view of a cross section under a microscope or by converting the constituent material mass to volume.

g) **Glass transition temperature**: When polymer matrixes in laminates are heated to a specific temperature at a given rate, there will be a dramatic turndown point on the temperature-modulus curve. At this temperature, the polymer matrix will undergo a transition from a solid glassy state to a flexible elastic state, and a series of changes will occur in its physical parameters. This phenomenon is referred to as the glass transition

h) **Water or moisture absorption**: The laminate weight will increase by about 1– 1.2% after saturation by moisture absorption.

i) **Linear expansion coefficient:** The linear expansion coefficients of laminates are orthotropic. For carbon /epoxy, $\alpha_1 \approx 0,\ \alpha_2 \approx 22.$

j) **Moisture expansion coefficient**: The moisture expansion coefficients of laminates are also orthotropic. For carbon/epoxy, $\beta_1 \approx 0,\ \beta_2 \approx 0.6.$

4.4.3 Applications of Composites:

a) These composites are ideal for applications such as lightweight, rigid, deployable structures; rapid manufacturing; and dynamic reinforcement.

b) Vibration damping, and radiation shielding applications

c) Special type of composite armor used in military applications.

d) Another class of composite materials involve woven fabric composite consisting of longitudinal and transverse laced yarns. Woven fabric composites are flexible as they are in form of fabric.

e) Wood is a naturally occurring composite comprising cellulose fiber which includes a wide variety of different products such as wood fiber board, plywood, oriented strand board, wood plastic composite (recycled wood fiber in polyethylene matrix),

f) Particulate composites have particle as filler material dispersed in matrix, which may be nonmetal, such as glass, epoxy. Automobile tire is an example of particulate composite

g) Carbon composite is a key material in today's launch vehicles and heat shields for the re-entry phase of spacecraft. It is widely used in solar panel substrates, antenna reflectors and yokes of spacecraft.

h) Pipes and fittings for various purposes like transportation of potable water, fire-fighting, irrigation, seawater, desalinated water, chemical and industrial waste, and sewage are now manufactured in glass reinforced plastics.

i) The wings of wind turbines, in growing sizes in the order of 50 m length are fabricated in composites

4.5 Advanced engineering materials

New materials and the advancement of materials play a crucial role in emerging Engineering technologies that have been the major growth areas for the economy. Advancements in solar power, Medical and many more can all be achieved from new Materials and their utilization for the advancement.

- Application of Polymers
- Advanced Crystallography
- Nano-Technology
- Studies on Basic Materials and Properties
- Studies in Archaeology
- Medical field
- Textile Industry
- Petroleum Industry

Example 1: Biomaterials

Biomaterials are natural or synthetic, alive or lifeless, and which are usually made of multiple components that interact with biological systems. Biomaterials are used in medical applications to augment or replace a natural function. Biomaterials can be derived from nature or can be synthesized in the laboratory using different chemical approaches utilizing polymers, metallic components, ceramics or composite materials. Biomaterials should be compatible with the body. Biopolymers are polymers which are produced by living organisms. Proteins and peptides, Cellulose and starch, and DNA and RNA are all examples of biopolymers, in which the mono-metric units are amino acids, sugars, and nucleotides respectively.

- Joint replacements and artificial ligaments and tendons
- Bone plates and Bone cement
- Intraocular lenses (IOLs) for eye surgery
- Dental implants for tooth fixation
- Blood vessel prostheses, Heart valves and Stents
- Skin repair devices (artificial tissue)
- Cochlear replacements
- Drug delivery mechanisms
- Nerve conduits
- Surgical sutures, clips, Surgical mesh and staples for wound closure
- Pins and screws for fracture stabilization

Example 2: a) Nano Materials in Medicine and Diagnosis

The use of Nano Materials in medicine emphasizes many useful possibilities. Nano Materials in medicine involves applications of nano-particles which are currently under development and also longer-range research which involves the use of Nano-robots to make repairs at the cellular level. Nano medicine is the major advanced outcome in the field of medicine. The major applications of Nano Materials in medicine are Drug Delivery, Therapy, Anti-Microbial Techniques, and Cell Repair.

b) Nano Materials in electronics and Energy Production

Increasing capabilities of electronic devices can be increased while reducing their weight and power consumption using Nano Materials. Nano crystals deposited on plastic sheets form flexible electronic circuits. Nano magnets are used as switches. Silver nano-particle ink used to print prototype circuit boards using standard inkjet printers. Bucky balls are used to build dense, low power memory devices Efficient and cost-effective ways of energy production using Nano Materials are being explored. Various explorations are producing high-efficiency light bulbs, Generating electricity from waste heat using nano-tubes and many other efficient techniques are produced using Nano Materials.

- Silicon Nano photonics
- Nano-tube transistors
- Copper nano-particles
- Magnetic quantum dots
- Spintronic semiconductor devices
- Plasmonic cavities
- Nano Materials in Solar Cells

Example 3: Smart Materials

Smart Materials are materials that respond to changes in their environment and then undergo a material property change. These property changes can be leveraged to create an actuator or a sensor from the materials without any additional control or electronics required.

Smart material is a compound which has a visible and tangible reaction to external stimuli by undergoing a material property change. These stimuli can include chemical, electrical, mechanical, thermal, and magnetic changes in the environment. The response to these changes is dependent on the material.

Changes can include paint that self-heals when it is scratched, coatings which change color in response to the presence of chemicals, materials that have a “shape memory” when presented with a magnetic field, and metals that change shape at specific temperatures. In a simple sense, smart materials are a robust, solid-state sensor for the environment around them. It is up to the designer or engineer to use these sensors to the best effect in specific applications.

- Smart Materials act simultaneously as actuators and sensors
- These perform controlled mechanical actions without any external mechanism
- They are adaptive with the environmental condition
- Create the potential for new function development within applications.

Types of Smart Materials

Piezoelectric:

Piezoelectric materials convert electrical energy to mechanical energy, and vice versa. They offer a wide range of utility and can be used as actuators (provide a voltage to create motion), sensors, such as many accelerometers, and energy harvesters since the charge generated from motion can be harvested and stored.

Shape Memory Alloys:

The most commonly available Shape Memory Alloy is Nitinol, which was originally developed by the Naval Ordinance Laboratory. SMA's have the ability to change phase as a function of temperature, and in that process generate a force or motion. They are capable of relatively high energy but move slowly. Typically applications include morphing structures, thermal triggers, and some high strain energy absorbing applications.

Magnetostrictive:

Similar to piezoelectric materials that respond to changes in electrical fields, this class of materials responds to changes in magnetic fields and can perform as an actuator, or sensor if deformed. While they can work well, they exhibit a large hysteresis which must be compensated when using the material in sensor applications.

Shape Memory Polymers:

Shape Memory Polymers (SMP) is similar to Shape Memory Alloys except the obvious fact they are made from a polymer matrix. They possess much greater recoverable strains than the alloys, but typically under lower forces. Morphing structures has been the area of greatest use to date for SMP's.

Hydrogels:

Hydrogels can be tailored to absorb and hold water, or other liquids, under certain environmental conditions. Hydrogels have been around for a long time, specifically in disposable diapers. A key feature however are the gels can be tailored chemically to respond to different stimuli.

Electro-active Polymers:

There are many forms of electro-active polymers and many are still being refined. They have great potential as the flexibility of how they can be used provide advantages over some of the metals and ceramics mentioned above. Most typically applications include energy harvesting and sensing.

Bi-Component Fibers:

Adaptive thermal insulation can enable smart clothing that can change its thermal properties based on the environment.

4.6 Designation and coding of important non-metallic materials as per BIS

Bureau of India Standards (BIS) is a product certification scheme aims at providing Third Party Guarantee of quality, safety and reliability of products in India market place (mandatory beginning July 2013).

Products applied for BIS certification must conform to Indian (IS) standards and/or other additional technical requirements First step is to determine if your product falls under mandatory BIS category Using "Tariff Code" or "HS Code" is the most efficient way to find out if a product falls under mandatory BIS certification.

Examples for Rubber

IS 7466 : 1994	Rubber Gaskets for Pressure Cookers
IS 15627	Automotive vehicles– Pneumatic tyres for two and three-wheeled motor vehicles
IS 9573(Part 2):2017	Rubber Hose for Liquefied Petroleum Gas (LPG) - Specification Part 2- Domestic and Commercial Application.

Examples for Ceramic / Composite

IS 15622 : 2017	PRESSED CERAMIC TILES
IS 16415: 2015	Composite Cement- Specification.

Examples for Plastics

IS 9766:1992	Flexible PVC compounds (first revision)
IS 694	PVC insulated cables for working voltages up to and including 1100V
IS 14543	Packaged Drinking Water (Other than Packaged Natural Mineral Water)
IS 1293 : 2005	Plugs and socket-outlets of Rated Voltage up to and including 250 Volts and Rated current up to and including 16 amperes
IS 3854	Switches for domestic and similar purpose

Examples for other Materials

IS 2835 : 1987	Flat Transparent Sheet Glass.
IS 4151: 2015	Helmet for riders of Two Wheeler Motor Vehicles