Composites

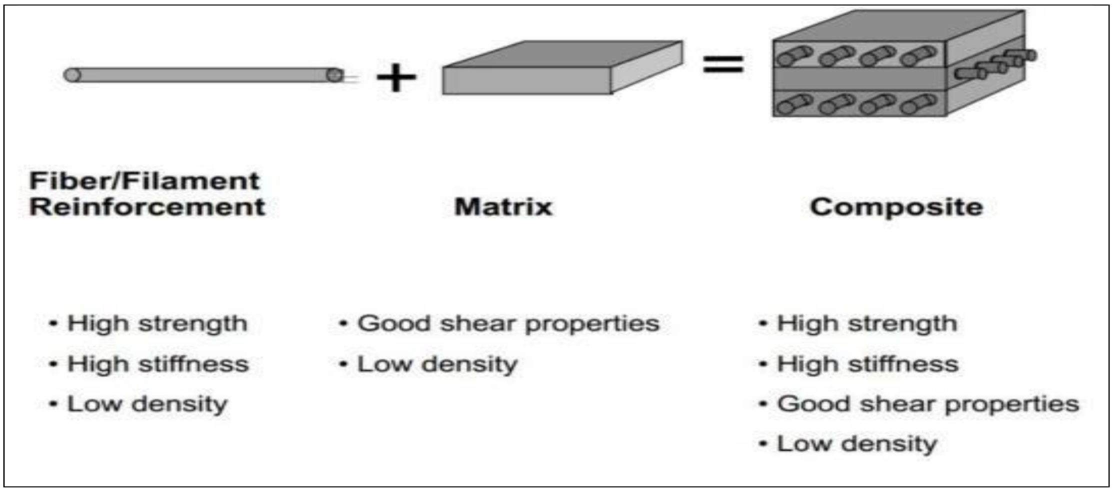
Definition

- ❖ Composites are combinations of two materials in which one of the materials, called the reinforcing phase, is in the form of fibers, sheets, or particles, and is embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer.
- ❖ Composites are artificially produced multiphase materials.

Composite Material

- ✓ A combination of two or more materials to form a new material system with enhanced material properties.

Reinforcement + Matrix = Composite



Advanced Composite Materials

- ✓ Definition: An advanced composite material comprises at least two chemically different materials (heterogeneity): reinforcement, and a matrix that binds the reinforcement and is separated from it by a sharp interface.

Phases of the composites

- Matrix Phase: Polymers, Metals, Ceramics, continuous phase, surrounds other phase (e.g.: metal, ceramic, or polymer)
- Reinforcement Phase: Fibers, Particles, or Flakes, dispersed phase, discontinuous phase (e.g.: metal, ceramic, or polymer) ƒ

→ Interface between matrix and reinforcement

The Main Characteristics of Composite Materials

- Heterogeneity: Non-uniformity of the chemical/physical structure
- Anisotropy: Direction dependence of the physical properties
- Symmetry: Tensorial nature of material properties
- Hierarchy: Stacking of individual structural units

Role of matrix and reinforcement

- ❖ Holds the fibres together.
- ❖ Protects the fibres from environment.
- ❖ Distributes the loads evenly between fibres so that all fibres are subjected to the same amount of strain.
- ❖ The compatibility, density, tensile strength, chemical and thermal stability of the reinforcement with matrix material is important for material selection, fabrication as well as application.
- ❖ In reinforced Composites, the matrix is the major load bearing constituent. The role of the reinforcement is to strengthen and stiffen the composite through prevention of matrix deformation by mechanical restraint. It also provides stability to the composite material.

- The matrix must stand up to the service conditions, viz., temperature, humidity, exposure to ultra-violet environment, exposure to chemical atmosphere, abrasion by dust particles, etc.

Classification of Composites

- Composite materials are commonly classified at following two distinct levels:

The first level of classification

- This is usually made with respect to the matrix constituent. The major composite classes include:

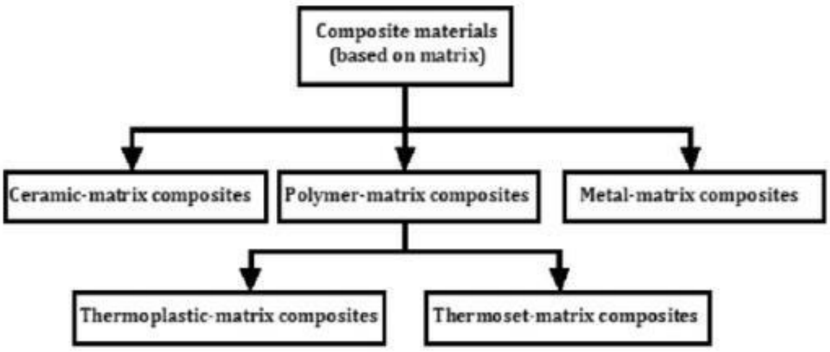
  (1) Organic Matrix Composites (OMCs),

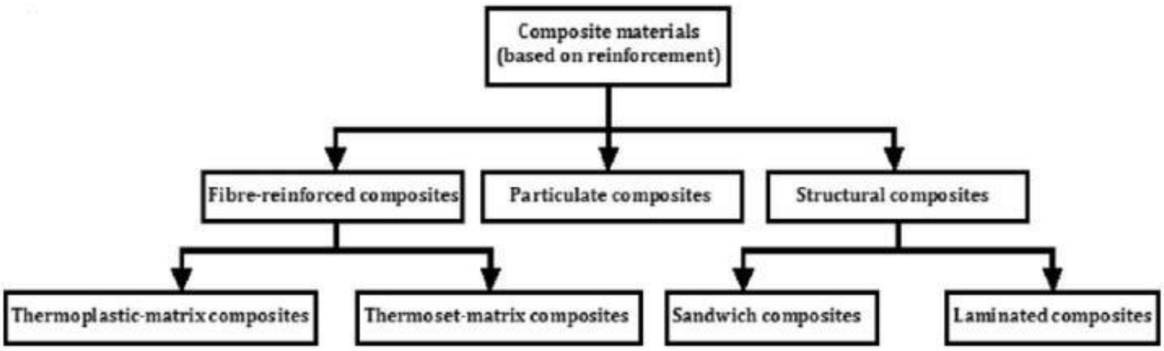
  (i) Polymer Matrix Composites (PMCs)

  (ii)Carbon matrix composites (carbon-carbon composites)

  (2) Metal Matrix Composites (MMCs)

  (3) Ceramic Matrix Composites (CMCs)





Classifications of Composites

The second level of classification

- This refers to the reinforcement form

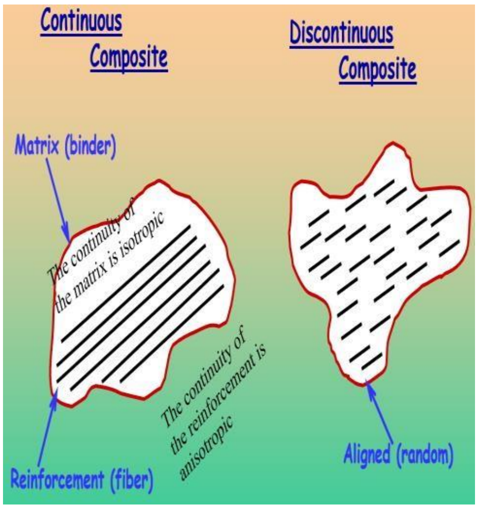
(1) Fibre reinforced composites

(i) Discontinuous fibres

(ii) Continuous fibres

(2) Laminar reinforced composites

(3) Particulate reinforced composites



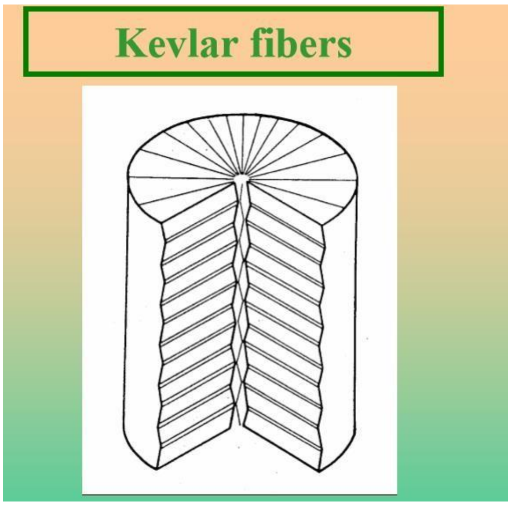


Figure.5.3.Continuous &discontinuous fiber   Kevlar fibers

Fibre-Reinforced composites

- Fibre-reinforced composites are those in which the dispersed phase is in the form of a fiber. In fibre-reinforced composites, high-strength fibres are encased within a tough matrix. The greatest reinforcing effect is obtained when fibers are continuous and parallel to one another, and maximum strength is obtained when the composite is stressed in tension in a direction parallel to the line of fibers.
- When such a composite is stressed within the elastic range, the strain developed in both fibers and matrix will be the same.
- If fibers are discontinuous, their strengthening effect will be less than that of continuous fibers. Also short discontinuous fibers will be considerably less effective than long fibers. Most fibre-reinforced components provide improved strength, fatigue resistance, stiffness and strength-to-weight ratio.

Characteristics of fibre-Reinforced composites

- Low relative density and hence high specific strength and modulus of elasticity.
- Good resistance to corrosion
- Good fatigue resistance, particularly parallel to fibre direction
- Generally low coefficient of thermal expansion

Many factors influence the characteristics of fibre-reinforced composites

- The length, diameter, orientation, amount and properties of the fibers.
- The properties of the matrix
- The bonding between the fibers and matrix

Fibre and matrix materials

- Some of the commonly used fibre and matrix materials in the fibre-reinforced composites are listed below:

S.No	Fibre materials	Matrix materials
1.	Polymers(Kevlar,nylon, polyethylene)	Thermosetting resins (Polyesterresins,epoxide resins)
2.	Metals(Be,Boron,W)	Thermoplastics(PA, PAI,PBT,PET,PES,PPS,PEEK)
3.	Glass(E-glass, S-glass)	Metal matrices(Al,Ti,Mg,Crand Ni together with their alloys)
4.	Carbon(high strength, high modulus)	Composite matrices
5.	Ceramics(Al_2O_3, B_4 C, SiC, ZrO_2)	
6.	Whiskers(Al_2O_3,Cr,graphite,SiC,Si_3N_4)	

Examples

- Some of the important fibre-reinforced composites and their typical applications are given below:

S.No	Fibre-reinforced composite system	Typical applications
1.	Borsic aluminium	Fan blades in engines, other aircraft and aerospace applications
2.	Kevlar-epoxyand Kevlar-Polyester	Aircraft, aerospace applications(space shuttle), boat hulls, sporting goods(tennis rackets, golf club shafts, fishing rods), flak jackets
3.	Graphite-polymer	Aerospace and automotive applications, sporting goods
4.	Glass-polymer	Light weight automotive applications, wear and marine applications, corrosion-resistant applications, sporting goods equipment, aircraft and aerospace components

Fiber Reinforced Polymer (FRP) Composites

- ✓ "A matrix of polymeric material that is reinforced by fibers or other reinforcing material"

Laminar Composites

- ✓ They are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

Particulate Composites

- ✓ They are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form.

Example

- ❖ Concrete -hard particles (gravel) + cement (ceramic/ceramic composite). Properties determined by particle size distribution, quantity and matrix formulation
- ❖ Electrical contacts (silver/tungsten for conductivity and wear resistance)
- ❖ Cast aluminium with SiC particles

Metal Matrix Composites (MMCs)

- ✓ A metal matrix composite (MMC) is a type of composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite.

Advantages of composite materials

- Composite materials exhibit superior mechanical properties such as high strength, toughness, elastic modulus, fairly good fatigue and impact properties.
- As fibre composites are light weight materials, the specific strength and specific modulus are much higher than the conventional materials.
- In aerospace applications, the power to weight ratio is about 16 with composites compared to 5 with conventional materials.
- They exhibit good corrosion resistance.
- Assembly of components made of composites is much easy and quick.
- They are not much sensitive to thermal shocks and temperature changes.
- High Strength with Low Weight: Composites exhibit a higher strength to weight ratio than steel or aluminum and can be engineered to provide a wide range of tensile, flexural and impact strength properties.

Limitations of composites

- ❖ High cost of raw materials and fabrication.
- ❖ Composites are more brittle than wrought metals and thus are more easily damaged.

.

- Matrix is weak, therefore, low toughness
- Reuse and disposal may be difficult.
- Difficult to attach

Applications of Composites

- **Commercial aircraft:**

  Used for air-conditioning duct, radar dome, landing gear door, seats, floorings, window reveals, ceiling panels, propeller blades, nose, wing body, elevators, ailerons, air brake, etc.

- **Military aircraft:**

  Used for speed brake, rubber trunnion, forward fuse lag, elevators, ailerons, landing gear doors, horizontal stabilizers, etc.

- **Missiles:**

  Used for remote piloted vehicles, filament wound rocket motors, wings, rotor cases etc.

- **Space hardwares:**

  Used for antennas, struts, support trusses, trusses for telescopes, storage tanks for gases and fluids at cryogenic temperatures etc.

- **Automobile and trucks:**

  Used for drive shafts, bumpers, door and window frames, starter motor commutators, body panels, radiator and other hoses, timing and V belts, drive chains etc.

- **Electrical and electronics:**

  Used for microphone housing, miniature-electronic card holder, ribs to protect printed circuit boards, parabolic antenna etc.; electrical equipments-switch casings, cable and distribution cabinets, junction boxes etc.

- **Marine applications:**

  Used for small boat hulls, sonar domes, masts, tanks, decks, submarine masts, spinnaker pole on the racing yatch, plates in nuclear submarine lead acid batteries etc.

UNIT-V

NEW MATERIALS 9

Ceramics – types and applications – composites: classification, role of matrix and reinforcement, processing of fiber reinforced plastics – metallic glasses: types, glass forming ability of alloys, melt spinning process, applications - shape memory alloys: phases, shape memory effect, pseudoelastic effect, NiTi alloy, applications – nanomaterials: preparation (bottom up and top down approaches), properties and applications – carbon nanotubes: types.

Introduction

- Mechanical engineers search for high temp material so that gas turbines, jet engines etc. can operate more efficiently and wear resistance materials to manufacture bearing materials.
- Electrical engineers search for materials by which electrical devices or machines can be operated at a faster rate with minimum power losses
- Aerospace & automobile engineers search for materials having high strength-to weight ratio.
- Electronic engineers search for material that are useful in the fabrication & miniaturization of electronic devices
- Chemical engineers search for highly corrosion-resistant materials

In this chapter let us discuss new engineering materials such as ceramics, composites, metallic glasses, shape memory alloys, Nano-phase materials and carbon Nano tubes.

Ceramics

Introduction

- The term ceramic comes from the Greek word keramikos, which means burnt stuff, indicating that desirable properties of these materials are normally achieved through a high- temperature heat treatment process called firing.

Definition

- Ceramic materials are inorganic, non-metallic materials. Most ceramics are compounds between metallic and non-metallic elements for which the interatomic bonds are either totally ionic or predominantly ionic but having some covalent character.

Properties of ceramics:

- Ceramics are non-metallic and inorganic solids that are processed at high temperature.
- They are hard, wear resistant and brittle with low toughness and ductility.
- They are good electrical and thermal insulators due to the absence of conducting electrons.
- They have relatively high melting temperature and good chemical stability.
- They possess a very low thermal conductivity since they do not have enough free electrons.
- Oxidation resistant.

Classification of ceramics

Natural ceramics (Traditional ceramics)

- They are made from three basic components: clay, silica and feldspar. Structural clay products such as building brick, sewer pipe, drain pipe, roof and floor title etc., are made of natural clay, which contain all three basic components.

- Example: Glasses, tiles, bricks and porcelain.
- Silica is used as refractory component in traditional ceramics. This is also called as flint or quartz having a high melting temperature.

Manufactured ceramics (Engineering ceramics)

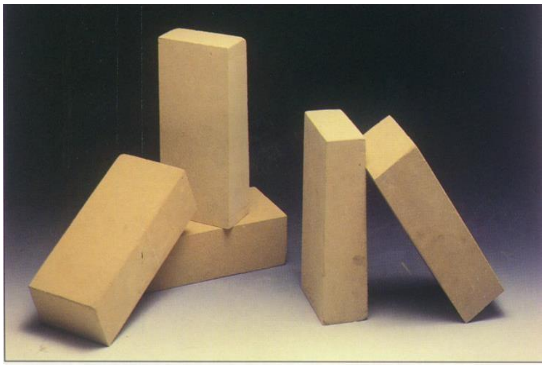
- Manufactured ceramics like SiC, Al_2 O_3, Silicon Nitride (Si_3N_4), Magnesia (Magnesium oxide, MgO) and many varieties of oxides, carbides, nitrides, borides and more complex ceramics.
- The manufactured ceramics are usually called as “High-tech ceramics” or “fine ceramics”.

Functional classification

- Abrasives: Ex-Alumina, Carborundum
- Pure oxide ceramics: Ex-MgO, Al_2 O_3, SiO_2
- Fired clay products: Ex-Bricks, Tiles, Porcelain
- Inorganic glasses: Ex-Window glass, lead glass
- Cementing materials: Ex-Portland cement, lime
- Rocks: Ex-Granites, Sandstones
- Minerals: Ex-Quartz, calcite
- Refractories: Ex-Silica bricks, Magnesite

Structural classification

- Crystalline ceramics: Single phase like MgO , Multiphase like Al_2 O_3,
- Non-Crystalline ceramics: Inorganic glasses like window glass
- Glass –bonded ceramics: Fired clay products
- Cement-Crystalline and non-crystalline phases

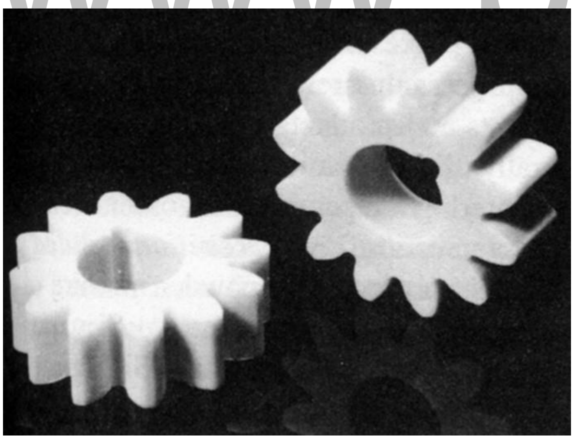


Refractory brick

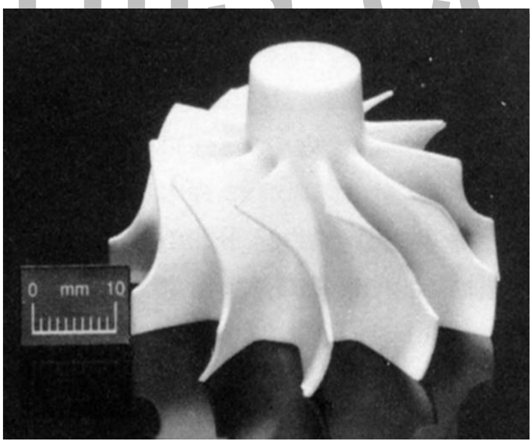
Ceramic brake disc

Automotive SiC components

Glass containers



Gear (Alumina)



Rotor (Alumina)

Figure 5.1 Examples of Ceramics

Ceramic processing

Processing of ceramics generally takes place in 4 steps:

- Powder processing (raw materials)

- Forming (desired shape)
- sintering (firing)
- Finishing-include densification, sizing, heat treatment, painting, and electroplating.

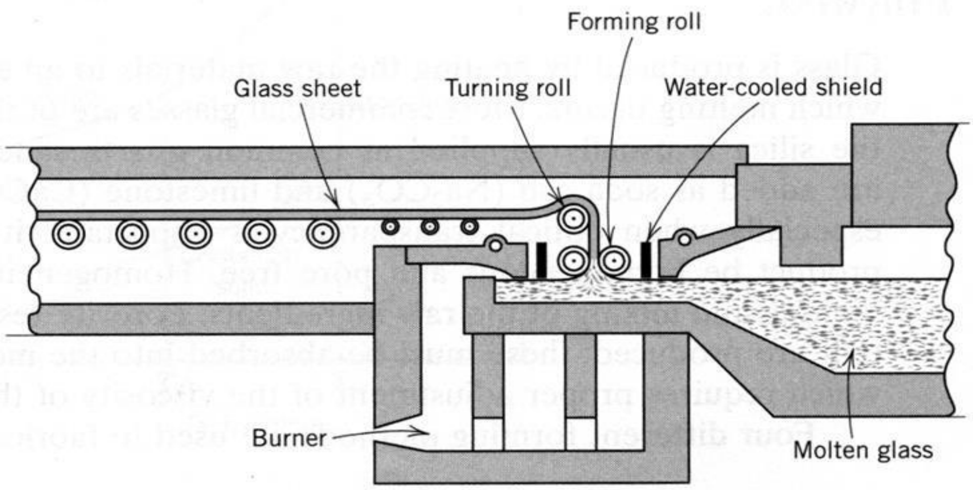


Figure 5.2 Ceramics processing set up

Types of ceramics

Glasses

- Glasses are amorphous solids. They are non- crystalline silicates containing other oxides like Na_2O, K_2O and Al_2O_3.

Properties

- They are less ductile and more brittle
- They have low thermal conductivity compared to metals
- They are good insulators

Applications

- They are used for making windows space, furnace windows, vehicle windows
- They are used in containers and electric bulbs.
- They are also used in optical systems in spectro photometric devices
- They are used in sealed beam head lights, ovenware etc.,

Glass ceramics

- Even though most of the glasses are amorphous, special glasses are made crystalline through a carefully controlled heat treatment. They are called glass ceramics.

Properties

- They are relatively high mechanical strength
- They have low coefficients of thermal expansion
- They have good dielectric properties
- They have good biological compatibility

Applications

- They are used as ovenware, tableware, oven windows and range tops.
- They also serve as electrical insulators and as substracts for printed circuit boards.
- They are used for architectural cladding, heat exchangers and regenerators.

Clay products

- Ceramics are produced from earth minerals by the action of heat and diffusion techniques are called Clay products.
- Clay products are classified into two cases (i) structural clay (ii) white ware.

Structural clay

- These products include building bricks, tiles and sewer pipes.

White ware

- It is a class of ceramic products that include porcelain, china, pottery, sanitary ware, vitreous tile, stoneware.

Properties

- Mechanical strength is more when fired at elevated temperature

- Resistance to chemical attack
- They are resistance to wear

Applications

- ❖ They are used for various elements of buildings like walls, wall and floor facing materials, lining materials for chemical industry apparatus, chimney and sewer pipes.
- ❖ Tableware, wall tiles, sanitary ware and roof tiles are used to provide protection and decoration.

Refractories

- ❖ Refractories are ceramics having the capacity to withstand high temperature without melting or decomposing. Refractories are available in the form of bricks, shaped products and coatings. The oxides of Al, Si ad Mg are the most important materials used in the manufacturing of refractories. They are divided into three groups:

  (i) Acid refractories

  (ii) Basic refractories

  (iii)Neutral refractories

Properties

- At high temperatures acid refractories also react with limes and basic oxides.
- They withstand high temperature without melting
- It will provide thermal insulation.

Application

- ❖ They are used for high temperature applications.
- ❖ They are repainted in metal processing applications to provide compatibility with the metal.
- ❖ They are in furnace lining for metal refining

Abrasives

- They are hard and wear resistant material that is used to wear, grind or cut away other material. To provide toughness, the abrasive particles are bonded by a glass or polymer matrix. Diamond abrasives are typically bonded with a metal matrix.
- Example: Diamond, silicon carbide, tungsten carbide, aluminium oxide and silica sand.

Cement

- ✓ Ceramic raw materials are joined using a binder that does not require firing or sintering in a process called cementation.
- ✓ Fine alumina powder solutions catalyzed with phosphoric acid produce aluminium phosphate cement at 1650^0 C.

$$Al_2 O_3 + 2H_3 PO_4 \rightarrow 2AlPO_4 + 3H_2O$$

- ✓ Application: cement is used to bind sand and gravel together to produce concrete.
- ✓ Portland cement is the most important cement.

Advanced ceramics

- **Advanced ceramics** are prepared from highly refined synthetic raw materials using chemical processing techniques. They are primarily pure compounds oxides, carbides, nitrides and borides. Because of its mechanical strength and its usage in industrial applications, advanced ceramics are termed as fine ceramics or engineering ceramics.

METALLIC GLASSES

Definition:

Metallic glasses are the amorphous metallic solids which have high strength, good magnetic properties and better corrosion resistance and will possess both the properties of metals and glasses.

Examples: Alloys of Fe, Ni, Al, Mn, Cu, Cr and Co mixed with metalloids such as Si, Ge, As, B, C, P and N.

CONCEPT BEHIND THE FORMATION OF METALLIC GLASSES

Generally, liquids can be made into glassy state by increasing the rate of cooling. In a similar manner the metals can also be made into glassy state by increasing the rate to cooling to a very high level [2 x 10^6 °C per second]. At that state the atoms will not be able to arrange orderly because of its rapid cooling rate.

Thus, the atoms will not be allowed to go to crystalline state, rather it goes to amorphous state and it will form a new type of material. These new types of materials which are made by rapid cooling technique (i.e., the temperature decreases suddenly with respect to time) are called ***metallic glasses.***

The cooling rate for the formation of metallic glasses varies from material to material. **Glass Transition Temperature**

The temperature at which the metals [alloys] in the molten form transforms into glasses i.e., liquids to solids is known as ***glass transition temperature (Tg).***

It was found that the glass transition temperature for metallic alloys varies from 20°C to 300°C.

PREPERATION OF METALLIC GLASSES

Principle

"*Quenching*" *is* a technique used to form metallic glasses**,** Q*uenching* means rapid cooling. Actually, atoms of any materials move freely in a liquid state. Atoms can be arranged *regularly* when a liquid is cooled *slowly*. Instead, when a liquid is *quenched*, there will be an *irregular pattern, which results in the formation of metallic glasses.*

Technique

The process involved in the formation of metallic glasses is melt spinning technique. This technique is illustrated in Fig.

Experimental Setup

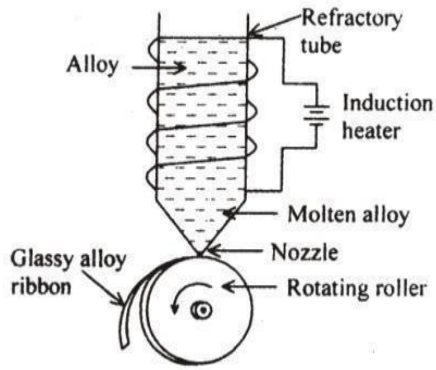


Figure.5.4- Melt spinning technique

The setup consists of a refractory tube with fine nozzle at the bottom. The refractory tube is placed over the rotating roller made up of copper. An induction heater is wounded over the refractory tube in order to heat the alloy inside the refractory tube as shown in Fig.5.4

Preparation

The alloy is put into the refractory tube and the induction heater is switched ON. This heats the alloy and hence the super-heated molten alloy is ejected through the nozzle of the refractory tube onto the rotating roller and is made to cool suddenly. The ejection rate may be increased by increasing the gas pressure inside the refractory tube. Thus due to rapid quenching a glassy alloy ribbon called metallic glass is formed over the rotating roller.

Metallic glasses of various thicknesses can be formed by increasing (or) decreasing the diameter and speed of the roller.

TYPES OF METALLIC GLASSES

Metallic glasses are of two types viz,

(i) Metal-metalloid glasses

Examples: Metals : Metalloids

Fe, Co, Ni: Ge, Si, B, C

(ii) Metal – Metal glasses

Examples: Metals : Metals

Ni : Niobium

Mg : Zn

Cu : Zr

PROPERTIES OF METALLIC GLASSES

Since the atoms in the metallic glasses are disordered, they have some peculiar properties as follows:

(i) Structural Properties

a. Metallic glasses have tetrahedral closely packed(TCP) structure rather than hexagonal closely packed (HCP) structure.

b. They do not have any crystal defects such as grain boundaries, dislocations etc.

(ii) Mechanical Properties

a. The metallic glasses are very strong in nature.

b. They have high corrosion resistance.

c. They possess malleability, ductility etc.

(iii) Magnetic Properties

a. Metallic glasses can be easily magnetized and demagnetized.

b. They have very narrow hysteresis loop as shown in fig .In Fig the hysteresis loop of the metal alloy in crystalline phase is also given for reference.

c. They exhibit very low hysteresis loss and hence transformer core loss is very less.

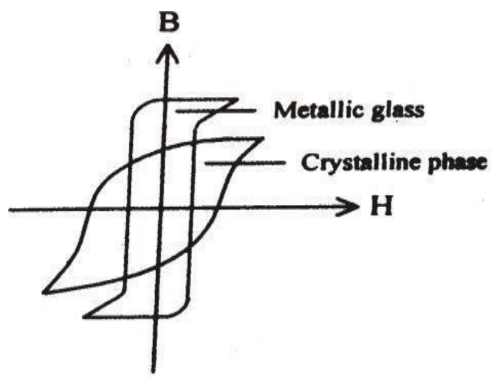


Figure.5.5. Hysteresis loop

(iv) Electrical Properties

a.Metallic glasses have high electrical resistance .

b.The electrical resistance for metal glasses will not vary with temperature.

c.They possess very low eddy current losses.

APPLICATIONS OF METALLIC GLASSES

*Since the metallic glasses possess low magnetic loss, high permeability, saturation magnetization and low coercivity, ***these materials are used in cores of high power transformers.***

*As the metallic glasses are malleable and ductile, it can be used in simple filament winding to reinforce pressure vessels.

*Since the metallic glasses are very strong/hard they are used to make different kinds of springs.

*As the metallic glasses are similar to the soft magnetic alloys, they are used in leads of tape recorder, cores of transformers and magnetic shields.

*Because of their high resistivity, they are used to make computer memories, magneto-resistance sensors etc.

*Since they have high corrosion resistance, they are used in reactor vessels, surgical clips, marine cables etc.

*Since some metallic glasses can behave as super conductors, they are used in the production of high magnetic fields.

*Since the metalic glasses are not affected by irradiation, they are used in nuclear reactors.

NANO MATERIALS

- Nanomaterials are newly developed materials with the grain size in the range 1 to 100 nm at least in one dimension. 1nm=one billionth of a meter (10^{-9}m).
- Nanomateriasl are categorized according to their dimensions

Classification of Nanomaterials

Nanomaterials dimension	Examples
All three dimensions < 100 nm	Nanoparticles, quantum dots, nanoshells, nanorings, microcapsules
Two dimensions < 100 nm	Nanotubes, fibres, nanowires
One dimension < 100 nm	Thin films, layers and coatings

- **Nanoscience** is the study of materials that exhibit remarkable properties, functionality and phenomena due to the influence of small dimensions.
- **Nanotechnologies** are the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale.
- Some **good examples** to bring to the classroom:

Our **fingernails grow** at the rate of 1 nm per second;
The **head of a pin** is about 1 000 000 nm in diameter;
A **human hair** is about 80 000 nm in diameter;
A **DNA molecule** is 1–2 nm wide;
The **transistor** of a latest-generation Pentium Core Duo processor is 45 nm.

Synthesis of nanomaterials

- The nano materials are synthesized into two categories, namely
  - Top-down process
  - Bottom-up process

Top-down process

- In the top-down process, a bulk material is crushed into fine particles.
- Example: 1.Ball milling 2.Laser ablation 3.sputtering 4. Plasma arcing 5.Electron beam evaporation 6.Photolithography

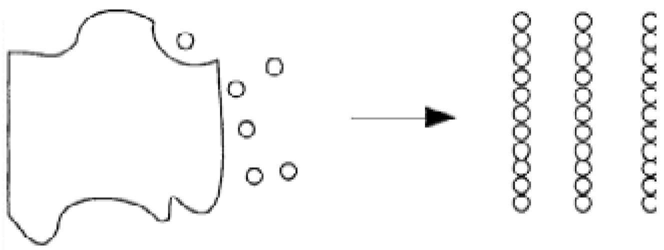


Figure 5.11 Top-down process

Bottom-up process

- In this process, nano materials are produced by arranging atom by atom.
- Example: 1. Chemical vapor deposition 2. Sol- gel method 3. Electro deposition, etc.

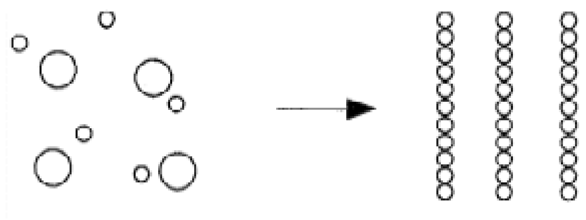


Figure 5.12 Bottom-up process

Laser ablation method

- Pulsed Laser technique is a thin film deposition technique.
- PLD consists of an ultra-high vacuum chamber where graphite target and substrate are attached parallel to each other.
- When laser pulse of suitable wavelength and sufficient energy falls on the graphite target. The surface of the target is then heated up and the material is vaporized.
- High energy species are emitted from the surface.
- The argon gas present inside the vacuum chamber is used to sweep the carbon atoms towards the collector.
- It is then deposited as a thin film on a substrate.
- The quality of the film grown, the size of the nano particles and the rate of deposition depend on various lattice parameters such as the laser energy and pulse duration.

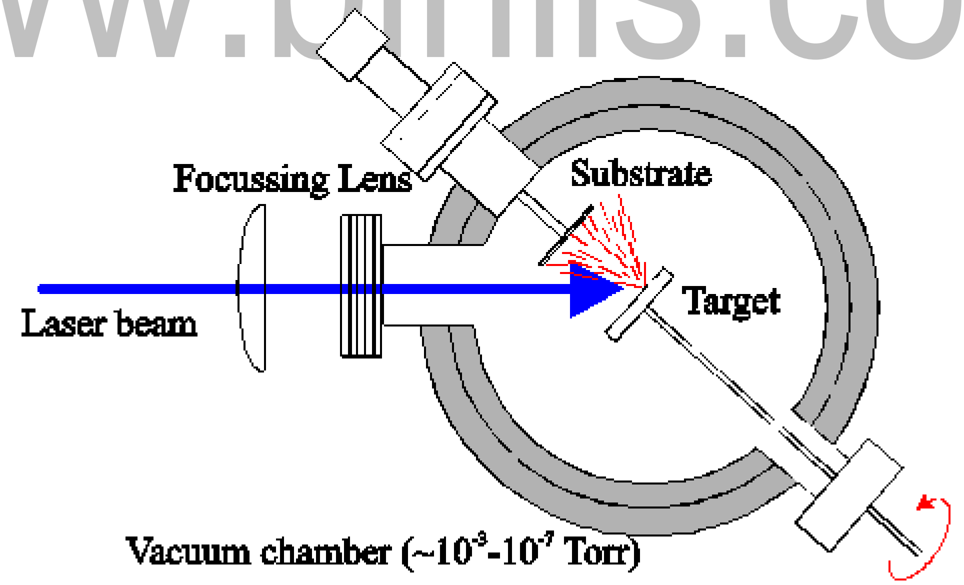


Figure 5.13 Laser ablation method

Advantages

- Flexible, esay to implement
- Growth in any environment
- The process is controlled by temperature and laser output power

Disadvantages

- Uneven coverage
- Not well suited for large scale film growth

Applications

- To produce high quality thin films and nano particles

Chemical Vapour Deposition

- ✓ CVD is a chemical method used to produce nano materials.
- ✓ The CVD apparatus consists of quartz tube container, tubular furnace , tungsten boat, inert gas and silicon substrate.
- ✓ The silicon substrate is placed inside the a tungsten boat. The whole set up is kept inside the quartz tube.
- ✓ The quartz tube container is maintained the inert atmosphere.
- ✓ The reactants are admitted into the container and it is maintaied at suitable temperature.
- ✓ The hot atoms collide with cold atoms and undergo condensation through nucleation and form small clusters.
- ✓ The thin film coating is formed on the silicon substrate because of chemical reaction. The unused gases flow through the outlet.
- ✓ The hydrogen reduction of silicon tetra chloride, is used to produce the epitaxial growth of pure silicon.The chemical reaction involved is

$$SiCl_4 + 2H_2 \rightarrow Si + 4HCl$$

Advantages

- CVD is a low cost and high yield method
- High purity nano materials are prepared
- Both SWNTs and MWNTs can be produced

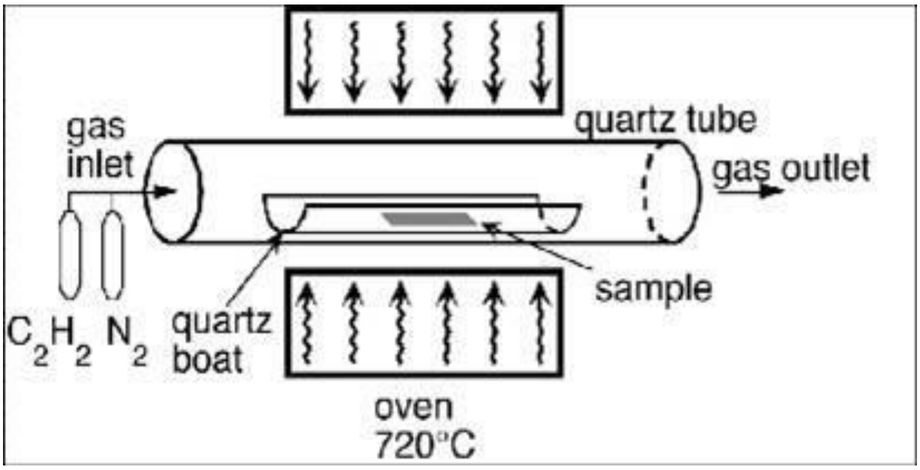


Figure 5.14 Chemical Vapour Deposition

Disadvantages

- Control of size depends on many parameters
- Control of shape is also difficult

Applications

Ics, Nano sensors, opto electronic devices

Properties of nano materials

Physical properties

- Interparticle spacing decreases with decrease in grain size
- Melting point reduces with decrease in particle size
- Ionisation potential changes with cluster size of the nano materials
- Increase surface to volume ratio causes decrease in interparticle spacing

Mechanical properties

- If the grains are nano scale, many of their mechanical properties such as hardness, elastic modulus, fracture toughness and fatigue strength are modified.
- Very high ductility and super elasticity behavior at low temperature

Magnetic properties

- Mano materials are more magnetic than bulk materials
- Exhibit giant magneto resistance

Electronic properties

- Energy bands will be very narrow
- Electrical conductivity increases with reduction in particle size

Optical properties

- Gold nano particles of 100 nm appear orange in colour while 50 nm nano spheres appear green

Applications

Energy technology

- ✓ Nano particles of Ni, Pd and Pt are useful in hydrogen storage devices
- ✓ Fabrication of ionic batteries
- ✓ Addition of nano particles Ceria to diesel fuel improves fuel economy
- ✓ Magnetic refrigeration

Material technology

- Carbon nano particles are used as a filler to reinforce car tyres and car bumpers
- Nano Tio_2 is hydrophobic and antibacterial and they used in self-cleaning windows, paints
- Used in cosmetics, food and agriculture

Bio medical

- Silver nano particles are used as bone cement, surgical instruments, wound dressings
- Cancer cell detection, artificial heart valves and implant materials
- Nano robots inserted into our body can modify neuron networks of brain
- Nano titania is used in many sun screens to block harmful UV rays
- Bio sensitive nano particles are used for tagging of DNA and DNA chips
- Controlled drug delivery

Electrical and Electronics

- Used for fabricating nano transistors, multilayer capacitors, quantum computing, display technology, photonic crystals, fast logic gates and solar cells.
- Nano magnets are used in high density magnetic recording, CDs, mobiles, lap-tops, RAM and READ/WRITE heads.
- Molecular nano technology is aimed to device robotic machines, molecular size power sources and batteries

Mechanical Engineering

- Since they are stronger, lighter etc., they are used to make hard metals.
- Smart magnetic fluids are used in vacuum seals, magnetic separators etc.
- They are also used in Giant Magneto Resistant (GMR) spin valves.
- Nano- MEMS (Micro-Electro Mechanical Systems) are used in ICs, optical switches, pressure sensors, mass sensors etc.

Carbon Nanotubes

The Amazing and Versatile Carbon – Chemical basis for life

- ✓ With an atomic number of 6, Carbon is the 4th most abundant element in the Universe by mass after (Hydrogen Helium and Oxygen). It forms more compounds that any other element, with almost 10 million pure organic compounds.

Graphite consists of hexagonal honeycomb like arrangement of carbon atoms. asingle hexagonal sheet like layer of graphite is known as Graphene.

- ✓ Carbon Nanotubes were discovered in 1991 by Sumio Iijima. Carbon Nanotubes like fullerenes (C_{60}), grapheme and nanotubes are great interest for the current research as well as for future applications.

Definition

- ✓ Carbon Nanotubes are molecular-scale tubes of graphene with large potential applications. They are long, flexible, and thin cylinders of carbon having a very broad range of electronic, thermal, physical, and structural properties.

Types of CNTs

CNTs are classified by its diameter, length, and chirality. They are

1. Single Wall Carbon Nanotubes (SWCNTs)
2. Multiple Wall Carbon Nanotubes (MWCNTs)

Single-walled carbon nanotube structure

- ✓ Single-walled carbon nanotubes consist of one tube of Graphite. SWCNTs diameter range from 0.5 nm to 2.0 nm and their length is few μm.
- ✓ This can be formed in three different designs:

Armchair structure,

Chiral structure, and

Zigzag structure.

- ✓ The different ways of rolling the graphite sheet gives different single-walled nanotube's structure.
- ✓ A single-walled nanotube's structure is represented by a pair of indices (n,m) called the chiral vector.

The chiral vector is represented by

$$C_h = na_1 + ma_2$$

Where n and m are positive integers

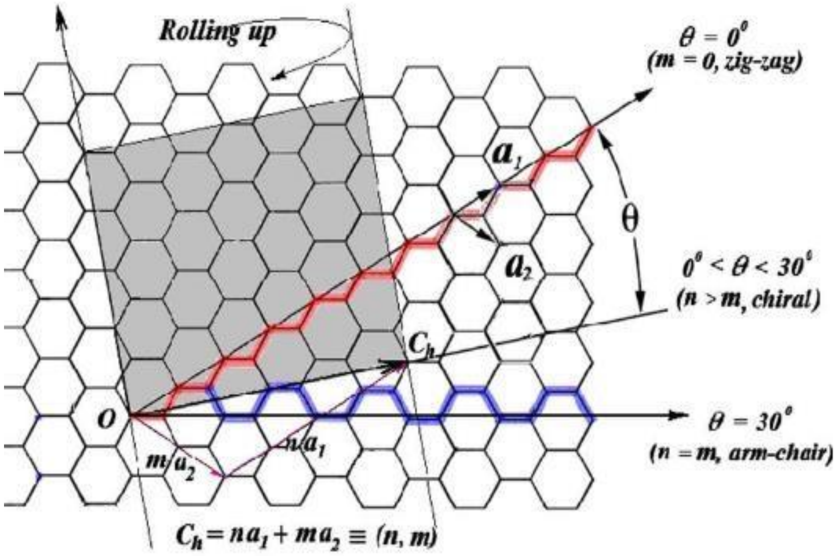


Figure 5.15 Rolled sheet of CNTs

- ✓ The tubes marked as (m, 0) has C-C bonds are parallel to the tube axis, at an open end; a zigzag pattern is formed and are called **Zigzag structure**.
- ✓ The tubes marked as (m=n) has C-C bonds are perpendicular to the tube axis, and are called **arm chair structure**.
- ✓ The tubes marked as (m>n) and $0^\circ < \theta < 30^\circ$, C-C bonds are inclined to the tube axis are called **chiral structure**.

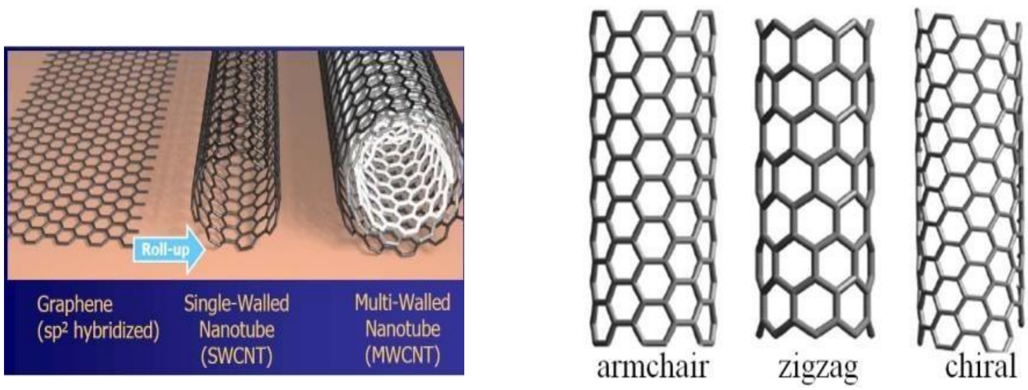


Figure 5.16 Types of CNTs

Multiple Wall Carbon Nanotubes (MWCNTs)

- ✓ Multi walled carbon nanotubes consist of several number concentric Graphite sheets. MWCNTs diameter range from 2 nm to 25 nm and their length is few μm.

Properties of CNTs

- ❖ Carbon nanotubes have a higher tensile strength than steel and Kevlar. Their strength comes from the sp^2 bonds between the individual carbon atoms. This bond is even stronger than the sp^3 bond found in diamond.
- ❖ CNTs have high electrical conductivity than copper.
- ❖ CNTs have high strength/ weight ratio. They are 20 times stronger than steel.
- ❖ Carbon nanotubes have been shown to be very good thermal conductors. The thermal conductivity of carbon nanotubes is dependent on the temperature of the tube.
- ❖ CNTs share both properties of semiconductor and metal.
- ❖ Band gap decreases with increase in diameter of CNTs.
- ❖ Pure CNTs display ferromagnetic behavior.

Methods of synthesizing CNTs

- ➢ **The various synthesizing CNTs are:**
  1. Carbon arc discharge method
  2. Laser ablation technique,
  3. Chemical Vapour Deposition (CVD) technique

Laser ablation technique

- Pulsed Laser technique is a thin film deposition technique.
- PLD consists of an ultra-high vacuum chamber where graphite target and substrate are attached parallel to each other.
- A quartz tube containing a block of graphite is heated in a furnace at $1200^\circ C$.
- A flow of argon gas is maintained throughout the reaction.
- When laser pulse of suitable wavelength and sufficient energy falls on the graphite target.
- The surface of the target is then heated up and the material is vaporized.

- High energy species are emitted from the surface.
- The argon gas present inside the vacuum chamber is used to sweep the carbon atoms towards the collector.
- It is then deposited as a thin film on a substrate.
- Ultrafast laser pulses are potential and able to prepare large amounts of SWCNTs.
- The quality of the film grown, the size of the nano particles and the rate of deposition depend on various lattice parameters such as the laser energy and pulse duration.

Advantages

- Flexible, esay to implement
- Growth in any environment
- The process is controlled by temperature and laser output power

Disadvantages

- Uneven coverage
- Not well suited for large scale film growth

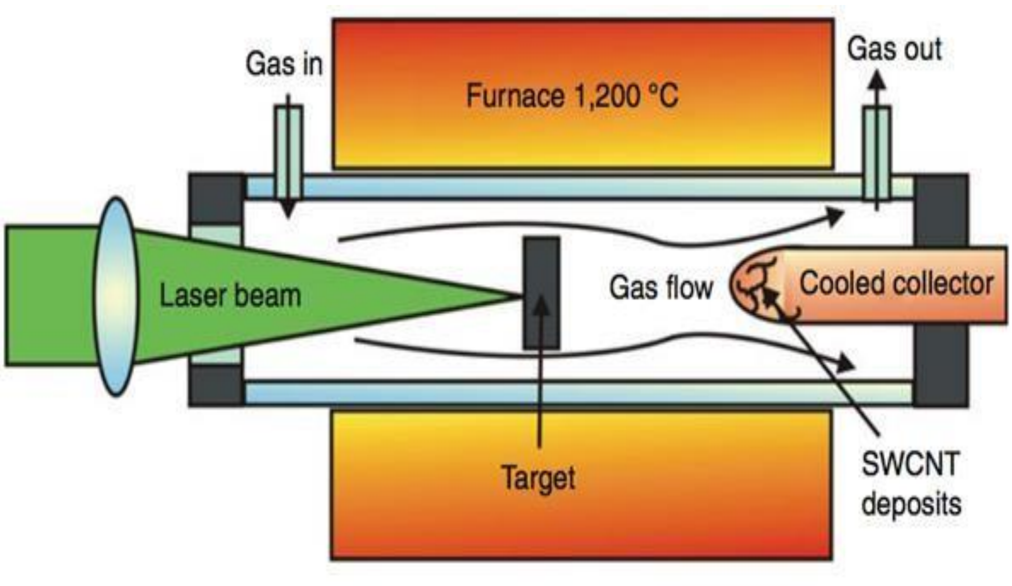


Figure 5.17 Laser Ablation technique of CNTs

Chemical Vapour Deposition (CVD) technique

Construction& working

- CVD is a chemical method used to produce carbon nanotubes.
- The CVD apparatus consists of quartz tube container, tubular furnace , tungsten boat, inert gas and silicon substrate.
- The silicon substrate is placed inside the a tungsten boat. The whole set up is kept inside the quartz tube.
- The quartz tube container is maintained the inert atmosphere.
- The reactants $(C_2H_2 \ and \ N_2)$ are admitted into the container and it is maintaied at suitable temperature $(720^\circ C)$.
- The hot atoms collide with cold atoms and undergo condensation through nucleation and form small clusters.
- The thin film coating is formed on the silicon substrate because of chemical reaction. The unused gases flow through the outlet.
- The hydrogen reduction of silicon tetra chloride, is used to produce the epitaxial growth of pure silicon CNTs. The chemical reaction involved is

$$SiCl_4 + 2H_2 \rightarrow Si + 4HCl$$

Advantages

- CVD is a low cost and high yield method
- High purity nano materials are prepared
- Both SWNTs and MWNTs can be produced

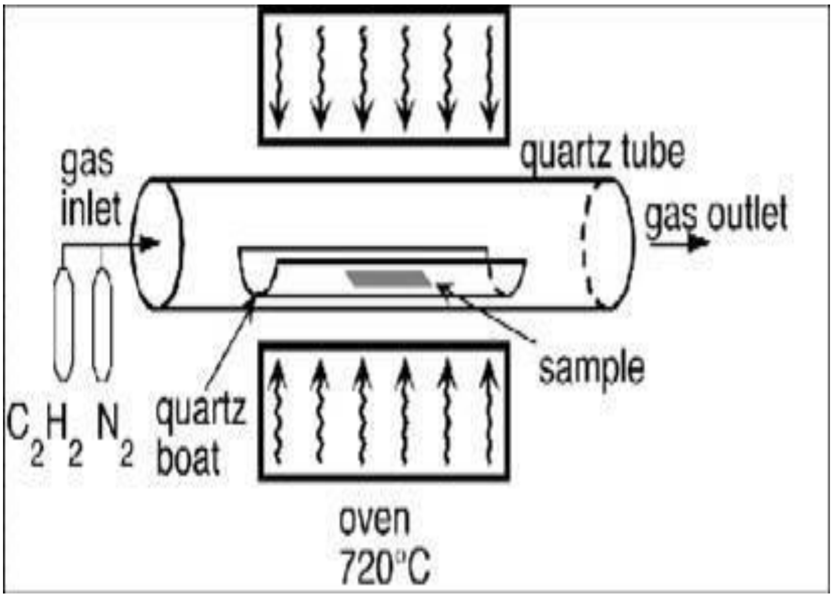


Figure 5.19 Chemical Vapour Deposition of CNTs

Disadvantages

- Control of size depends on many parameters
- Control of shape is also difficult

Applications

Ics, Nano sensors, opto electronic devices

SHAPE MEMORY ALLOYS

Shape memory alloys (SMA) *are the alloys which change its shape from its original shape to new shape and while heating /cooling it will return to its original shape.*

Transformation temperature

In SMA, the shape recovery process occurs not at a single temperature rather it occurs over a range of temperature [may be few degrees].

Thus, the range of temperature at which the SMA switches from new shape to its original shape is called ***transformation temperature (or) memory transfer temperature.***

Below the transformation temperature the SMA can be bent into various shapes. Above
the transformation temperature the SMA returns to its original shape. This change in shape was mainly caused due to the change in crystal structure (phase) within the materials, due to the rearrangement of atoms within itself.

PHASES (STRUCTURES) OF SMA

In general the SMA has two phases (crystal structures) viz.,

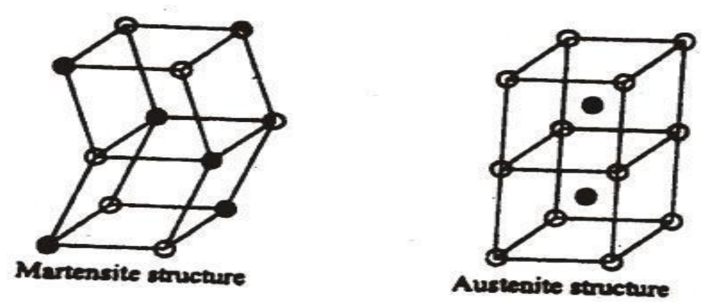


Figure.5.6. Two phases of SMA

(i) Martensite

Martensite is an interstitial super solution of carbon in γ-iron and it crystallizes into **twinned structure** as shown in fig. 4.3.1. The SMA will have this structure generally at lower temperatures and it is soft in this phase.

(ii) Austenite

Austenite is the solid solution of carbon and other alloying elements in γ-iron and it crystallizes into **cubic structure** as shown in fig4.3.1. The SMA will attain this structure at higher temperatures and it is hard in this phase

PROCESSING OF SMA

Shape memory effect

It is very clear that at lower temperature the SMA will be in martensite structure and when it is heated then it will change its shape to austenite structure and while cooling it will again return to martensite form. This effect is called ***shape memory effect.***

Let us consider a shape memory alloy, for which the temperature decreased. Due to decrease in temperature, phase transformation take place from austenite to twinned martensite as shown in fig 4.3.3 [Process 1] i.e., a micro constituent transformation takes place from the platelet structure (Austenite) to needle like structure (martensite).

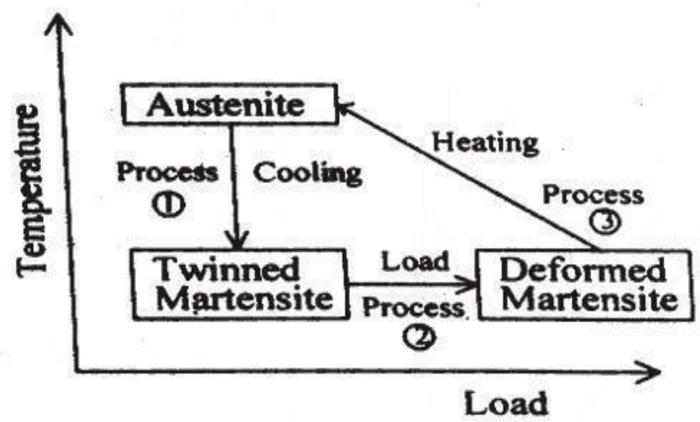


Figure.5.7. Phase transformation

During this state the twinned martensite phase will have same size as that of austenite phase as shown (Macroscopic view). Hence macroscopically if we see, no change in size (or) shape is visible between the Austenite phase and twinned Martensite phase of the SMA.It is found that the transformation from austenite to martensite takes place not only at a single temperature, but over a range of temperatures.

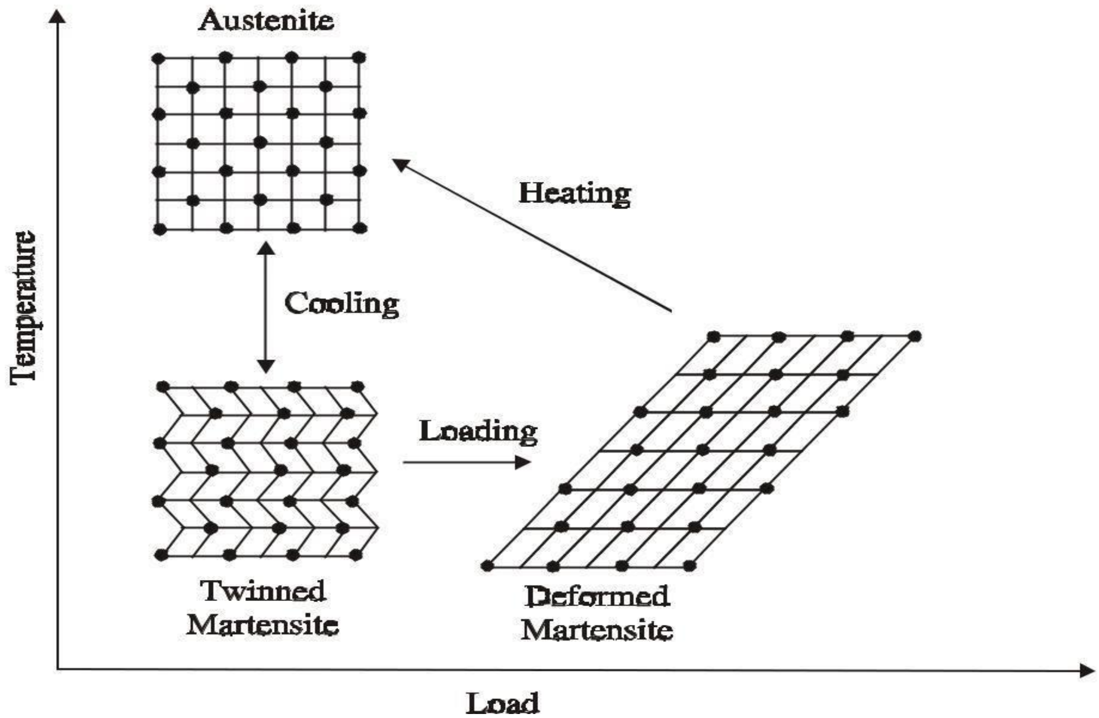


Figure.5.8. Transformation from austenite to martensite

Both austenite and twinned martensite is suitable in a particular range of temperature. Now when the twinned martensite is applied a load, it goes to deformed martensite phase as indicated in fig (Process 2). During the transformation from twinned martensite to deformed martensite the change in shape and size occur both microscopically and macroscopically as shown in fig 4.3.4

Now when the material is further heated it will go from deformed martensite to austenite form (Process 3) and the cycle continues as shown in fig 4.3.4

CHARACTERISTICS OF SMA

(i) The transformation occurs not only at a single temperature rather they occur over a range of temperatures.

(ii) **Pseudo – elasticity:** *Pseudo-elasticity occur in some type of SMA in which the change in its shape will occur even without change in its temperature*

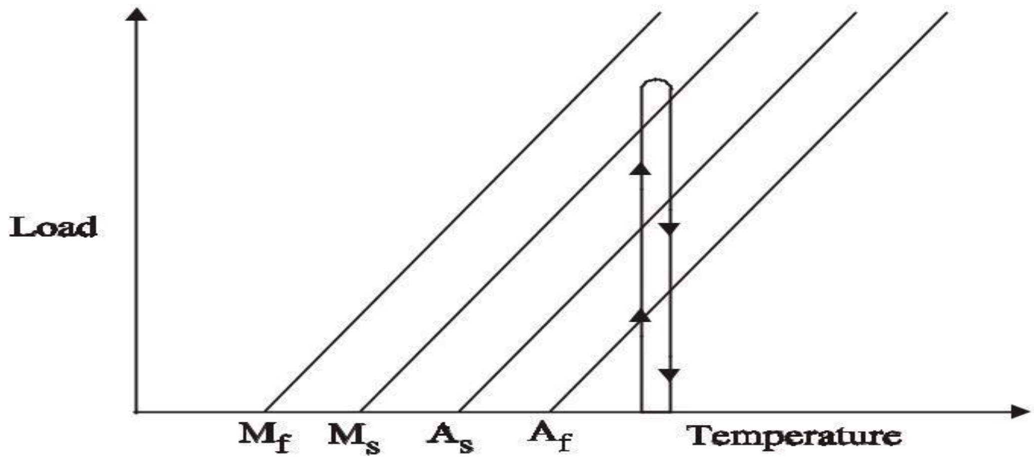


Figure.5.9. Transformation over a range of temperatures.

(i) **Super – elasticity:** *The shape memory alloys which have change in its shape at constant temperature are called* ***super-elastic SMAs*** *and that effect is known as super-elasticity.*

Here, at a single temperature, when the load is applied the SMA will have a new shape(deformed Martensite) and if the load is removed it will regain its original shape (Twinned Martensite), similar to pressing a **rubber** (or) **a spring.**

(iv)Hysterisis: For an SMA, during cooling process, a martensite starts (ms) and ends(me) and during heating process, austenite starts (As) and ends (Ae).

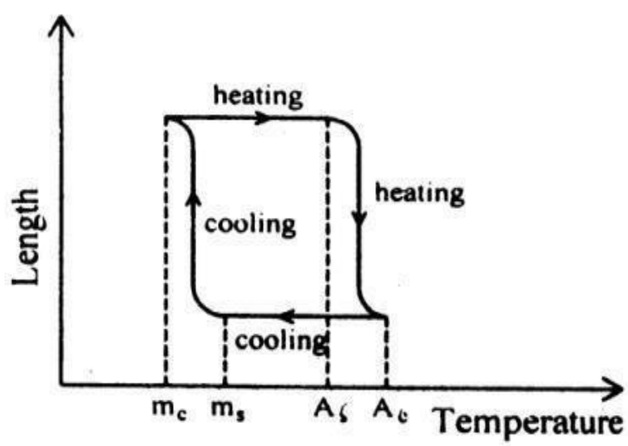


Figure.5.10. Cooling & Heating process

It is found that they do not overlap with each other and the transformation process exhibits the form of hysterisis curve as shown in fig.(4.3.6)

iii.Crystallographically the thermo-elastic martensites are reversible.

APPLICATIONS OF SMA

Shape memory alloys have vast applications in our day-to-day life, as follows:

1.We know that the recently manufactured eye glass frames can be bent back and forth, and can retain its original shape within fraction of time. All these materials are made up of Ni-Ti alloys, which can withstand to maximum deformation.

2.We might have seen toys such as butterflies, snakes etc. which are movable and flexible. These materials are made using SMAs.

3.The life time of Helicopter blades depends on vibrations and their return to its original shape. Hence shape memory alloys are used in helicopter blades.

4.The SMA is cooled and sent into vein, due to body temperature it changes its shape and act as a blood clot filter, by which it controls the blood flow rate.

3.The SMA is mainly used to control and prevent the fire and toxic gases (or) liquids to a large extent. For example, if an SMA is placed in a fire safety valve, when fire occurs, then due to change in temperature the SMA changes its shape and shuts off the fire. Similar principle has been used in the area of leakage in toxic gases (or) liquids.

4. The Ni-Ti spring is used to release the hot milk and the ingredients at certain temperature and to close it after particular time, thereby we can get coffee automatically [coffee makers].

5. SMA is used for cryofit hydraulic couplings i.e., to join the ends of tubes. Here, the SMA material is pasted in between the two tubes to be joint at a particular temperature when the temperature change the SMA expands and thus the two ends are joined.

6. Using SMA the circuit can be connected and disconnected, depending on the variation in temperature. Hence SMA is used as a circuit edge connector.

7. They are used in controlling and preventing cracks.

8. They are used in relays and activators.

9. They are used for steering the small tubes inserted into the human body.

10. They are used to correct the irregularities in teeth.

11. Ni-Ti SMA is also used in artificial hip-joints, bone-plates, pins for healing bones-fractures and also in connecting broken bones.

Advantages

i. SMA is very compact in nature.

ii. It is safe and smart.

iii. They are flexible.

iv They are Non-Corrosive.

Disadvantages

i.Cost is high

ii.Efficiency is low.

iii.Transformation occurs over a range of temperatures.

iv.Structural arrangements may sometime get deformed.