MATERIAL SCIENCE

3rd Sem Mechanical.

MODULE-4 - OTHER MATERIALS, MATERIAL SELECTION.

Syllabus: CERAMICS: Structure, types, Properties and application of ceramics. Mechanical / Electrical behaviour & Processing of ceramics.

PLASTICS: Various types of polymers/plastics & their application. Mechanical behaviours and processing of plastics, Failure of plastics.

OTHER MATERIALS:- Brief description of other materials such as optical and thermal materials, smart materials - fibre optic materials, piezo electrics, shape memory alloys:- Shape memory alloys - Nitinol, superelasticity. Biological applications of smart materials - materials used as implants in human body. Selection of materials; Performance of materials in service, Residual life assessment - use of non destructive testing. Economics, Environment & Sustainability.

CERAMICS:-

Definition - Ceramic materials are inorganic, non metallic materials that consist of metallic and non metallic elements bonded together primarily by ionic and/or covalent bonds.

The properties of ceramic material varies greatly due to the difference in bonding. But in general ceramic materials are hard & brittle with less toughness & ductility. They are also good thermal & electrical insulators & possess high melting temperatures & chemical stability because of stability of their strong bonds.

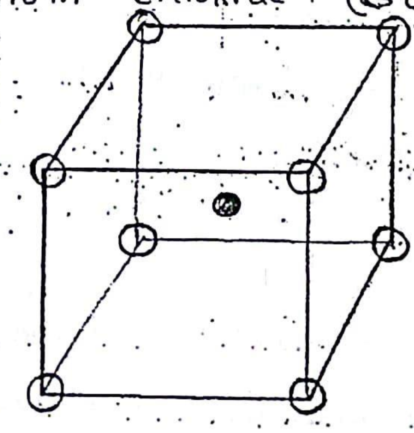
STRUCTURE :-

Like all other materials, the properties of ceramics are also dictated by its crystal structure, i.e., type of atoms present, type of bonding b/w the atoms and the way the atoms are packed together.

The bondings in ceramic material is either ionic or covalent or combination of ionic and covalent. The strength of ionic bond depends on the size of the charge on each ion and on the radius of each ion, whereas the strength of the covalent bond depends on the number of electrons being shared.

Examples for crystal structure in ceramics

A- Cesium chloride (CsCl) crystal structure:



The cesium chloride (CsCl) is basically ionic bonded ceramic material consisting of equal number of Cs^+ & Cl^- ions. The radius ratio for CsCl is 0.94, cubic coordination number = 8, i.e., 8 chloride ions surrounds a central cesium ion for the CsCl unit cell.

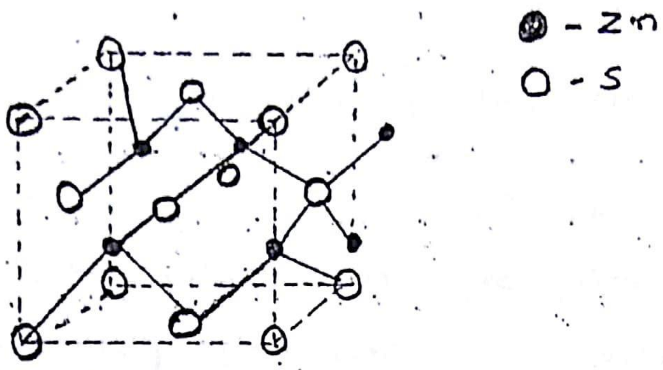
O - Chloride ion.
● - cesium ion.

For ceramic materials, where it is dominated by ionic bonds, the crystal structure is defined by,

→ Magnitude of electrical charge on each ion.

→ Relative sizes of the cations & anions.

* Zinc blende Structure (ZnS)



Zinc blende Structure [Both Dominated by covalent bonds]

The zinc blende structure has the chemical formula ZnS and the unitcell is as shown in the fig. above. The unit cell has four zinc and four sulphur atoms. Each Zn or S atom has a co-ordination number of 4 and is tetrahedrally covalently bonded to other atoms.

Types, Properties and application of ceramics :-

CERAMIC MATERIALS

- Clay Products
  - Structural Clay Products
  - white wares
- Glasses
  - Glasses
  - Glass ceramics
- Refractories
  - Fire clay
  - Silica
  - Alumina basic magnesia
  - Special (Alumina Beryllia Zirconia Mullite)
- Cements
- Abrasives
- Advanced ceramics

1. Clay Products :- Clay is one of the most widely ceramic raw material, which can be used as mined without any upgrading of Quality.

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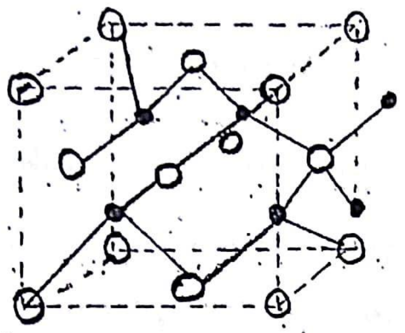

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1. Clay Products:- Clay is one of the most widely ceramic raw material, which can be used as mined without any upgrading of quality.

Clay based products are categorized as

(i) White wares - The white ware ceramics becomes white after high temperature firing.

Applications :- porcelain, pottery, tableware, china & plumbing fixtures.

(ii). Sand clay products :- These products are made from common clay by using soft-mud process, salt glazing.

Applications :- Building bricks, tiles, sewage pipes & flower pots.

2. Glasses :- Glass is an amorphous, hard, brittle & transparent material which is obtained by fusing a mixture of a number of metallic silicates, commonly sodium, potassium, calcium boron etc.;

Types of glasses

1.a – Toughened glass

1.b – Laminated glass

1.c – Foam or cellular glass.

2. glass ceramics

1.a - Toughened glass :- It is made by dipping still hot articles in an oil bath so that the outer layers of the article to shrink and acquire state of compression while inner layers are in state of tension.

Applications :- window shields in moving vehicles, furnaces etc.;

1.b - Laminated glass :- It is made by pressing or bonding together two or more sheets of glass. They are shatter proof, shock proof & can withstand changes in temperatures.

Applications :- Bullet proof glass, safety glass in aircrafts, helicopters, submarines etc.;

1.c. Foam glass :- It is made by heating a mixture of pulverized glass and a foaming agent.

Applications :- Used as insulating materials.

2.a. Glass ceramics :- These are the most sophisticated ceramic materials. They combine the nature of crystalline ceramics with glass. They possess good mechanical & thermal shock resistance, low co-efficient of thermal expansion, high thermal conductivity.

Applications :- kitchen ware, table ware, heat exchangers & regenerators.

3. REFRACTORIES :- Refractory are ceramic material that can withstand high temperature without suffering a deformation. On the basis of composition of refractory ceramics, they are classified as fire clay, silica, basic and special refractories.

a. Fire clay refractories :- Fire clay bricks are made from high purity fire clays, silica & Alumina mixtures [55% SiO_2 & 35% Al_2O_3 to 55% Al_2O_3 & 40% SiO_2].

Applications :- Furnace lining.

b. Silica refractories :- Silica is the major ingredient in the silica refractories. They can withstand high temperature as high as 1800°C.

Applications :- Roof of steel & glass making furnaces, lining of acid convertors & containment vessels etc.

* Basic Refractories :- These refractories are rich in Magnesia. They also contain calcium, chromium & iron compounds. They possess good crushing strength, resistance to attack by slag.
Applications :- lining of basic convertors, Reverberatory furnaces for smelting lead, copper, antimony ores etc.,

* Special Refractories :- Special refractories are ceramic materials made from beryllia, zirconia, carbide compounds in addition to carbon & graphite.
Applications :- Beryllia refractories are used as moderator in nuclear reactors, Zirconia refractories are used in high frequency electric furnaces. Carbon & graphite refractories are used as materials for construction of electrodes, linings of atomic reactors, chemically resistant furnaces.

4. CEMENTS :- The characteristic feature of the cement is that when mixed with water, they form a paste that subsequently sets & hardens. The cement forms a bonding phase that chemically binds particulate aggregate into a single cohesive structure. Cement is produced by a process called Calcination.
Applications :- Largely used in civil engg construction.

5. ABRASIVES :- Abrasive ceramics are used to grind, cut or wear away other materials which are necessarily softer. Abrasive ceramics material includes expensive material like natural & synthetic diamonds & other materials like silicon carbide, tungsten carbide, aluminium oxide & silica.

*. Electrical behaviour of ceramics

Ceramics are probably the best known electrical insulators. They are also known as piezoelectrics that can generate an electrical response to the applied mechanical forces or vice versa. Ceramic materials because of its dielectric properties finds applications in personal computers, electronic devices etc., They are widely used in capacitors.

PROCESSING OF CERAMICS:

Processing of ceramics cannot be formed by Rolling, extrusion or drawing because of their inherent brittleness. Their high Melting temperature also add restrictions on the use of casting techniques. Processing of ceramics can takes place through Powder metallurgy (PM) techniques.

The basic steps in the processing of ceramics by agglomeration of particles are

*. Material preparation
* Forming or casting.
* Thermal treatments by drying and firing.

*. Material preparation:- Most ceramic products are made by the agglomeration of particles. The raw materials for these products vary depending on the required properties of the finished product. The particles & other ingredients such as binders & lubricants may be blended wet or dry. Sometimes wet & dry

Applications!- Abrasive powders are coated on some type of paper or cloth, loose abrasive grains are used for grinding, lapping & polishing wheels.

6. ADVANCED CERAMICS!- Advanced ceramics are just beginning to be used in applications ranging from Automobile I.C. engines to gas turbine engines. Advanced ceramics material includes silicon carbide, silicon nitride, zirconia, Alumina, Sapphire, Tungsten carbide etc.,

MECHANICAL & ELECTRICAL BEHAVIOUR OF CERAMICS:-

1. MECHANICAL BEHAVIOUR!- Mechanical behaviour of ceramic materials explains how a material responds to mechanical forces. As a class of ~~ceramic~~ materials, ceramics are relatively brittle. The tensile strength of ceramic materials vary from very low values of less than 0.69 MPa to about 7×10^3 MPa. They also have a large difference b/w their tensile & compressive strengths, with compressive strengths usually being about 5 to 10 times higher than tensile strength.

Many ceramic materials are hard & have low impact resistance due to their ionic-covalent bondings. However, there are many exceptions to these generalizations. For example plasticised clay is a ceramic material that is soft & easily deformable due to weak secondary bonding forces b/w layers of strongly ionic-covalently bonded atoms.

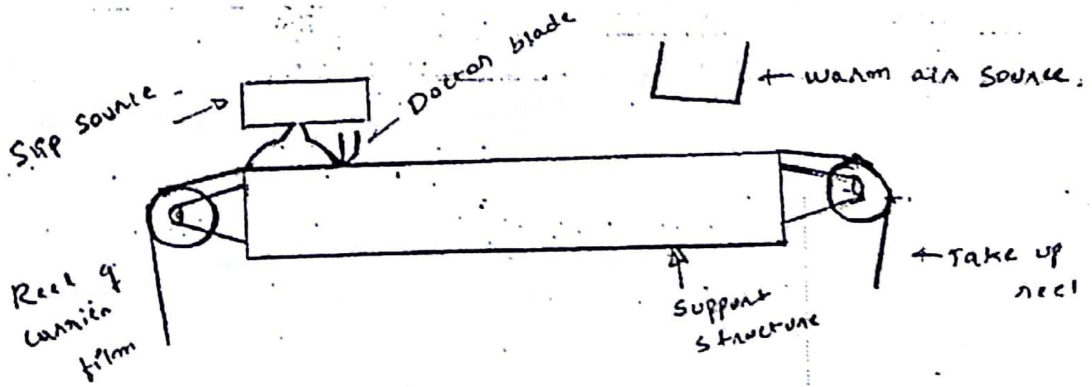
Processing are combined.

*. Forming :- Ceramic products made by the agglomeration of particles may be formed by variety of methods in dry, plastic or liquid conditions. Pressing, slip casting, Tape casting and extrusion are commonly used ceramic forming methods.

(a) Pressing :- Ceramic particulate raw materials can be pressed in the dry, plastic or wet condition into a die to form shaped products.

(b) Slip casting :- In this process, aqueous slurry of ceramic powder is poured into plaster of paris mold. As water begins to move out due to capillary action, thick mass builds along mold wall. It is possible to form solid piece by pouring more slurry.

(c) Tape casting :- Tape casting is also known as doctor blade process used for making thin ceramic tapes. In this, slurry of Ceramic powder + binders + plasticizers is spread over plastic substrate. Tape is then dried using hot air. Later tape is subjected to binder burnout & sintering



(d) Extrusion :- Viscous mixture of ceramic particles, binders & other additives is fed through an extruder where continuous shape of green ceramic is produced. Then the product is dried & sintered.

* Thermal treatments :-

(a) Drying & binder removal :- The purpose of drying ceramics is to remove water from the plastic ceramic body before it is fired at higher temperatures. Then the bulk of organic binders can be removed from ceramic parts by heating in the range of 200 to 300°C.

(b) Sintering :- The process by which small particles of a material are bonded together by solid-state diffusion is called sintering. Sintering results in the transformation of porous compact into a dense, coherent product. In the sintering process, particles are coalesced by solid-state diffusion at very high temperature but below the melting point of the compound being sintered.

PLASTICS

The word plastic comes from greek word Plastikos, meaning "able to be shaped and molded". Plastics can be broadly classified into two major groups on the basis of their chemical structure, i.e., thermoplastics and thermosetting plastics.

Types of Plastics:-

(1) Thermoplastics. (2) Thermosetting plastics.

(1) Thermoplastics :- The material that softens when heated above the melting temperature and becomes hard after cooling is called thermoplastics. Thermoplastics can be reversibly heated melted by heating & solidified by cooling for limited no of cycles without affecting the mechanical properties. In the molten state, they are liquids and in the mushy state they are glassy or partially crystalline. The molecules are joined end to end into a series of long chains, each chain being independent of the other. Above the melting point, all crystalline structure disappears & the long chain becomes randomly scattered.

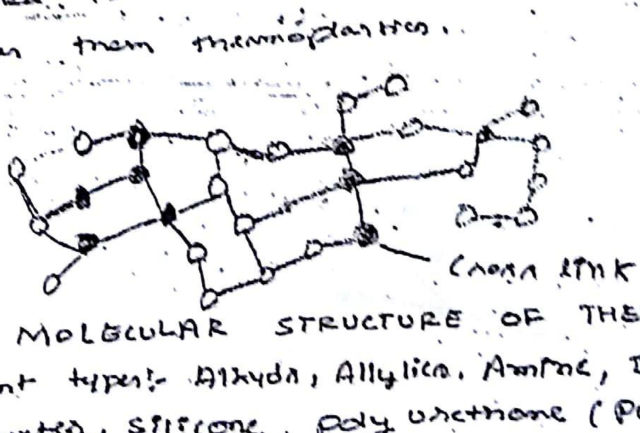
The important properties of thermoplastics are high strength, toughness, better hardness, chemical resistance, durability, transparency & water proofing.

MOLECULAR STRUCTURE OF THERMOPLASTICS

Types of thermoplastics:- Acrylonitrile Butadiene Styrene (ABS), Acetals, Acrylics, cellulosics, polyamide, polycarbonates, Polyethylene (PE) etc.,

Applications:- Dashboards, car trims, toys, phones, handles, electrical products, bearings, gears, rope, hinges, glass frames etc.,

(2) THERMOSETS:- The property of material becoming permanently hard and rigid after cooling when heated above the melting temperature is called thermosets. The solidification process of plastics is known as curing. The transformation from the liquid state to the solid state is irreversible process. The thermosets can't be recycled. During curing, the small molecules are chemically linked together to form a complex interconnected network structures as shown in the fig. below. This cross-linkage prevents the slippage of individual chains; Therefore, the mechanical properties are not temperature dependent as compared to thermoplastics. Hence thermosets are generally stronger than thermoplastics.



MOLECULAR STRUCTURE OF THERMOSETS

Different types:- Alkyds, Allylics, Amino, Bakelite, epoxy, phenolic Polyester, silicone, Poly urethane (PUR), Vinyl ester.

Applications:- High temperature applications like electrical equipments, motor brush holders, printed circuit boards, kitchen utensils, spectacle lenses, encapsulation etc., PROCESSING OF PLASTICS:- There are different molding techniques available for producing plastic components. The selection of a particular technique depends upon the following factors. (1) Type of material (thermoplastic or thermosetting)

(2) If thermoplastic, the temperature at which it becomes soft and deformable

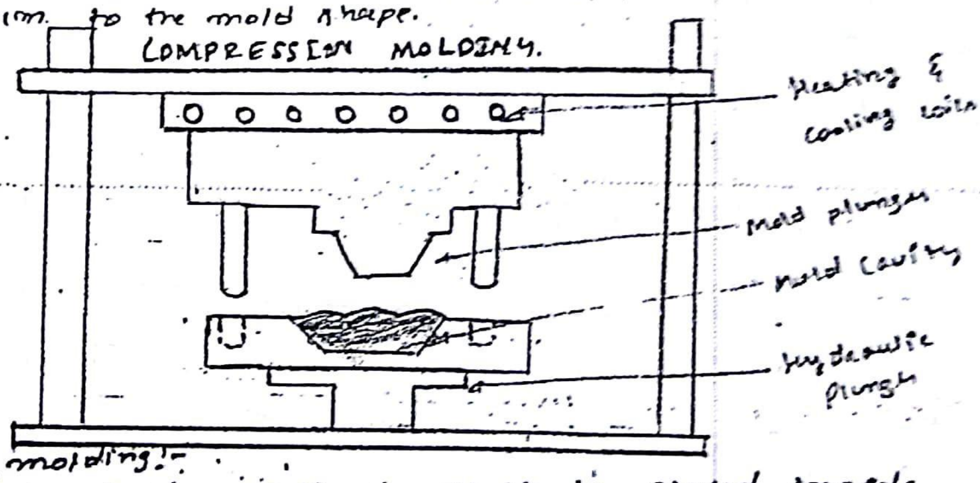
(3) Size and geometry of the finished product.

(4) Stability of the material being formed at atmospheric conditions.

Some of the common molding techniques used include compression molding, transfer molding, injection molding and extrusion molding.

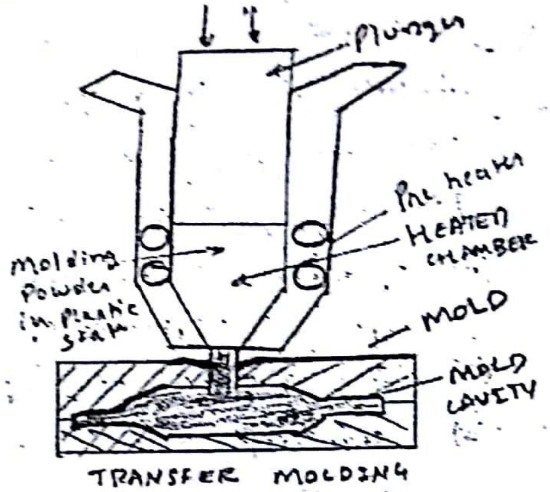
(a) Compression molding:- In compression molding, pre-determined quantity of plastic ingredients in proper proportions is placed at the lower female cavity. Both the mold pieces are heated. The mold is closed, heat & pressure are applied which causes the plastic to become viscous and conform to the mold shape.

COMPRESSION MOLDING.



(b) Transfer molding:-

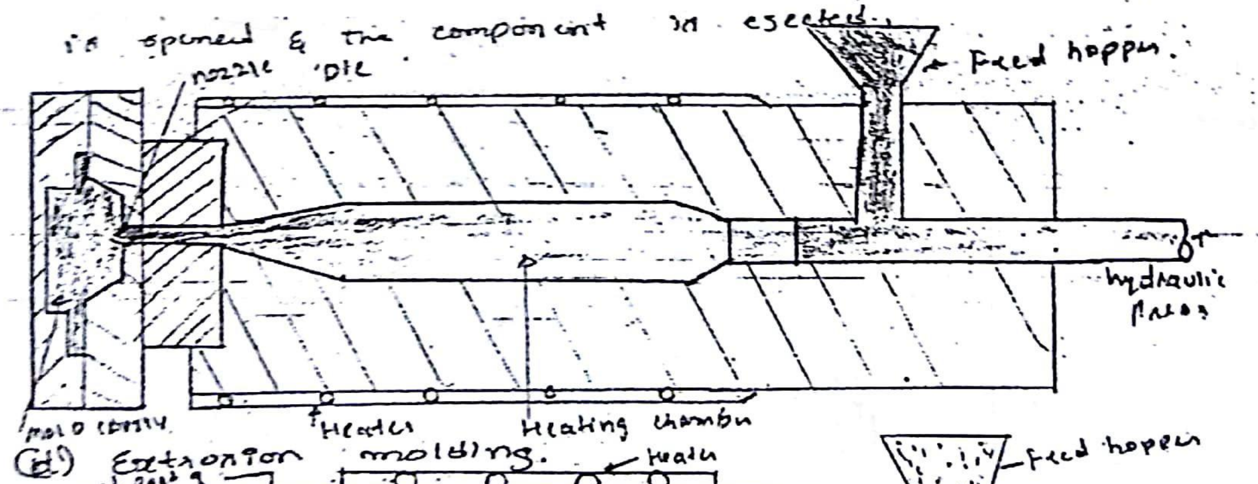
In this method pelletized plastic is placed inside heated chamber maintained at the minimum temperature at which molding powder just begins to become plastic. This plastic material is then injected through an orifice into the mold by a plunger working at higher pressure. Due to very high friction developed at the orifice, the temperature rises to such an extent that molding powder becomes viscous liquid & consequently flows into the mold & cures at that temperature. The molded component is then ejected mechanically.



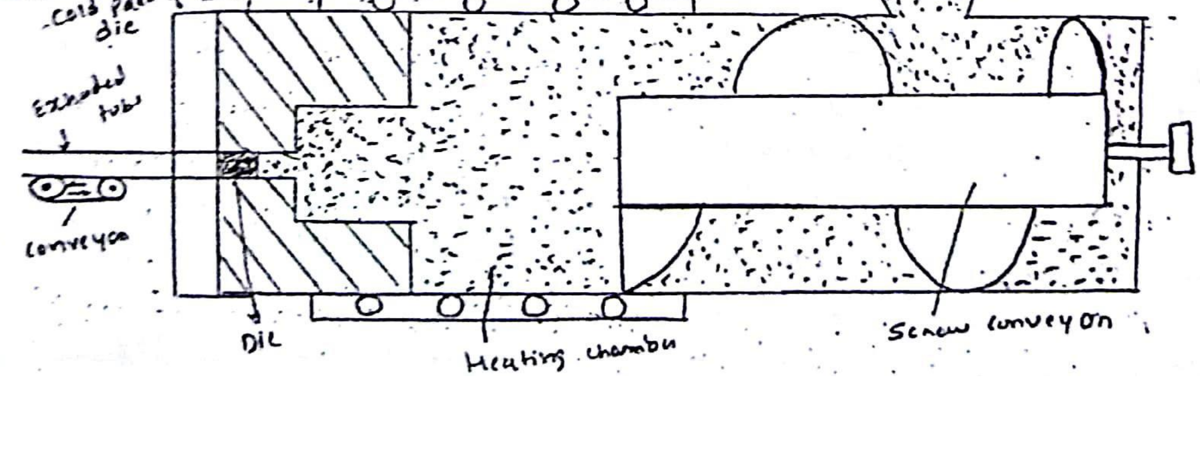
TRANSFER MOLDING

(c) Injection molding:

It is the most widely used technique for molding thermoplastics. The measured amount of pelletized material is fed from a hopper into the heating chamber, where it is melted to form a viscous liquid. The molten plastic is then injected into the mold cavity through nozzle by means of plunger. The pressure is maintained until the plastic is completely solidified. Finally the mold is opened & the component is ejected.



(d) Extrusion molding.



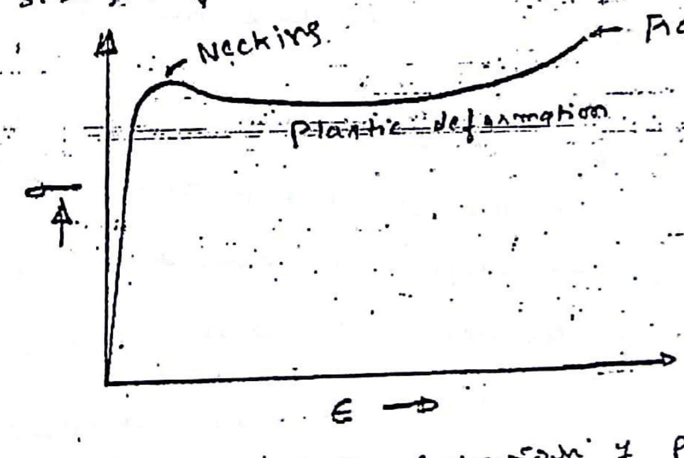
Here in Extrusion moulding, the granulas or pelletized plastic material is fed from a hopper into a chamber through which it is forced by a mechanical screw into a heated die. Extrusion takes place as thin molten plastic is forced through a die orifice. Extruded length is solidified by water spray or by using blower.

MECHANICAL BEHAVIOUR OF PLASTICS:-

Mechanical behaviour of plastics explains how a plastic responds to mechanical forces or loads & what are its mechanical properties.

(1) Hardness:- Plastics are not very hard. The hardness is in the range of 5-50 BHN, of commonly used plastics. Generally thermosets are harder than thermoplastics.

(2) Stress - Strain behaviour:- When the plastic is subjected to uni-axial load, it deforms permanently & ultimately fails as shown in the fig below. Tensile strength of plastics may be in the range of 10 to 100 MPa, whereas Young's modulus ranges from 10 MPa to 400 MPa. Tensile strength of the material decreases with increasing temperature.



Stress - strain behaviour of plastic.

(c) Fatigue behaviour :- Fatigue failure of thermosets is brittle in nature, but in case of thermoplastic failure occurs due to initiation of crack propogation. The flexural fatigue strength of plastics may be in the range of $10^5 - 10^7$ no. of cycles to failure at room temperature (20°C).

FAILURE OF PLASTICS :- Failure of plastic materials can be viewed in 3 different ways i.e., mechanical, thermal and Environmental. Mechanical failure occurs when a product is exposed to external forces that are greater than the product is designed to handle. Thermal failure occurs when a product fails due to exposure to extreme temperatures. Environmental failure occurs when a product is failed to perform desired function when it is subjected to undesirable Environmental conditions, i.e., Exposure to UV rays, extreme weather, pollution etc.,

* Factors to be considered for the failure of plastic material.

→ Material Selection :- It is essential to choose a proper material for a particular application.

→ Design :- A sound design must be done by keeping in mind the working conditions of material. Poor design leads to failure of product.

→ Manufacturing Process :- It is essential to choose a proper manufacturing process depending upon the particular application of Product.

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.

The present section deals with some of those smart materials like optical materials, optical fibres, shape memory alloys, piezo electrics.

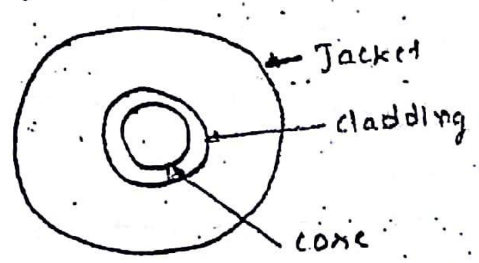
*. **OPTICAL MATERIALS** :- Optical materials are substances that are used to manipulate the flow of light. This can include reflecting, absorbing, focusing or splitting of an optical beam. Let us now discuss the properties of few optical materials.

(a) BK7 :- BK7 is the most common borosilicate crown glasses used for visible and near infrared optics. Its high homogeneity, low bubble and inclusion content & straightforward manufacturability makes it a good choice for transmissive optics. The transmission range for BK7 is 380 – 2100 nm. It is not recommended for temperature sensitive applications, such as precision mirrors. BK7 is relatively hard and possesses good scratch resistant properties.

Fibre optic communication is based on the principle that light in a glass medium can carry more information over longer distances than electrical signals can carry in a copper or co-axial medium or radio frequencies through a wireless medium.

Basically Fibre optics is a applied science & engineering concerned with design and application of optic fibres.

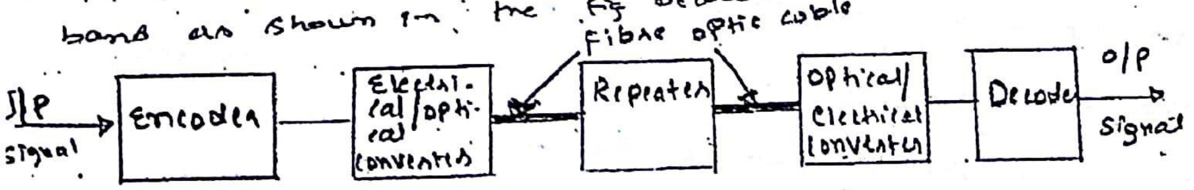
<u>Optical fibres</u>:- An optical fibre is a very thin and flexible medium of cylindrical shape. The three principal sections of fibres are (a) core (b) cladding and (c) the jacket.



The innermost section, core is made up of glass or plastic. The cladding which surrounds the core is also made up of glass or plastic. The jacket is made up of plastic or polymer and other materials which protects the structure from moisture, abrasion, mechanical shocks & other environmental hazards. The optical properties of cladding are different from that jacket.

The actual working structure of the optical fibre is the core. The light entering entering the core at a suitable angle propagates through it, suffering a number of total internal reflections at the core cladding interfaces.

Optical fibres serves as cables for communications to carry optical signals from one end to the other over a wide band as shown in the fig below.



THE COMPONENTS OF OPTICAL FIBRE COMMUNICATION S/M.

Generally high purity silica glass is used as fibre material. Fibre diameters normally range b/w 5 to 100 μm. Fluroaluminate and chalcogenide glasses and sapphire are the materials which can be used as fibre optic material.

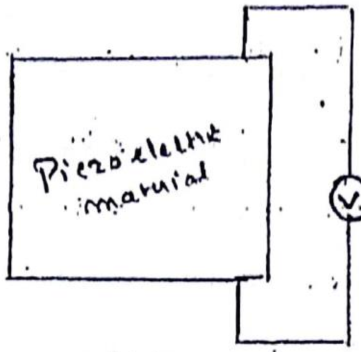
Advantages:- * They can carry more data
* They are less susceptible than metal cables to interference
* They are much thinner & lighter
* Data can be transmitted digitally rather than analogically.

Applications:- Fibre optics is used in myriad applications. Due to its low weight, high bandwidth capacity & immunity to electromagnetic and RF interference, fibre optics is used extensively in avionics on both military & commercial aircraft systems. Applications include radar links, video s/m's, sensor networks & in-flight entertainment s/m's.

PIEZOELECTRIC MATERIALS:-

The piezoelectric effect was discovered in 1880 by the Jacques and Pierre Curie brothers. They found out that when a mechanical stress was applied on crystals such as tourmaline, topaz, Quartz, Rochelle salt and cane sugar, an electrical charges appeared, and this voltage was proportional to the applied stress. So piezoelectric materials are those which produces an electric field when subjected to mechanical force (vice-versa).

Piezo electric effect :- let us consider a sample of Piezo electric material, when this material is subjected to mechanical force like Tensile or compressive, depending upon the applied load, the charge density at the ends of the sample changes, which further changes voltage difference b/w the ends of the sample.



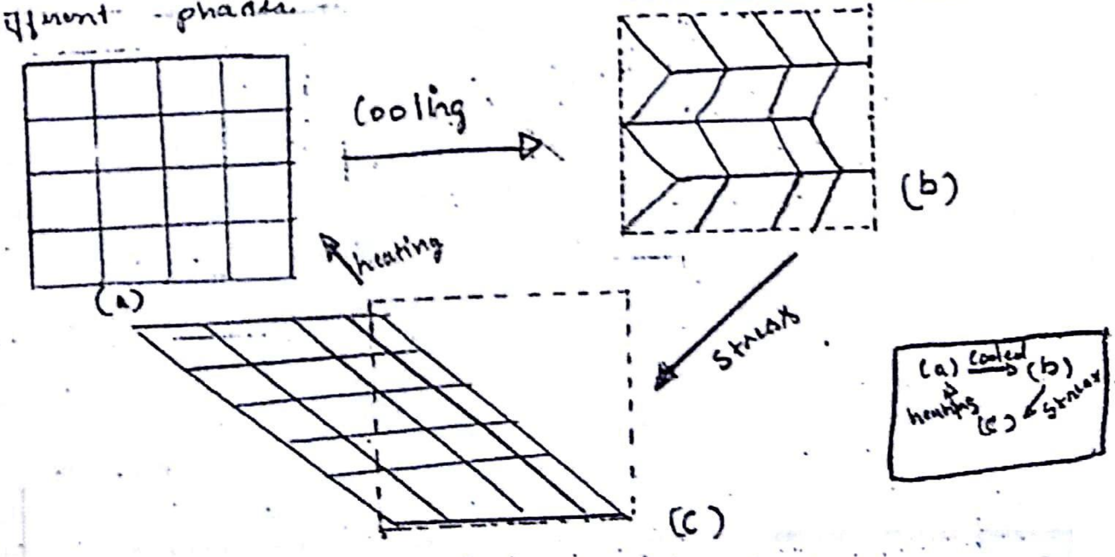
Piezo electric materials :- $BaTiO_3$ (Barium Titanate) is commonly used piezoelectric material. Quartz is also a well known piezoelectric material. Few other piezo electric material includes lead zirconate ($PbZrO_3$), lead titanate ($PbTiO_3$).

Application :- Medical, Aerospace, nuclear, instrumentation fields etc., SONAR, Scanning probe microscope, ultrasonic transducers, quartz clocks etc.,

SHAPE MEMORY ALLOYS (SMA's)

A Swedish physicist Arne Olander discovered the "the Shape Memory Effect" (SME) in gold - cadmium alloy in 1932. The alloy was deformed when cooled & then heated to return to original remembered shape. This effect is called SME, the alloy which shows this effect are called SMA's. So basically "SMA is an alloy that remembers its original shape and this alloy when deformed, can remember & return to its original shape when it is heated."

PRINCIPLE OF OPERATION :- The SME occurs due to a temperature & stress dependent shift in the material's crystalline structure b/w two different phases, Martensite (low temp phase) & austenite (high temp phase). The temp-erature where the phase transformation occurs is called Transformation temperature. Fig below shows a simplified representation of material's crystalline arrangement during different phases.

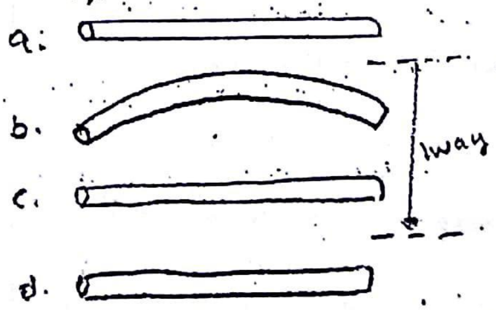


Here when SMA's, in its austenite phase, the structure of the material is symmetrical ie., each grain of the material is cubic with right angles as shown in the fig (a). When this alloy cools, it forms a martensite phase & collapses to a structure with different shape as shown in fig (b). Now if any external stress is applied, the alloy will yield and deform to an alternate state as shown in the fig (c). If this alloy is now heated again above the transformation temperature, the austenite phase will be formed & the structure of the material returns to the original cube form (a).

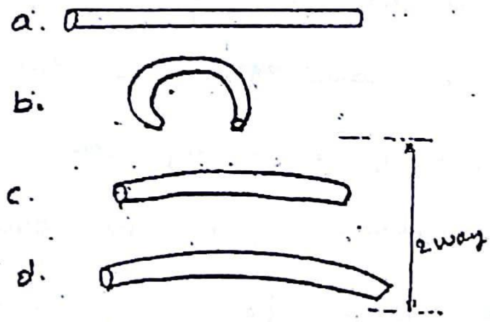
One way and two way memory effect :-

One way memory effect :- If the shape memory alloy (SMA) recovers a specific shape upon heating and retains the same shape even when it is cooled. The effect is known as one way memory effect.

Two way memory effect :- The SMA recovers a specific shape upon heating and then returns to an alternate shape when cooled (below transition temperature). The effect is known as two way memory effect.



one way memory effect



two way memory effect.

NITNOL:- Reriearchenn of U.S. Naval Ondance Laboratory found SME in nickel - titanium alloy (NiTi) in 1961 by accidents while studying the heat & Corrosion resistance of NiTi alloy. Today NiTi alloys are commonly referred as "Nitinol", for NiTi Naval Ordance Laboratory.

The shape memory effect must be programmed into the SMA with an appropriate thermal procedure. The alloy is formed into desired austenite form and heated into a specific temperature. The temperature & the duration of the heating depends on the alloy & required properties. For NiTi alloy, generally 500°C and over 5 minutes are used.

SUPERELASTICITY:- In the SMA's instead of the phase transformation due to temperature, this transformation of phase occurs due to mechanical stress. When SMA's are loaded in the austenite phase, the material will transform to the martensite phase above a critical stress, proportional to the transformation temperature. Upon continued loading, the twinned Martensite will begin to detwin, allowing the material to undergo large deformations. Once the stress is released, the martensite transforms back to austenite & the material recovers its original shape.

Some SMA's :- Ag-Cd, Au-Cd, Cu-Al-Ni, Cu-Sn, Cu-Zn, In-Ti, Ni-Al, Ni-Ti, Fe-Pt, Mn-Cu & Fe-Mn-Si.

Applications :- Bioengineering, especially for broken bones, orthopaedic implants, cardiovascular devices. Fire & Security sprinklers, eye glasses, helicopter blades.

SMART MATERIALS - BIOLOGICAL APPLICATIONS

(Implants in human body)

- The bio compatibility of the SMA's is one of the important points which make them suitable for biomedical applications, as orthodontic devices, orthopaedic implants, cardiovascular devices, surgical instruments & endodontic files.
- Broken bones can be mended with SMA's.
- Memory metals can also apply to hip replacements.
- For clogged blood vessels, an alloy tube is crushed & inserted into the clogged veins. Since the memory metal has a memory transfer temperature close to body heat, the memory metal expands to open the clogged arteries.
- SMA's finds applications in Dental braces & dental arch wires.

Residual life assessment of materials (RLA)

Residual life of a engineering material is the time period during which it shall retain the fitness for service characteristics. Traditionally, "visual inspection" has been the method for carrying out RLA studies, but soon it was realized that a scientific method or approach was required for assessing the Residual life of extremely costly equipments. with respect to this, Non destructive testing are considered, besides other techniques.

Conducting RLA is an important process to maintain the efficient operation of a process plant unit & to avoid the failure of critical equipments, which lead to costly downtime problem. RLA studies are done on power plant components, aircraft components & other machineries which are subjected fatigue / creep loading conditions.

RLA makes use of NDT test results with the operational parameters to estimate the Residual life of any equipment.

NON-DESTRUCTIVE TESTING (NDT)

As the name suggests, Non destructive testing (NDT) techniques includes all types of testing techniques in which, the material / product under test is not destroyed and may be reused.

Sometimes abbreviation NDE (NON DESTRUCTIVE EVALUATION) is used to describe NDT techniques. However it would be more appropriate to call those techniques as NDE, which are meant for evaluation of material properties such as fiber volume fraction, composition of alloys, grain size, fatigue behaviour etc., other techniques that are used for inspection of incoming materials, inspection of voids, porosities etc., should be called as NDT Techniques.

We know that no material can be categorized as absolutely perfect i.e., having zero defect. So one should be able to locate and assess the severity of the defects present in any material or component without impairing their future usefulness. To meet this techniques various NDT techniques are used. They are:-

(1) Radiography
(2) Ultrasonic Testing
(3) Acoustic Emission testing
(4) Eddy - current testing
(5) magnetic method
(6) Liquid penetrant Inspection. etc.