

Module 1: Introduction to Composites

Lecture 1: Definition and Introduction

Introduction

Note: This particular Pdf Covers Introduction about Composite materials, Classifications, advantages, disadvantages, applications and functions of matrix and reinforcements.
100% long answer type question will come

There is an unabated quest for new materials which will satisfy the specific requirements for various applications like structural, medical, house-hold, industrial, construction, transportation, electrical; electronics, etc. Metals are the most commonly used materials in these applications. In the yore of time, there have been specific requirements on the properties of these materials. It is impossible of any material to fulfill all these properties. Hence, newer materials are developed. In the course, we are going to learn more about composite materials. First, we will deal with primary understanding of these materials and then we will learn the mechanics of these materials.

In the following lectures, we will introduce the composite materials, their evolution; constituents; fabrication; application; properties; forms, advantages-disadvantages etc. In the present lecture we will introduce the composite materials with a formal definition, need for these materials, their constituents and forms of constituents.

Definition of a Composite Material

A composite material is defined as a material which is composed of two or more materials at a microscopic scale and has chemically distinct phases.

Thus, a composite material is heterogeneous at a microscopic scale but statistically homogeneous at macroscopic scale. The materials which form the composite are also called as *constituents* or *constituent materials*. The constituent materials of a composite have significantly different properties. Further, it should be noted that the properties of the composite formed may not be obtained from these constituents. However, a combination of two or more materials with significant properties will not suffice to be called as a composite material. In general, the following conditions must be satisfied to be called a composite material:

1. The combination of materials should result in significant property changes. One can see significant changes when one of the constituent material is in platelet or fibrous form.
2. The content of the constituents is generally more than 10% (by volume).
3. In general, property of one constituent is much greater (≥ 5 times) than the corresponding property of the other constituent.

The composite materials can be natural or artificially made materials. In the following section we will see the examples of these materials.

Why we need these materials?

There is unabated thirst for new materials with improved desired properties. All the desired properties are difficult to find in a single material. For example, a material which needs high fatigue life may not be cost effective. The list of the desired properties, depending upon the requirement of the application, is given below.

1. Strength
2. Stiffness
3. Toughness
4. High corrosion resistance
5. High wear resistance

6. High chemical resistance
7. High environmental degradation resistance
8. Reduced weight
9. High fatigue life
10. Thermal insulation or conductivity
11. Electrical insulation or conductivity
12. Acoustic insulation
13. Radar transparency
14. Energy dissipation
15. Reduced cost
16. Attractiveness

The list of desired properties is in-exhaustive. It should be noted that the most important characteristics of composite materials is that their properties are *tailorable*, that is, one can design the required properties.

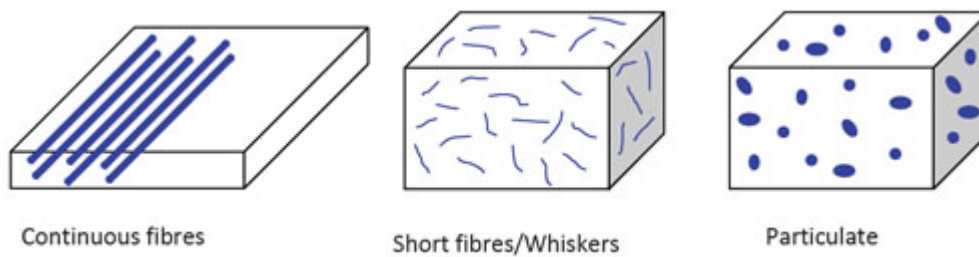


Figure 1.1 Types of reinforcement in a composite

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History of Composites

The existence of composite is not new. The word “composite” has become very popular in recent four-five decades due to the use of modern composite materials in various applications. The composites have existed from 10000 BC. For example, one can see the article by Ashby [1]. The evolution of materials and their relative importance over the years have been depicted in Figure 1 of this article. The common composite was straw bricks, used as construction material.

Then the next composite material can be seen from Egypt around 4000 BC where fibrous composite materials were used for preparing the writing material. These were the laminated writing materials fabricated from the papyrus plant. Further, Egyptians made containers from coarse fibres that were drawn from heat softened glass.

One more important application of composites can be seen around 1200 BC from Mongols. Mongols invented the so called “modern” composite bow. The history shows that the earliest proof of existence of composite bows dates back to 3000 BC - as predicted by *Angara Dating*. The bow used various materials like wood, horn, sinew (tendon), leather, bamboo and antler. The horn and antler were used to make the main body of the bow as it is very flexible and resilient. Sinews were used to join and cover the horn and antler together. Glue was prepared from the bladder of fish which is used to glue all the things in place. The string of the bow was made from sinew, horse hair and silk. The composite bow so prepared used to take almost a year for fabrication. The bows were so powerful that one could shoot the arrows almost 1.5 km away. Until the discovery of gun-powder the composite bow used to be a very lethal weapon as it was a short and handy weapon.

As said, “Need is the mother of all inventions”, the modern composites, that is, polymer composites came into existence during the Second World War. During the Second World War due to constraint impositions on various nations for crossing boundaries as well as importing and exporting the materials, there was scarcity of materials, especially in the military applications. During this period the fighter planes were the most advanced instruments of war. The light weight yet strong materials were in high demand. Further, applications like housing of electronic radar equipments require non-metallic materials. Hence, the Glass Fibre Reinforced Plastics (GFRP) were first used in these applications. Phenolic resins were used as the matrix material. The first use of composite laminates can be seen in the *Havilland Mosquito Bomber* of the British Royal Air Force.

The composites exist in day to day life applications as well. The most common existence is in the form of concrete. Concrete is a composite made from gravel, sand and cement. Further, when it is used along with steel to form structural components in construction, it forms one further form of composite. The other material is wood which is a composite made from cellulose and lignin. The advanced forms of wood composites can be ply-woods. These can be particle bonded composites or mixture of wooden planks/blocks with some binding agent. Now days, these are widely used to make furniture and as construction materials.

An excellent example of natural composite is muscles of human body. The muscles are present in a layered system consisting of fibers at different orientations and in different concentrations. These result in a very strong, efficient, versatile and adaptable structure. The muscles impart strength to bones and vice a versa. These two together form a structure that is unique. The bone itself is a composite structure. The bone contains mineral matrix material which binds the collagen fibres together.

The other examples include: wings of a bird, fins of a fish, trees and grass. A leaf of a tree is also an excellent example of composite structure. The veins in the leaf not only transport food and water, but also impart the strength to the leaf so that the leaf remains stretched with maximum surface area. This helps the plant to extract more energy from sun during photo-synthesis.

What are the constituents in a typical composite?

In a composite, typically, there are two constituents. One of the constituent acts as a reinforcement and other acts as a matrix. Sometimes, the constituents are also referred as *phases*.

What are the types of reinforcements?

The reinforcements in a composite material come in various forms. These are depicted through Figure 1.1.

1. **Fibre:** Fibre is an individual filament of the material. A filament with length to diameter ratio above 1000 is called a fibre. The fibrous form of the reinforcement is widely used. The fibres can be in the following two forms:
 - a. **Continuous fibres:** If the fibres used in a composite are very long and unbroken or cut then it forms a continuous fibre composite. A composite, thus formed using continuous fibres is called as *fibrous composite*. The fibrous composite is the most widely used form of composite.
 - b. **Short/chopped fibres:** The fibres are chopped into small pieces when used in fabricating a composite. A composite with short fibres as reinforcements is called as *short fibre composite*.

In the fibre reinforced composites, the fibre is the major load carrying constituent.

2. **Particulate:** The reinforcement is in the form of particles which are of the order of a few microns in diameter. The particles are generally added to increase the modulus and decrease the ductility of the matrix materials. In this case, the load is shared by both particles and matrix materials. However, the load shared by the particles is much larger than the matrix material. For example, in an automobile application carbon black (as a particulate reinforcement) is added in rubber (as matrix material). The composite with reinforcement in particle form is called a *particulate composite*.
3. **Flake:** Flake is a small, flat, thin piece or layer (or a chip) that is broken from a larger piece. Since these are two dimensional in geometry, they impart almost equal strength in all directions of their planes. Thus, these are very effective reinforcement components. The flakes can be packed more densely when they are laid parallel, even denser than unidirectional fibres and spheres. For example, aluminum flakes are used in paints. They align themselves parallel to the surface of the coating which imparts the good properties.
4. **Whiskers:** These are nearly perfect single crystal fibres. These are short, discontinuous and polygonal in cross-section.

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The classification of composites based on the form of reinforcement is shown in Figure 1.2. The detailed classification further is given in Figure 1.3. The classification of particulate composites is depicted further in Figure 1.4. Some of the terms used in these classifications will be explained in the following paragraphs/lectures.

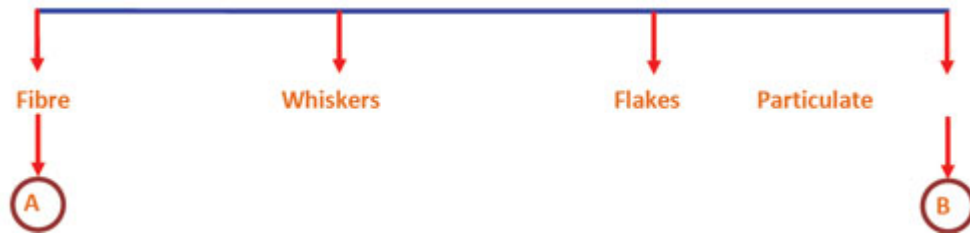


Figure 1.2: Classification of composites based on reinforcement type

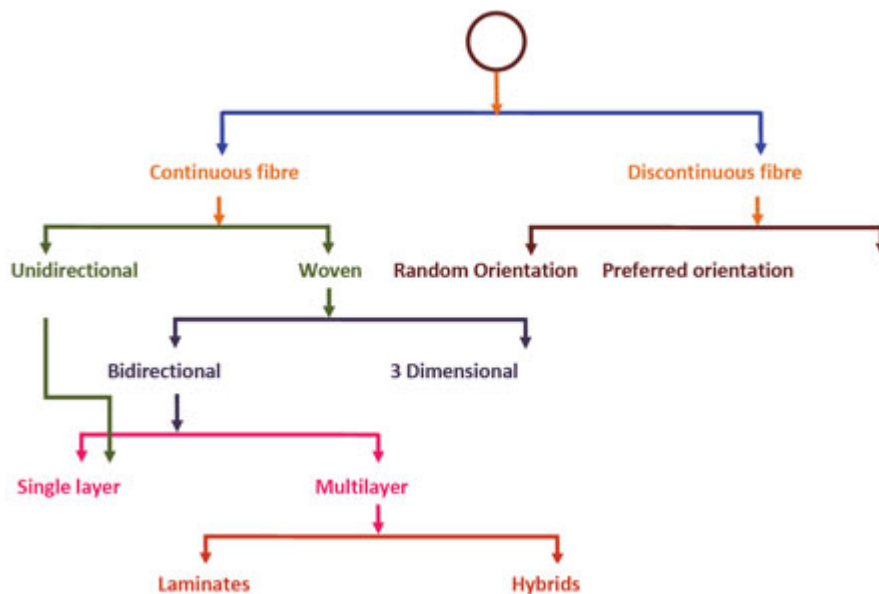


Figure 1.3: Classification of fibre composite materials

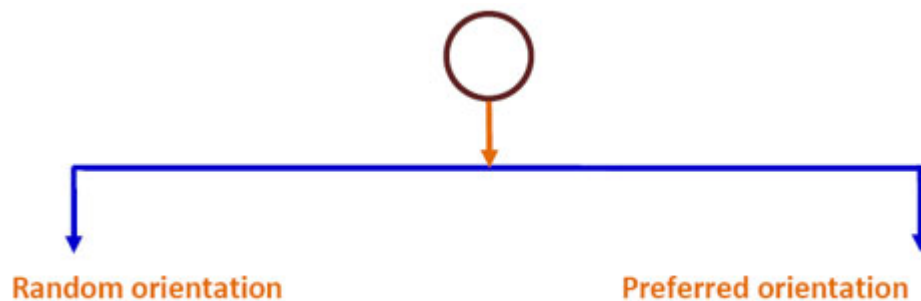


Figure 1.4: Classification of particulate composites

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Lecture 4: Matrix Materials

Introduction

In the previous lecture we have introduced various advanced fibres along with their fabrication processes, precursor materials and key features. In the present lecture we will introduce some matrix materials, their key features and applications.

What are the matrix materials used in composites?

The matrix materials used in composites can be broadly categorized as: Polymers, Metals, Ceramics and Carbon and Graphite.

The polymeric matrix materials are further divided into:

1. Thermoplastic – which soften upon heating and can be reshaped with heat and pressure.
2. Thermoset – which become cross linked during fabrication and does not soften upon reheating.

The metal matrix materials are: Aluminum, Copper and Titanium.

The ceramic materials are: Carbon, Silicon carbide, Silicon nitride.

The classification of matrix materials is shown in Figure 1.11.

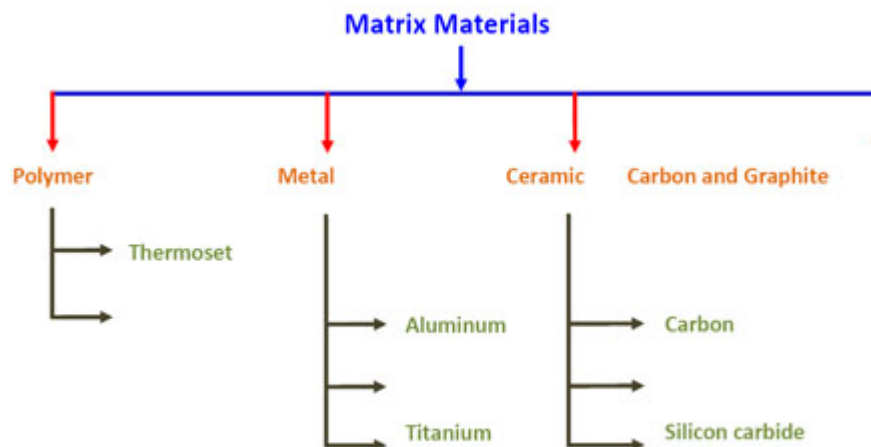


Figure 1.11: Matrix materials

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Lecture 2: Reinforcement: Materials and Forms

Introduction

In the previous lecture we have introduced the composite. Then we have seen the constituents of a typical composite material. Further, based on the reinforcement, the classification of the composite was presented.

In the present lecture we will introduce natural fibres and some advanced fibres. We will see, in brief, the key features of these advanced fibres.

What are the functions of a reinforcing agent?

The functions of a reinforcing agent are:

1. These are the main load carrying constituents.
2. The reinforcing materials, in general, have significantly higher desired properties. Hence, they contribute the desired properties to the composite.
3. It transfers the strength and stiffness to the matrix material.

What are the functions of a matrix material?

The matrix performs various functions. These functions are listed below:

1. The matrix material holds the fibres together.
2. The matrix plays an important role to keep the fibres at desired positions. The desired distribution of the fibres is very important from micromechanical point of view.
3. The matrix keeps the fibres separate from each other so that the mechanical abrasion between them does not occur.
4. It transfers the load uniformly between fibers. Further, in case a fibre is broken or fibre is discontinuous, then it helps to redistribute the load in the vicinity of the break site.
5. It provides protection to fibers from environmental effects.
6. It provides better finish to the final product.
7. The matrix material enhances some of the properties of the resulting material and structural component (that fibre alone is not able to impart). For example, such properties are: transverse strength of a lamina, impact resistance

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Lecture 5: Terminologies

What are the advantages of the composite materials?

The following are the advantages of composites:

1. *Specific stiffness and specific strength:*

The composite materials have high specific stiffness and strengths. Thus, these material offer better properties at lesser weight as compared to conventional materials. Due to this, one gets improved performance at reduced energy consumption.

2. *Tailorable design:*

A large set of design parameters are available to choose from. Thus, making the design procedure more versatile. The available design parameters are:

1. Choice of materials (fiber/matrix), volume fraction of fiber and matrix, fabrication method, layer orientation, no. of layer/laminae in a given direction, thickness of individual layers, type of layers (fabric/unidirectional) stacking sequence.
2. A component can be designed to have desired properties in specific directions.

3. *Fatigue Life:*

The composites can with stand more number of fatigue cycles than that of aluminum. The critical structural components in aircraft require high fatigue life. The use of composites in fabrication of such structural components is thus justified.

4. *Dimensional Stability:*

Strain due to temperature can change shape, size, increase friction, wear and thermal stresses. The dimensional stability is very important in application like space antenna. For composites, with proper design it is possible to achieve almost zero coefficient of thermal expansion.

5. *Corrosion Resistance:*

Polymer and ceramic matrix material used to make composites have high resistance to corrosion from moisture, chemicals.

6. *Cost Effective Fabrication:*

The components fabricated from composite are cost effective with automated methods like filament winding, pultrusion and tape laying. There is a lesser wastage of the raw materials as the product is fabricated to the final product size unlike in metals.

7. *Conductivity:*

The conductivity of the composites can be achieved to make it a insulator or a highly conducting material. For example, Glass/polyesters are non conducting materials. These materials can be used in space ladders, booms etc. where one needs higher dimensional stability, whereas copper matrix material gives a high thermal conductivity.

The list of advantages of composite is quite long. One can find more on advantages of composite in reference books and open literature.

What are the disadvantages of Composites?

1. Some fabrics are very hard on tooling.
2. Hidden defects are difficult to locate.
3. Inspection may require special tools and processes.
4. Filament-wound parts may not be repairable. Repairing may introduce new problems.
5. High cost of raw materials.
6. High initial cost of tooling, production set-up, etc.
7. Labour intensive.
8. Health and safety concerns.
9. Training of the labour is essential.
10. Environmental issues like disposal and waste management.
11. Reuse of the materials is difficult.
12. Storage of frozen pre-pregs demands for additional equipments and adds to the cost of production.
13. Extreme cleanliness required.
14. The composites, in general, are brittle in nature and hence easily damageable.
15. The matrix material is weak and hence the composite has low toughness.
16. The transverse properties of lamina or laminate are, in general, weak.
17. The analysis of the composites is difficult due to heterogeneity and orthotropy.

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Lecture 6: Applications

Introduction

This lecture is dedicated to the use of composites. The use of composites is almost ubiquitous! The use of composites is an inexhaustive list. In the following we cite some important applications.

What are the applications of the composite materials?

The applications of the composites are given in the following as per the area of application.

Aerospace:

- Aircraft, spacecraft, satellites, space telescopes, space shuttle, space station, missiles, boosters rockets, helicopters (due to high specific strength and stiffness) fatigue life, dimensional stability.
- All composite voyager aircraft flew nonstop around the world with refueling.
- Carbon/carbon composite is used on the leading edges nose cone of the shuttle.
- B2 bomber - both fiber glass and graphite fibers are used with epoxy matrix and polyimide matrix.
- The indigenous Light Combat Aircraft (LCA - Tejas) has Kevlar composite in nose cone, Glass composites in tail fin and carbon composites form almost all part of the fuselage and wings, except the control surfaces of the wing.
- Further, the indigenous Light Combat Helicopter (LCH – Dhruvh) has carbon composites for its main rotor blades. The other composites are used in tail rotor, vertical fin, stabilizer, cowling, radome, doors, cockpit, side shells, etc.

Missile:

- Rocket motor cases
- Nozzles
- Igniter
- Inter stage structure
- Equipment section
- Aerodynamic fairings

Launch Vehicle:

- Rocket motor case
- Interstage structure
- Payload fairings and dispensers
- High temperature Nozzle
- Nose cone
- Control surfaces

Composite Railway Carrier:

- Composite railway auto carrier
- Bodies of Railway Bogey
- Seats
- Driver's Cabin
- Stabilization of Ballasted Rail Tracks
- Doors
- Sleepers for Railway Girder Bridges

- Gear Case
- Pantographs

Sports Equipments

- Tennis rockets, golf clubs, base-ball bats, helmets, skis, hockey sticks, fishing rods, boat hulls, wind surfing boards, water skis, sails, canoes and racing shells, paddles, yachting rope, speed boat, scuba diving tanks, race cars reduced weight, maintenance, corrosion resistance.

Automotive

- Lower weight and greater durability, corrosion resistance, fatigue life, wear and impact resistance.
- Drive shafts, fan blades and shrouds, springs, bumpers, interior panels, tires, brake shoes, clutch plates, gaskets, hoses, belts and engine parts.
- Carbon and glass fiber composites pultruded over on aluminum cylinder to create drive shaft.
- Fuel saving –braking energy can be stored in to a carbon fiber super flywheels.
- Other applications include: mirror housings, radiator end caps, air filter housing, accelerating pedals, rear view mirrors, head-lamp housings, and intake manifolds, fuel tanks.

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Module 1: Introduction to Composites**Lecture 6: Applications****Infrastructure Structures:**

- Corrosion is a major design consideration such as in the chemical and on off- shore oil plate forms
- Skeletal Structures
- Walls and Panels
- Doors, Windows, Ladders, Staircases
- Chemical and Water Tanks
- Cooling Towers
- Bridge Decks
- Antenna Dishes
- Bridge enclosures
- Aerodynamic fairings

Industrial:

- Drive,
- conveyer belts,
- hoses,
- tear and puncture resistant fabrics,
- rotor vanes,
- mandrels,
- ropes,
- cables.

Medical:

- Wheelchairs,
- Crutches,
- Hip joints,
- Heat valves,
- Dentistry,
- Surgical equipments

Electronic:

- Chips in electronic computing devices are laminated hybrid systems composed of a number of layers (materials) which serve different functions.
- Chip must have good heat transfer properties and must be able to withstand induced thermal stresses without delaminating.
- The composite finds a vast usage in electronic packaging materials. The Styrofoam, particle bonded materials formed from paper pulp, air-bubble cushioned plastic sheets, etc. are some of the popular materials used in the packing.

Military:

- Helmets,
- bullet proof vests,
- impact resistant vehicles,

- lighter and less detectable ships,
- portable bridges.

Marine:

The Glass reinforced fibre plastics are used in:

- Ship and Boat Hulls
- Masts
- Instrument Panels
- Hydrofoils
- Hovercrafts
- Propellers
- Propulsion shafts
- Rudders
- Heat exchangers
- Flywheel
- Piping
- Ventilation ducts
- Engine and equipment foundations

Wind Power Engineering:

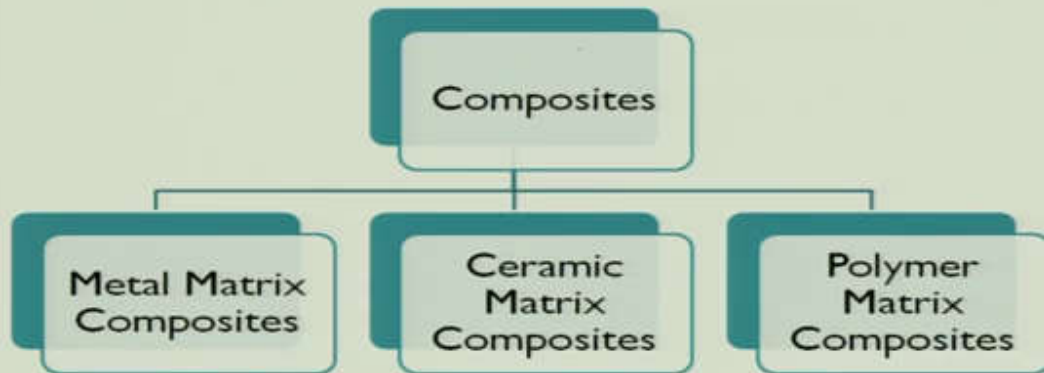
- Rotor blades including blade shell, integral webs, spars or box structure.
- Mast
- Generator housing

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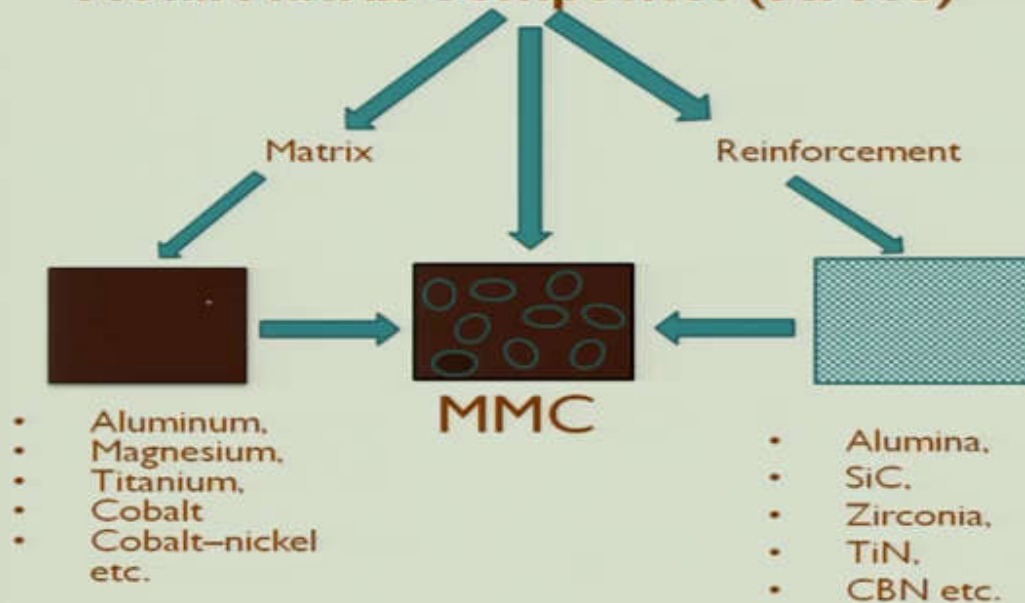
Out of MMC,CMC,PMC one long answer question can expect and from FRC, natural and reinforcements can expect short answer questions.

Important Reinforcements: Glass,Aramid or Kevlar

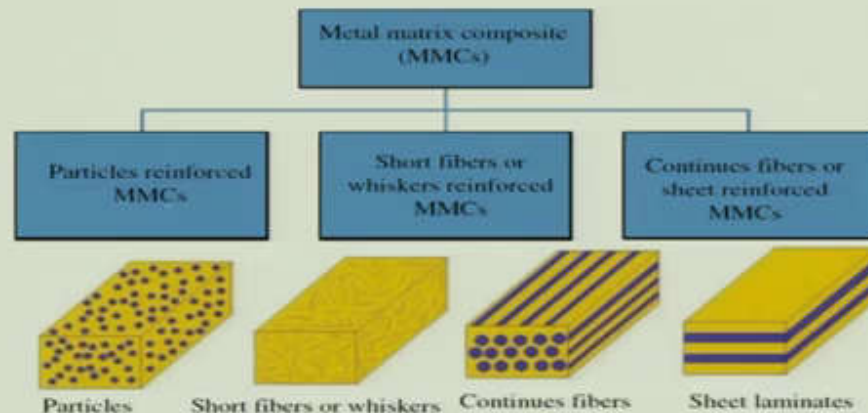
Classification of Composites



Metal Matrix Composites (MMCs)



Classification of MMCs



Mistry et. al. "Research review of diversified reinforcement on aluminum metal matrix composites: fabrication processes and mechanical characterization." *Science and Engineering of Composite Materials*.

Metal Matrix Composites (MMC)

- A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramics or organic compound.
- Reinforcement: Alumina, SiC, Zirconia, TiN, cBN (cubic boron nitride) etc.
- Matrix: Aluminum, Steel, Magnesium, Titanium, Cobalt and Cobalt-nickel etc.

Reinforcements for MMC

- The reinforcement material is embedded into the matrix to enhance or reduce their properties like wear resistance, hardness, density, porosity, mechanical strength, thermal expansion, thermal and electric conductivities.
- The reinforcement can be either continuous or discontinuous

Matrices for MMC

- The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous.
- In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

Advantages of MMC

- Higher temperature capability
- Fire resistance
- Higher transverse stiffness and strength
- No moisture absorption
- Higher electrical and thermal conductivities
- Better radiation resistance
- Higher specific strength and modulus over metals.
- Lower coefficients of thermal expansion than metals by reinforcing with graphite.
- Fabric ability of whisker and particulate-reinforced MMCs with conventional metalworking equipment.

Disadvantages of MMC

- Higher cost of some material systems .
- Relatively immature technology .
- Complex fabrication methods for fiber-reinforced systems (except for casting).

Metal Matrix Composites: applications

Space applications



Space Shuttle - main cargo bay struts

material: MMC - 6061/B/50f
total weight saving: 145 kg (-44% vs Al)
materials costs: > 1'000 US-\$ / kg

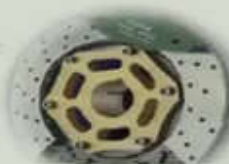
Metal Matrix Composites: applications

Automotive applications – brake discs and drums

*Alcan cast engineered products
(formerly: Duralcan®)*

brake discs & drums

material: MMC - type A359/SiC/20p
VW Lupo
Toyota RAV-4EV
Plymouth Prowler
GM EV-1, Precept, Impact
Ford Prodigy
race carts (various)
....



Metal Matrix Composites: applications

Railway applications – brake discs and drums



ICE - brake discs

material: MMC - A359/SiC/20p
weight of disc: 74 kg (~38% vs cast iron)
total weight saving: 10 tons (192 discs)
successfully tested: over 1 Mio km

application introduced in the new Copenhagen metro



Metal Matrix Composites: applications

Aerospace applications



Metal Matrix Composites: applications

Power transmission – composite conductors



electrical conductors (3M)

material: MMC - Al/Nextel610/45f

tensile strength: 1200 MPa

density: 3.2 g/cm³

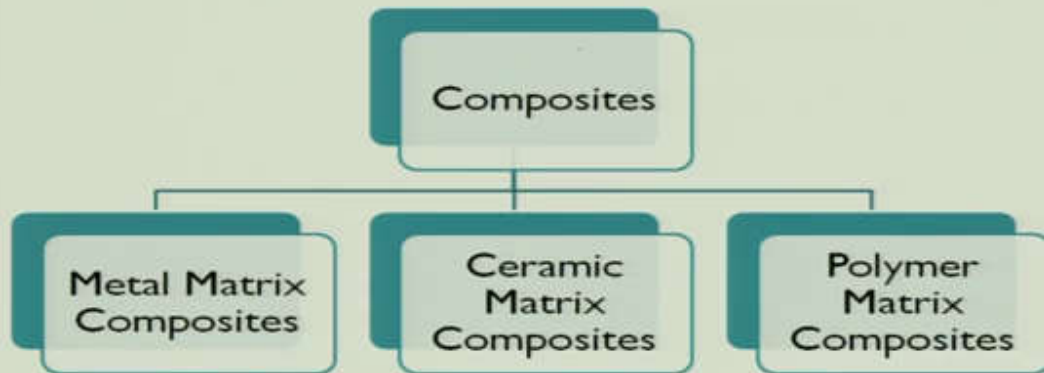
CTE: 6.6 ppm/K

electrical conductivity: 34 % IACS



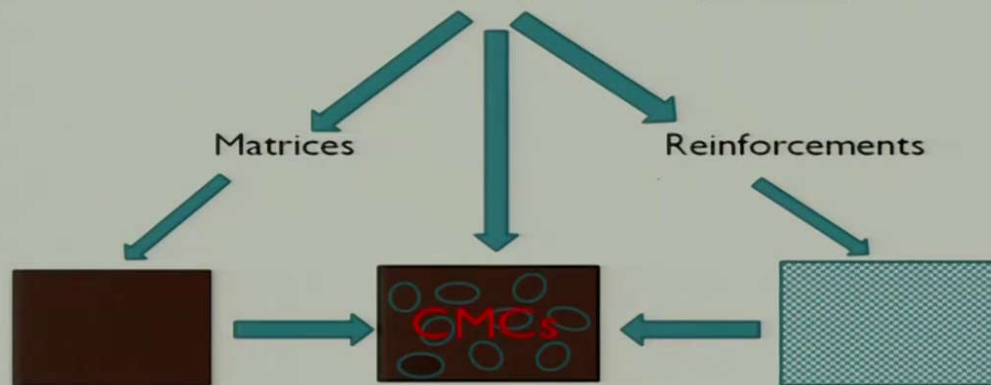
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Classification of Composites



Introduction

Ceramic Matrix Composites (CMCs)



Introduction



<i>Matrix</i>
SiC ✓
Si ₃ N ₄
MoSi ₂
B ₄ C
BN (hexagonal)
AlN
TiB ₂
TiN ¹
TiC ¹

<i>Particulates</i>	<i>Platelets</i>	<i>Whiskers</i>	<i>Fibers</i>
SiC, TiC, TiN, TiB ₂	SiC	B ₄ C	C, SiC
ZrO ₂ , TiB ₂ , Nb, SiC,	Si ₃ N ₄	Si ₃ N ₄	SiC, Al ₂ O ₃ , C
Si ₃ N ₄	Al ₂ O ₃	SiC	SiC, Al ₂ O ₃
TiB ₂ , Al ₂ O ₃	SiC	SiC	C, SiC
B ₄ C		SiC	
B ₄ C, BN			

Introduction

Ceramic matrix composites (CMCs) are a subgroup of composite material as well as a subgroup of technical ceramic.

- By definition, ceramic matrix composites are materials in which one or more distinct ceramic phases are intentionally added to another, in order to enhance some property that is not possessed by the monolithic ceramic materials.
- In ceramic matrix composites, a given ceramic matrix is reinforced with either discontinuous reinforcement, such as particles, whiskers or chopped fibers or with continuous fibers.
- The basic reinforcements which are included in the ceramic matrices are carbon, glasses, glass-ceramics, oxides and non-oxides

Properties of CMCs

1. High strength-to-weight ratio ✓
2. Wear resistance
3. Corrosion resistance
4. Greater Fatigue life
5. Low Electrical conductivity
6. Anisotropic
7. Lower Cost
8. Easy Processing
9. The matrix is relatively hard and brittle
10. The reinforcement must have high tensile strength to arrest crack growth
11. The reinforcement must be free to pull out as a crack extends, so the reinforcement-matrix bond must be relatively weak

Advantages of CMC's

1. Excellent wear and corrosion resistance in a wide range of environments and temperature
2. Higher strength to weight ratio
3. Higher strength retention at elevated temperature
4. Higher chemical stability
5. Non-catastrophic failure
6. High hardness
7. Lightweight

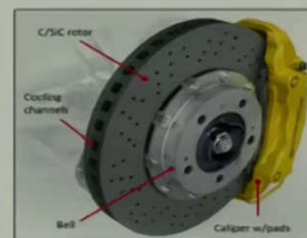
Disadvantages of CMC's

1. Processing routes for CMCs involve high temperatures – can only be employed with high temperature reinforcements.
2. CMCs are designed to improve toughness of monolithic ceramics, the main disadvantage of which is brittleness.
3. High processing temperature results in complexity in manufacturing and hence expensive processing.
4. Difference in the coefficients of thermal expansion between the matrix and the reinforcement lead to thermal stresses on cooling from the processing temperatures.

Applications of CMCs

Automotive Ind.-Braking systems

- Ceramic composite brakes: C/SiC
 - High braking performance
 - Low weight (2.4 g/cm^3)
 - Low wear rate
 - Operating temperatures $1,400^\circ\text{C}$
- First studied in 1990s, available in 2000s
 - Mercedes CL 55 AMG F1 Lim. Ed. (2000)
 - Porsche 911 GT2 (2001) (PCCB)
- 50,000-70,000 CMC brake discs manufactured in 2006
 - SICOMTM, BREMBOTM, etc.



Porsche Cars Great Britain Ltd.,
available at <http://www.porsche.com/uk/>
(Accessed 15 Oct 2014).

Aerospace Ind.-Nozzle

An F-16 Fighting Falcon F100 engine exhaust nozzle with five A500 ceramic matrix composite divergent seals, identified by the yellow arrows. (Air Force photo)

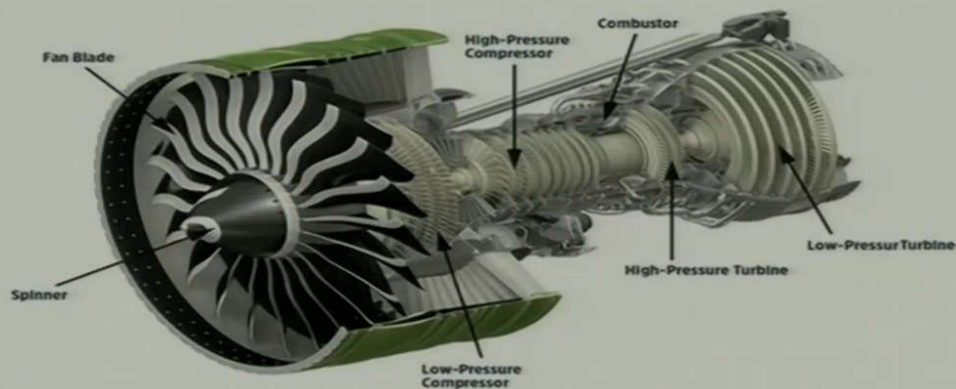


Oxide CMC exhaust ground test demonstrator consists of a 1.60-m diameter nozzle and 1.14-m diameter $\times$ 2.34-m conical center body with titanium end cap inspection portal



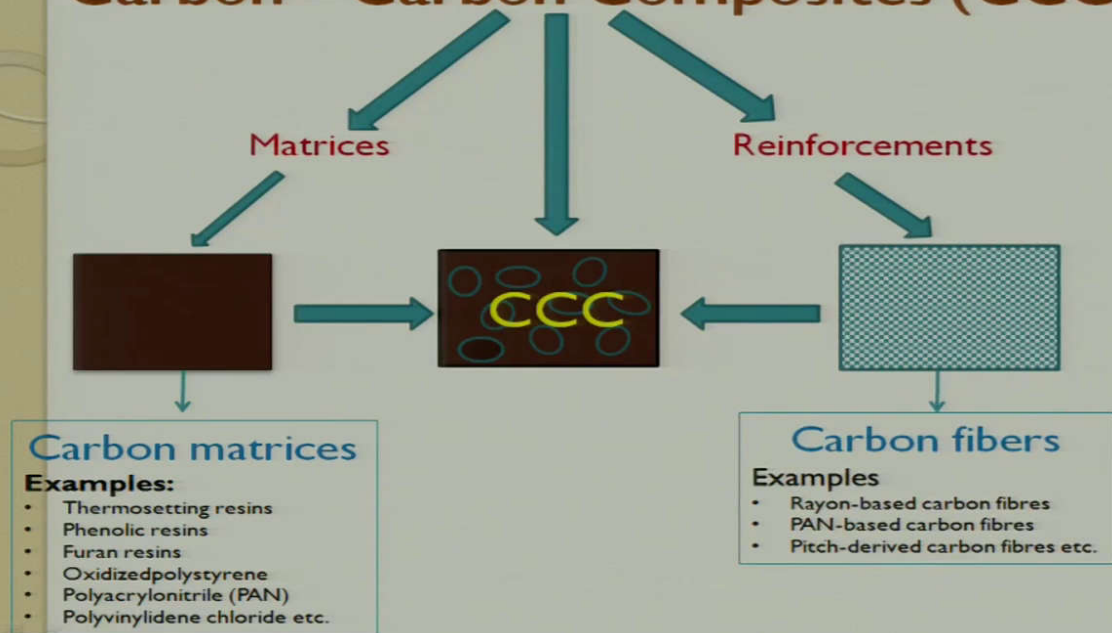
CMCs are excellent candidates for replacing the nickel-based super alloys currently used in exhaust nozzle parts, primarily due to their capacity to withstand the high temperatures and severe operational environment for much longer periods of time with minimal changes in structural behavior.

Aerospace Ind.-Nozzle

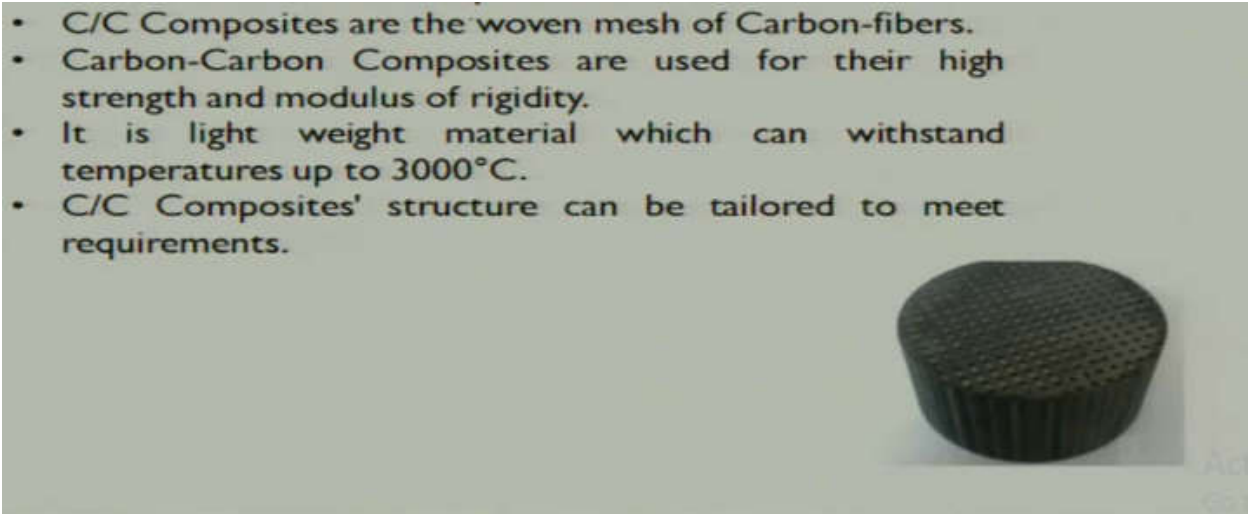


Aero engine Composites : The CMC invasion

Carbon – Carbon Composites (CCC)



- **C/C Composites consist of carbon fibers embedded in a carbon matrix (Both Reinforcement and Matrix are carbon)**
- **These materials are relatively new and expensive, and therefore, are not currently being utilized extensively.**



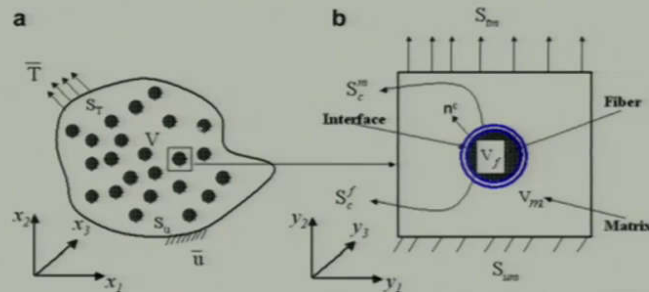
Carbon fiber (Reinforcements)

- High-performance C/C composites are tailored to the mechanical properties requirement of the final structure.
- The types of carbon fibers commercially available are high-tensile, high-modulus, and intermediate-modulus fibers.



Carbon fiber (Reinforcements)

- These fibers are prepared from pitch or polyacrylonitrile (PAN)
- Composed of carbon atoms bonded together to form a long chain.
- A super strong material that's also extremely lightweight.
- Five times stronger than steel , Two times stiffer , and about Two-Third times less in weight.



Carbon matrix

- The carbon matrix in C/C composites has to effectively transfer the mechanical loads to the fiber reinforcements
- It acts as a binder to maintain the alignment of the fibers and fiber bundles and at the same time isolates the fibers from one another.

Properties of CCC

- Excellent Thermal Shock Resistance(Over 2000°C)
- Low Coefficient of Thermal Expansion
- High Modulus of Elasticity (200 GPa)
- High Thermal Conductivity (100 W/m*K)
- Low Density (1830 Kg/m³)
- High Strength
- Low Coefficient of Friction (in Fiber direction)
- Thermal Resistance in non-oxidizing atmosphere
- High Abrasion Resistance
- High Electrical Conductivity
- Non-Brittle Failure

Advantages

- Light Weight ($1.6-2.0\text{g/cm}^3$)
- High Strength at High Temperature (up to $3000\text{ }^\circ\text{C}$) in non-oxidizing atm.
- Low Coefficient of thermal expansion.
- High thermal conductivity ($>\text{Cu \& Ag}$).
- High thermal shock resistance.

Disadvantages

- High fabrication cost.
- Porosity.
- Poor oxidation resistance – formation of gaseous oxides in oxygen atm.
- Poor inter-laminar properties.
- Low oxidation resistance
- Reacts with Oxygen at temperature above 490°C

Applications of CCC



Rocket nozzles and tips



Space shuttle nose tip and leading edges

<http://www.fibermaterialsinc.com/frSW.htm>

http://www.futureshuttle.com/conference/ThermalProtectionSystem/Curry_73099.pdf

Polymer-Matrix Composites (PMC)

Matrix – Polymer resin
Fibers – reinforcing medium

A) Glass Fiber-Reinforced Polymer (GFRP) Composites

Matrix – Plastic (most often epoxy, polyester resin)

Reinforcement – Glass fiber/E-glass (Diameter = 3-20 μm)

- ✓ Typically 55% SiO_2 , 16% CaO , 15% Al_2O_3 , 10% B_2O_3 , 4% MgO .
- ✓ Easily drawn into high-strength fibers from the molten state.

GFRP (Fiber volume fraction = 0.6), Epoxy matrix

Density	2100 kg/m^3 (Light weight)	
	<i>Longitudinal</i>	<i>Transverse</i>
Tensile Modulus (GPa)	45	12
Tensile strength (MPa)	1020	40



E-glass

Limitation – Service temperature up to 200°C (above which polymer/matrix starts deteriorating).



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APPLICATIONS

Automotive and marine bodies, plastic pipes, storage containers, and industrial floorings.



GFRP Chemical Containers
<http://www.hhzy.chemchina.com/hhzye/>



GFRP rebar used for making pedestrian bridges



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www.yrodcanada.com



Polymer-Matrix Composites (PMC)

B) Carbon Fiber-Reinforced Polymer (CFRP) Composites

Matrix – Polymer resin

Fibers – Carbon fiber (reinforcement)

- Carbon is a high-performance fiber material because
 - ✓ Highest specific modulus (E/ρ) and specific strength of all reinforcing fiber materials and retain same at elevated temperature.
 - ✓ At room temp. not affected by moisture or a wide variety of solvents, acids, and bases.
 - ✓ Manufacturing processes relatively inexpensive and cost effective.
- Fiber diameters normally range between 4 - 10 μm .

CFRP (Fiber volume fraction ≈ 0.6), Epoxy matrix

Density	1600 kg/m ³ (Light weight)	
	<i>Longitudinal</i>	<i>Transverse</i>
Tensile Modulus (GPa)	145	10
Tensile strength (MPa)	1240	40



Carbon fiber



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Reference: <http://www.easycomposites.co.uk/>



Carbon Fiber Wheel - BMW



Reference: <http://www.tcbmw.com/carbon-fiber-reinforced-plastic-cfp-wheels-announced/>



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Other applications - CFRP



Boeing 787 Dreamliner – nearly 50% frame of CFRP



Mountain bicycle frame



Lamborghini Aventador LP700-4



CFRP - Wheels, frame, seats



Racket

Reference: <http://www.centralcarbonfiber.com/application/index.html>



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Fiber reinforced Composites

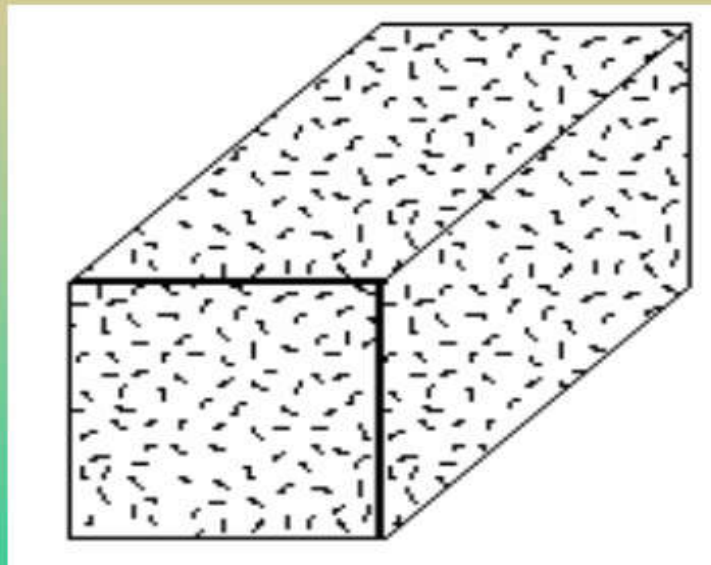
- Fiber reinforced composites are composed of fibers embedded in matrix material.
- A composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length
- Fibers are small in diameter and when pushed axially, they bend easily although they have very good tensile properties
- These fibers must be supported to keep individual fibers from bending and buckling

Fibers as the reinforcement (Fibrous Composites):

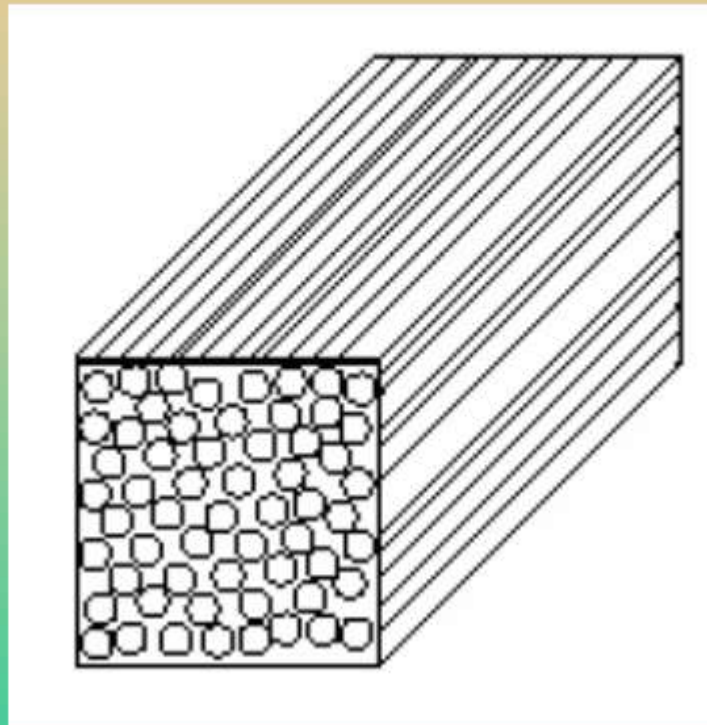
- a. Random fiber (short fiber) reinforced composites**
- b. Continuous fiber (long fiber) reinforced composites**

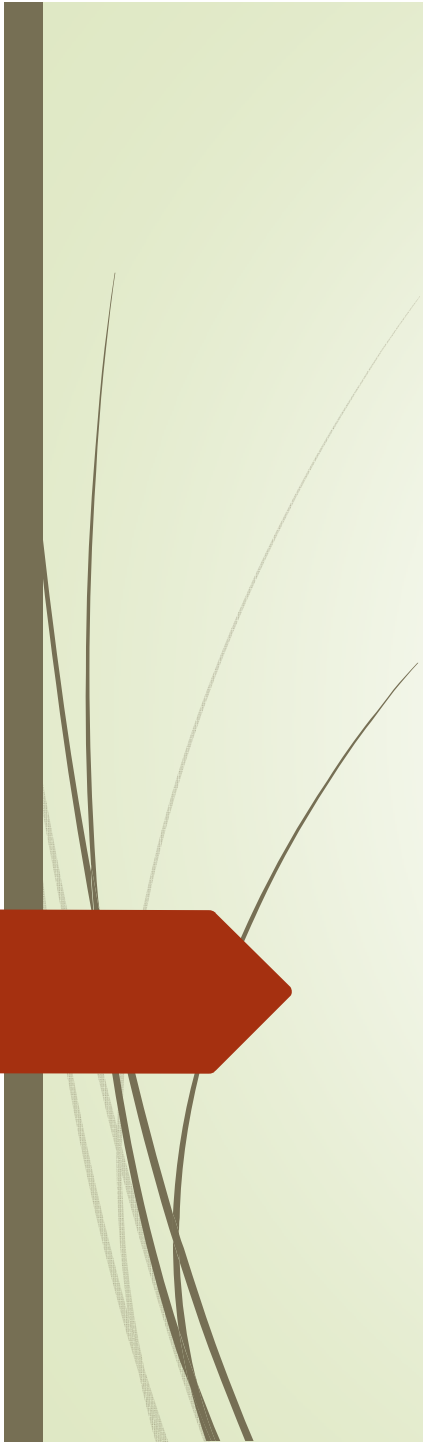
Fibers as the reinforcement (Fibrous Composites):

- a. Random fiber (short fiber) reinforced composites**



Fibers as the reinforcement (Fibrous Composites):
b. Continuous fiber (long fiber) reinforced composites

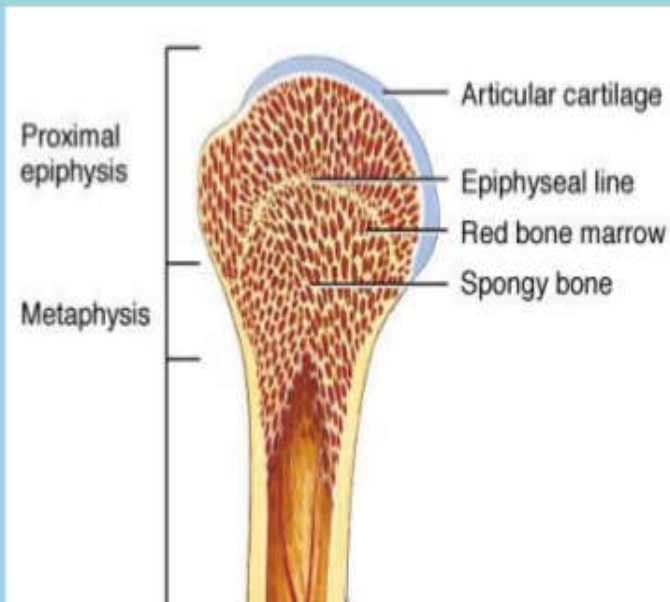




Natural composites

Natural composites

- Wood is a combination of cellulose fibre and lignin. Cellulose provides strength and lignin is the glue that bonds and stabilizes the fibres.



- In bone, collagen protein fibres form the matrix phase, which is reinforced with small rod like crystals of hydroxyapatite about 5nm x 5nm x 50nm size.



Glass fibers

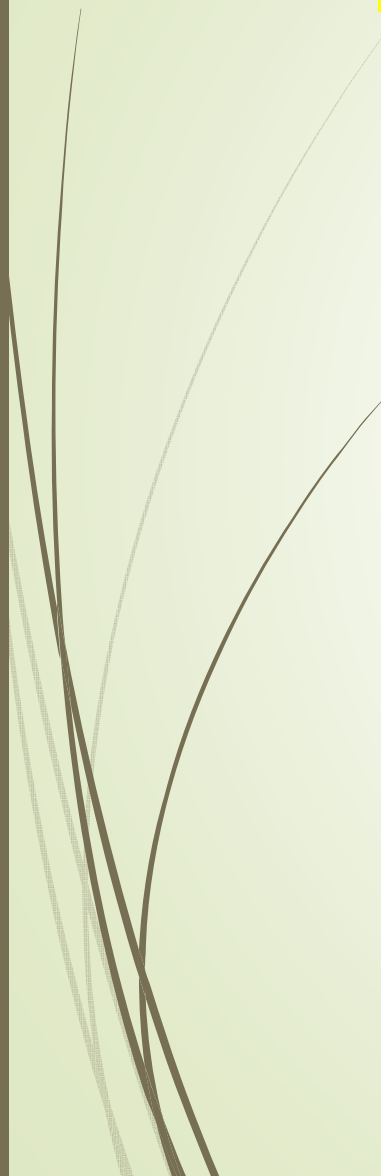
- Chemically glass means SiO_2
- glass fibers are available in continuous and staple forms
- Commonly used glass fibers are E – Glass and S- Glass
- E – Stands for electrical because E glass is a good electrical insulator in addition to having good strength
- S – Stands for the high Silica content that makes S glass withstand higher temperatures than other glasses

Advantages:

- Low cost
- High strength



limitations

- Poor abrasion resistance
 - Poor adhesion to polymer matrix material
 - Poor adhesion in humid environment
- 



How are glass fibers made?

- Raw material: sand, limestone, alumina
- Raw materials are melted in a hopper and the molten glass is fed into the electrically heated platinum crucibles; each crucible contains about 200 holes at its base.
- The molten glass is flows by gravity through the holes, forming fine continuous filaments; these are gathered together into a strand and a size is applied before it is wound on a drum.
- The final diameter is a function of crucible orifice diameter.

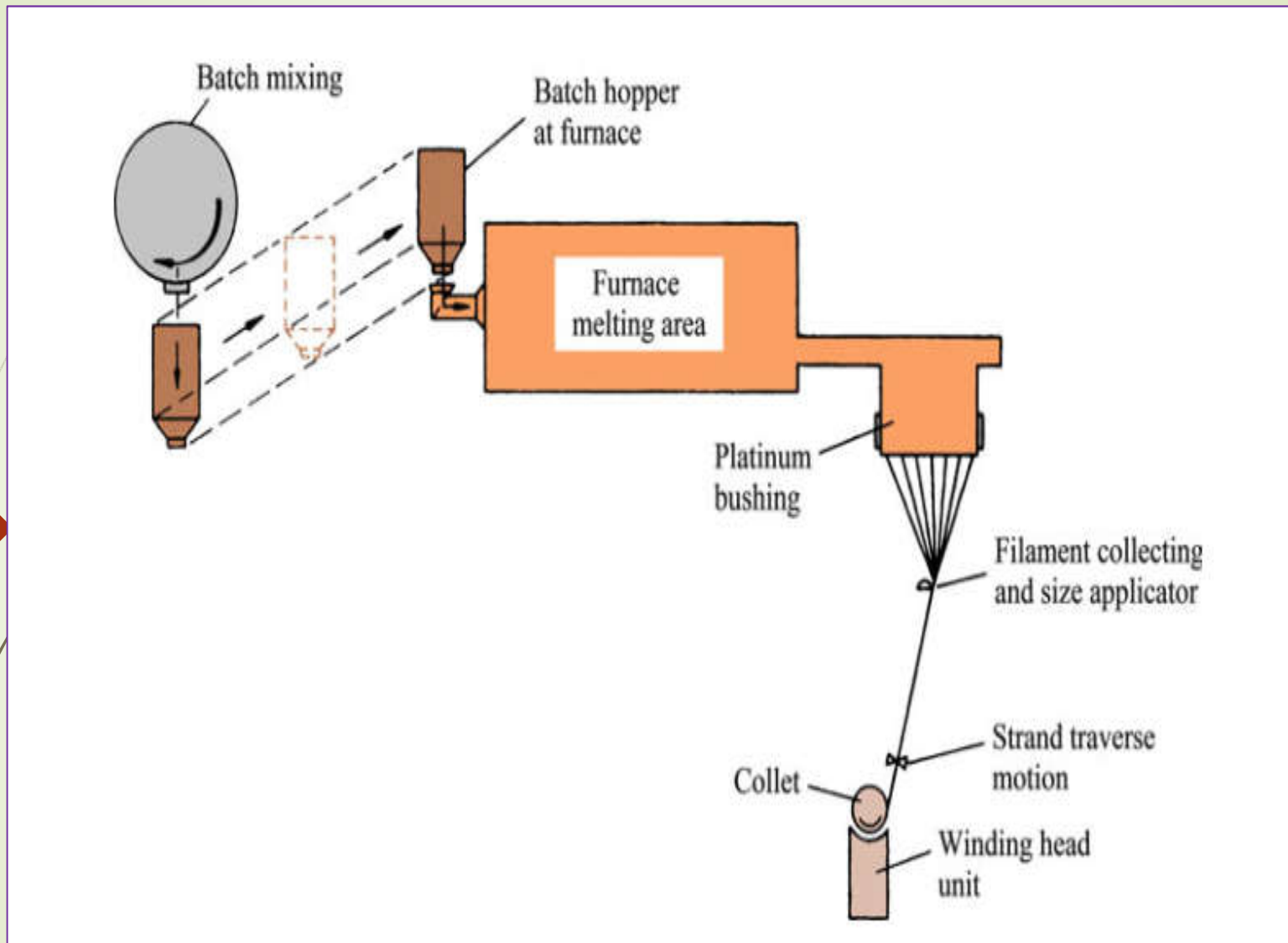


Fig: Schematic of glass fiber manufacture

Advanced Fibres

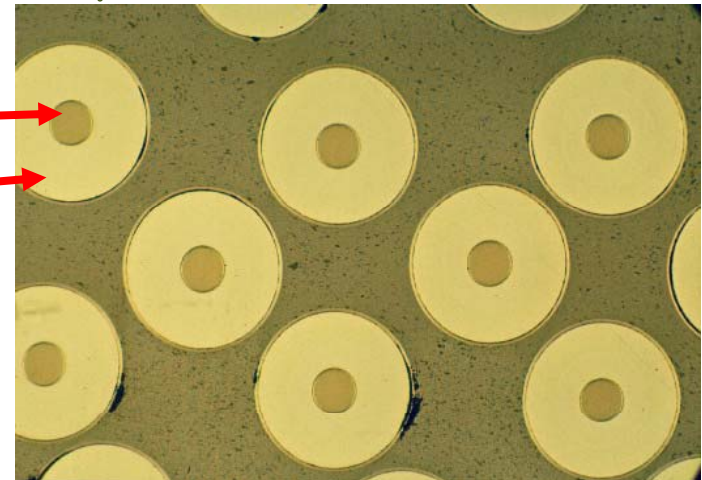
Ceramic Fibres: Boron

It was the first advanced fibre developed for structural application (Talley 1959)

- Ceramic monofilament fiber
- Manufactured by CVD on to a tungsten core of 12 μm diameter

Tungsten

Boron



- Fiber itself is a composite
- Circular cross section
- Fiber diameter ranges between 33 -400 μm and typical diameter is 140 μm
- Boron is brittle hence large diameter results in lower flexibility

CP Talley. J. Appl. Phys. 1959, Vol. 30, pp 1114.

Advanced Fibres

Ceramic Fibres: **Boron**

- Thermal coefficient mismatch between boron and tungsten results in thermal residual stresses during fabrication cool down to room temperature
- When coated with Sic or B_4C can be used to reinforce light alloys
- Strong in both tension and compression
- Exhibit linear axial stress-strain relationship up to $650^{\circ}C$
- High cost of production

Aramid fibers



Introduction

- Aramid is short form of Polyamide and Aromatic
- Developed by Dupont (U.S Based) and they gave it name called Kevlar fibers.

Definition:

- “The fiber forming substance is a long chain synthetic polyamide ” in which at least 85% of amide linkages are directly attached to two aromatic rings

Special features

- high resistance to Abrasion
- high resistance to organic solvents
- Non – conductive
- No melting point (Start degrading at 500 °C)
- low flammability

Applications:

- ✓ Bullet Proof jackets
- ✓ Ballistic protection

Advanced Fibres

Carbon fibres:

- carbon- carbon covalent bond is the strongest in nature

Guess who made the first carbon fibre?

Thomas Edison made carbon fibre from bamboo when experimenting for light bulb !

What is the difference between carbon and graphite fibres?

- Carbon fibre contains 80-95 % of carbon and graphite fibre contains more than 99% carbon
- carbon fibre is produced at 1300°C while graphite fibre is produced in excess of 1900°C

Caution ! - In general term carbon fibre is used for both fibres

Made from two types of precursor materials:

- 1) Polyacrylonitrile (PAN) (PAN Based)
- 2) Rayon Pitch - residue of petroleum refining (Pitch Based)

Module 1: Introduction to Composites
Lecture 4: Matrix Materials

**Important Mfg Methods: Pultrusion, Filament Winding
Autoclave, Hand Lay Up and RTM**

What are the thermoplastic matrix materials? What are their key features?

The following are the thermoplastic materials:

1. polypropylene,
2. polyvinyl chloride,
3. nylon,
4. polyurethane,
5. poly-ether-ether ketone (PEEK),
6. polyphenylene sulfide (PPS),
7. polysulphone.

Note: Study Fabrication techniques of MMC, CCC and differences between plastics, can expect one question.

The key features of the thermoplastic matrix materials are:

1. higher toughness
2. high volume
3. low cost processing
4. The use temperature range is upto 225 °C .

What are the thermoset matrix materials? What are their key features?

The thermoset matrix materials are:

1. polyesters,
2. epoxies,
3. polyimides

The key features of these materials are given for individual material in the following.

Polyesters

1. Used extensively with glass fibers
2. Inexpensive
3. Light weight
4. Temperature range upto 100 °C.
5. Resistant to environmental exposures

Epoxy

1. Expensive
2. Better moisture resistance
3. Lower shrinkage on curing
4. Use temperature is about 175 °C

Polyimide

1. Higher use temperature about 300 °C
2. Difficult to fabricate

What are the problems with the use of polymer matrix materials?

1. Limited temperature range.
2. Susceptibility to environmental degradation due to moisture, radiation, atomic oxygen (in space)
3. Low transverse strength.
4. High residual stress due to large mismatch in coefficients of thermal expansion between fiber and matrix.
5. Polymer matrix cannot be used near or above the glass transition temperature.

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Module 1: Introduction to Composites
Lecture 4: Matrix Materials

Comparison between Thermoplastics and Thermosets:

The comparison between the thermoplastic and thermoset matrix materials is given in Table 1 below:

Table 1.1: Comparison between thermoplastics and thermosets.

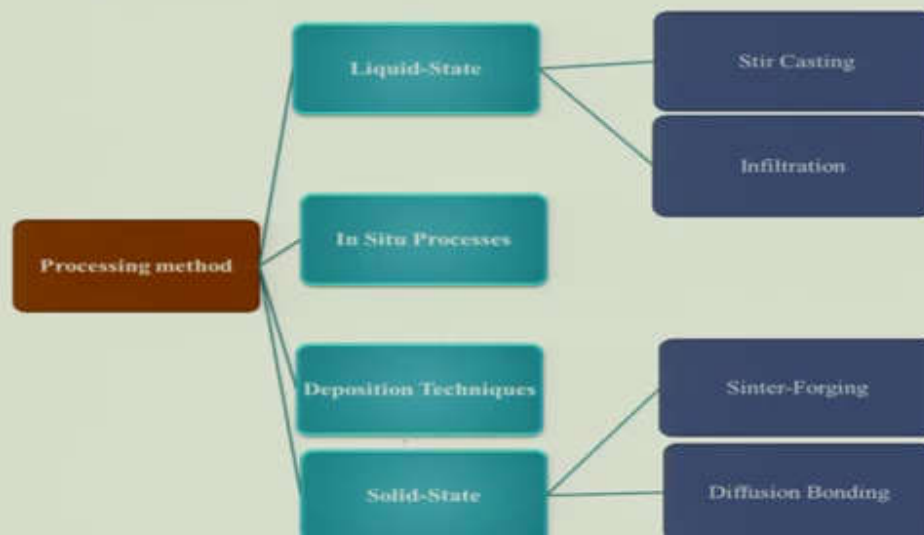
Thermoplastics	Thermosets
Soften upon heat and pressure	Decompose upon heating
Hence, can be repaired	Difficult to repair
High strains are required for failure	Low strains are required for failure
Can be re-processed	Can not be re-processed
Indefinite shelf life	Limited shelf life
Short curing cycles	Long curing cycles
Non tacky and easy to handle	Tacky and therefore, difficult to handle
Excellent resistance to solvents	Fair resistance to solvents
Higher processing temperature is required. Hence, viscosities make the processing difficult.	Lower processing temperature is required.

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Processing of Metal Matrix Composites

- Metal matrix composites materials can be produced by many different techniques.
- The focus of the selection of suitable process engineering is the desired kind, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application.
- By altering the manufacturing method, the processing and the finishing, as well as by the form of the reinforcement components it is possible to obtain different characteristic profiles, although the same composition and amounts of the components are involved.

Processing methods



I. Liquid state fabrication of Metal Matrix Composites (MMCs)

- Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal.
- In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained.
- Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix.

I. Liquid state fabrication of Metal Matrix Composites (MMCs)

The methods of liquid state fabrication of Metal Matrix Composites:

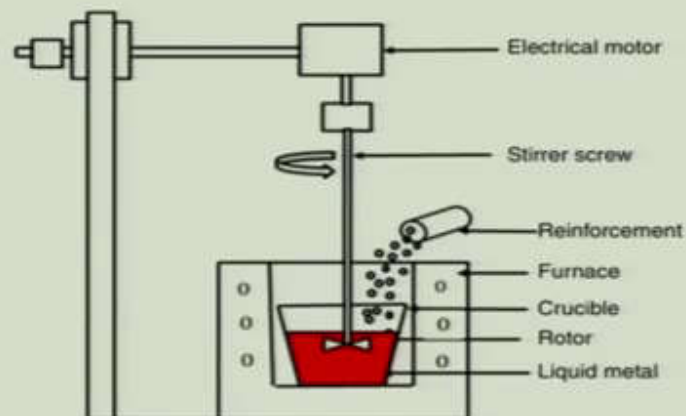
- **Stir Casting**
- **Infiltration**
 - **Gas Pressure Infiltration**
 - **Squeeze Casting Infiltration**
 - **Pressure Die Infiltration**

Stir Casting

- Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring.
- Stir Casting is the simplest and the most cost effective method of liquid state fabrication.

Stir Casting

Schematic diagram of Stir casting technique



Stir Casting

Stir Casting is characterized by the following features:

- Content of dispersed phase is limited (usually not more than 30 vol.%).
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous:
 - There are local clouds (clusters) of the dispersed particles (fibers);
 - There may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase.
- The technology is relatively simple and low cost.
- Distribution of dispersed phase may be improved if the matrix is in semi-solid condition.
- The method using stirring metal composite materials in semi-solid state is called Rheocasting.

Hashim, J., L. Looney, and M. S. J. Hashmi. "Metal matrix composites: production by the stir casting method." *Journal of Materials Processing Technology* 92 (1999): 1-7.

Infiltration

- Infiltration is a liquid state method of composite materials fabrication, in which a preformed dispersed phase (ceramic particles, fibers, woven) is soaked in a molten matrix metal, which fills the space between the dispersed phase inclusions.
- The motive force of an infiltration process may be either capillary force of the dispersed phase (spontaneous infiltration) or an external pressure (gaseous, mechanical, electromagnetic, centrifugal or ultrasonic) applied to the liquid matrix phase (forced infiltration).

Infiltration

Infiltration is one of the methods of preparation of tungsten-copper composites.

The principal steps of the technology are as follows:

- Mixing the tungsten powder with a binder.
- Compacting the powder by a molding method (Compaction should provide the predetermined porosity level).
- Sintering the green compact at 2200-2400F (1204-1315C) in Hydrogen atmosphere for 2 hrs.
- Placing the sintered part on a copper plate (powder) in the infiltration/sintering furnace.
- Infiltration of the sintered tungsten skeleton porous structure with copper at 2100-2300F (110-1260C) in either hydrogen atmosphere or vacuum for 1 hour.

Solid state fabrication of MMC

- Solid state fabrication of Metal Matrix Composites is the process, in which Metal Matrix Composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure.
- Low temperature of solid state fabrication process (as compared to Liquid state fabrication of MMC depresses undesirable reactions on the boundary between the matrix and dispersed (reinforcing) phases.
- MMC may be deformed also after sintering operation by rolling, Forging, pressing, Drawing or Extrusion. The deformation operation may be either cold (below the recrystallization temperature) or hot (above the recrystallization temperature).

Solid state fabrication of MMC

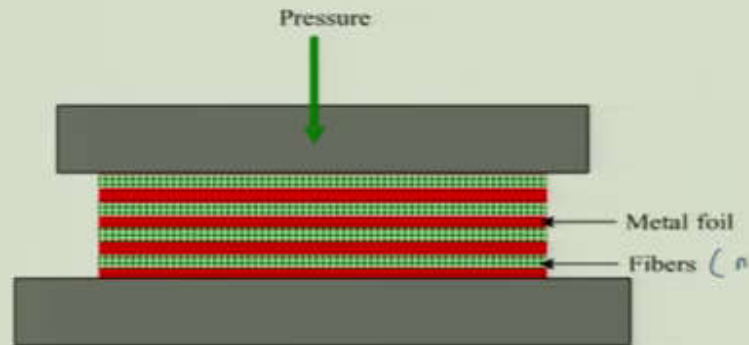
There are two principal groups of solid state fabrication of Metal Matrix Composites:



Diffusion Bonding

- Diffusion Bonding is a solid state fabrication method, in which a matrix in form of foils and a dispersed phase in form of long fibers are stacked in a particular order and then pressed at elevated temperature.
- The finished laminate composite material has a multilayer structure.
- Diffusion Bonding is used for fabrication of simple shape parts (plates, tubes)

Diffusion Bonding process

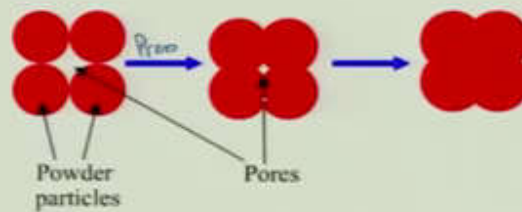


www.substech.com

Sintering

Sintering fabrication of Metal Matrix Composites is a process, in which a powder of a matrix metal is mixed with a powder of dispersed phase in form of particles or short fibers for subsequent compacting and **sintering** in solid state.

In contrast to the liquid state fabrication of Metal Matrix Composites, sintering method allows obtaining materials containing up to 50% of dispersed phase.



www.substech.com

In-situ fabrication of MMC

In situ fabrication of MMC is a process, in which dispersed (reinforcing) phase is formed in the matrix as a result of precipitation from the melt during its cooling and Solidification.

Different types of Metal Matrix Composites may be prepared by in situ fabrication method:

1. Particulate in situ MMC – Particulate composite reinforced by in situ synthesized dispersed phase in form of particles. Examples: Aluminum matrix reinforced by titanium boride (TiB_2) particles,
2. Short-fiber reinforced in situ MMC – Short-fiber composite reinforced by in situ synthesized dispersed phase in form of short fibers or whiskers. Examples: Titanium matrix reinforced by titanium boride (TiB_2) whiskers,
3. Long-fiber reinforced in situ MMC – Long-fiber composite reinforced by in situ synthesized dispersed phase in form of continuous fibers. Example: Nickel-aluminum (NiAl) matrix reinforced by long continuous fibers of Mo (NiAl-9Mo alloy).

Fabrication Methods

In general, C/C composites are processed by any one of the following four routes (sometimes a combination of two routes is used):

1. Impregnation and pyrolysis using thermosetting resin precursors
2. Impregnation and pyrolysis using thermoplastic pitch precursors
3. CVI
4. CVD

I. Thermosetting Resin-Based Processing of CCC

- The resins are usually dissolved in an organic solvent or furfuryl alcohol with a catalyst/curing agent before infiltration.
- The resin in the impregnated composite is cured and then pyrolyzed by heating it to a temperature in the range of 350°C–800°C
- Frequently hot pressing at pressures up to 10 MPa and temperatures in the range of 150°C–350°C for periods up to 10 h are used to enhance density during the curing process.
- The pyrolyzed composite is subsequently graphitized at temperatures in excess of 1000°C

2. Thermoplastic Pitch-Based Processing of CCC

- The pitch-impregnated preform is subjected to pyrolysis (carbonization) in an inert atmosphere to convert the organic compound to coke and a high-temperature treatment at 1000°C–2700°C for graphitization of coke.
- This densification process is carried out at atmospheric or reduced pressure and is usually repeated several times in order to get appreciable density
- It is a more efficient process, and the coke yield for pitch increases from 50 to 85 wt.%, when the pressure is increased to 70 MPa.

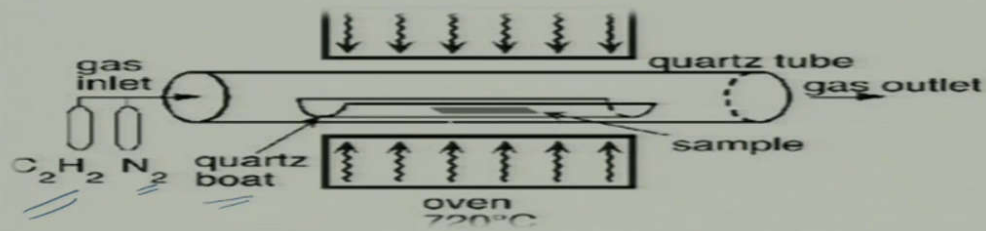
3. Chemical Vapor Infiltration (CVI) processing of CCC

- The infiltration of the gaseous precursor into the reinforcing fiber structure (preform) is driven by either diffusion process or an imposed external pressure.
- The deposition fills the space between the fibers, forming composite material in which matrix is the deposited material and dispersed phase is the fibers of the preform.
- Chemical Vapor Infiltration (CVI) is similar to Chemical Vapor Deposition (CVD), in which deposition the forms when the reactant gases react on the outer substrate surface.

Chemical vapor deposition (CVD)

- Preparation of C/C fiber pre-form of desired shape and structure
- Densification of the composite by CVD technique
- Infiltration from pressurized hydrocarbon gases (Methane /Propane) at 990-1210°C
- Gas is pyrolyzed from deposition on fibre surface
- Process duration depends on thickness of pre-form
- Heat treatment increases Modulus of Elasticity and Strength
- This process gives higher strength and modulus of elasticity

Chemical vapor deposition (CVD)



Module 1: Introduction to Composites

Lecture 7: Fabrication Processes

B. Spray Lay-Up:

Fibre is chopped in a hand-held gun and fed into a spray of catalyzed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions. The fabrication method is depicted in Figure 1.16.

The polyester resins can be used with glass rovings is best suited for this process.

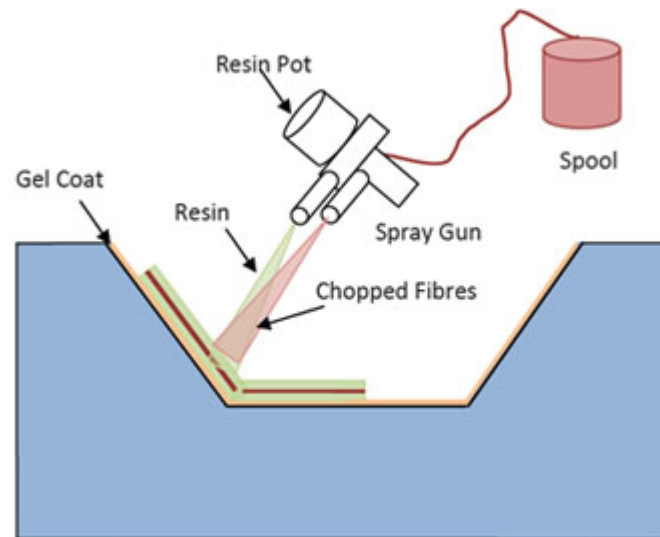


Figure 1.16: Wet or hand lay-up fabrication

Advantages:

The spray-up process offers the following advantages:

- It is suitable for small to medium-volume parts.
- It is a very economical process for making small to large parts.
- It utilizes low-cost tooling as well as low-cost material systems.

Limitations:

The following are some of the limitations of the spray-up process:

- It is not suitable for making parts that have high structural requirements.
- It is difficult to control the fiber volume fraction as well as the thickness. These parameters highly depend on operator skill.
- Because of its open mold nature, styrene emission is a concern.
- The process offers a good surface finish on one side and a rough surface finish on the other side.
- The process is not suitable for parts where dimensional accuracy and process repeatability are prime concerns. The spray-up process does not provide a good surface finish or dimensional control on both or all the sides of the product.
- Cores, when needed, have to be inserted manually.
- Only short fibres can be used in this process.
- Since, pressurized resin is used the laminates tend to be very resin-rich.

- Similar to wet/hand lay-up process, the resins need to be of low viscosity so that it can be sprayed.

Applications:

Simple enclosures, lightly loaded structural panels, e.g. caravan bodies, truck fairings, bathtubs, shower trays, some small dinghies.

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Module 1: Introduction to Composites

Lecture 7: Fabrication Processes

Introduction:

In this lecture we will see some of the important fabrication processes of composites. Further, we will see their advantages, disadvantages and applications.

What are the fabrication processes of composites materials? Describe the processes in brief along with the materials used in the process, their advantages, disadvantages and applications.

The fabrication processes are described in the following along with their advantages, disadvantages and applications in the following.

A. Wet/Hand Lay-Up:

The fibres are first put in place in the mould. The fibres can be in the form of woven, knitted, stitched or bonded fabrics. Then the resin is impregnated. The impregnation of resin is done by using rollers, brushes or a nip-roller type impregnator. The impregnation helps in forcing the resin inside the fabric. The laminates fabricated by this process are then cured under standard atmospheric conditions. The wet/hand lay-up process is depicted in Figure 1.15.

The materials that can be used have, in general, no restrictions. One can use combination of resins like epoxy, polyester, vinylester, phenolic and any fibre material.

Advantages:

- The process results in low cost tooling with the use of room-temperature cure resins.
- The process is simple to use.
- Any combination of fibres and matrix materials are used.
- Higher fibre contents and longer fibres as compared to other processes.

Disadvantages:

- Since the process is worked by hands, there are safety and hazard considerations.
- The resin needs to be less viscous so that it can be easily worked by hands.
- The quality of the final product is highly skill dependent of the labours.
- Uniform distribution of resin inside the fabric is not possible. It leads to voids in the laminates.
- Possibility of diluting the contents.

Applications:

The process is suitable for the fabrication of wind-turbine blades, boats and architectural mouldings.

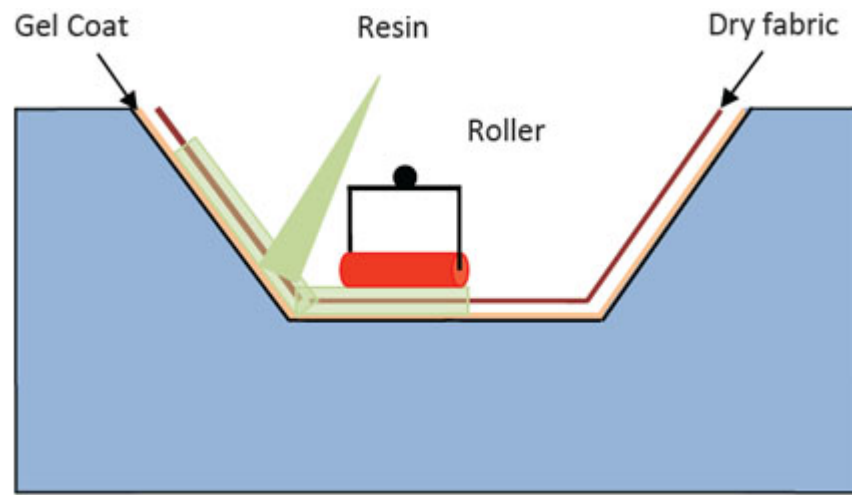


Figure 1.15: Wet or hand lay-up fabrication

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Module 1: Introduction to Composites

Lecture 7: Fabrication Processes

C. Autoclave Curing:

The key features of this process are as follows:

- An autoclave is a closed vessel for controlling temperature and pressure is used for curing polymeric matrix composites.
- Composites to be cured is prepared either through hand lay up or machine placement of individual laminae in the form of fibers tape which has been impregnated with resin.
- Components is then placed in an autoclave and subjected to a controlled cycle of temperature and pressure.
- After curing, the composite is “solidified”.
- One can use the fibres like carbon, glass, aramid etc. along with any resin.

Advantages:

- Large components can be fabricated.
- Since, the curing of matrix material is carried out under controlled environment, the resin distribution is better as compared to hand or spray lay-up processes.
- Less possibility of dilution with foreign particles.
- Better surface finish.

Disadvantages:

- Initial cost of tooling is high.
- Running and maintenance cost is high.
- Not suitable for small products.

Applications:

The process is suitable for aerospace, automobile parts like wing box, chassis, bumpers, etc.



Module 1: Introduction to Composites

Lecture 7: Fabrication Processes

D. Filament Winding:

This process is an automated process. This process is used in the fabrication of components or structures made with flexible fibers. This process is primarily used for hollow, generally circular or oval sectioned components. Fibre tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fibre feeding mechanism, and rate of rotation of the mandrel. The wound component is then cured in an oven or autoclave.

One can use resins like epoxy, polyester, vinylester and phenolic along with any fibre. The fibre can be directly from creel, non-woven or stitched into a fabric form.

The filament winding process is shown in Figure 1.17.

Advantages:

- Resin content is controlled by nips or dies.
- The process can be very fast.
- The process is economic.
- Complex fibre patterns can be attained for better load bearing of the structure.

Disadvantages:

- Resins with low viscosity are needed.
- The process is limited to convex shaped components.
- Fibre cannot easily be laid exactly along the length of a component.
- Mandrel costs for large components can be high.
- The external surface of the component is not smoothly finished.

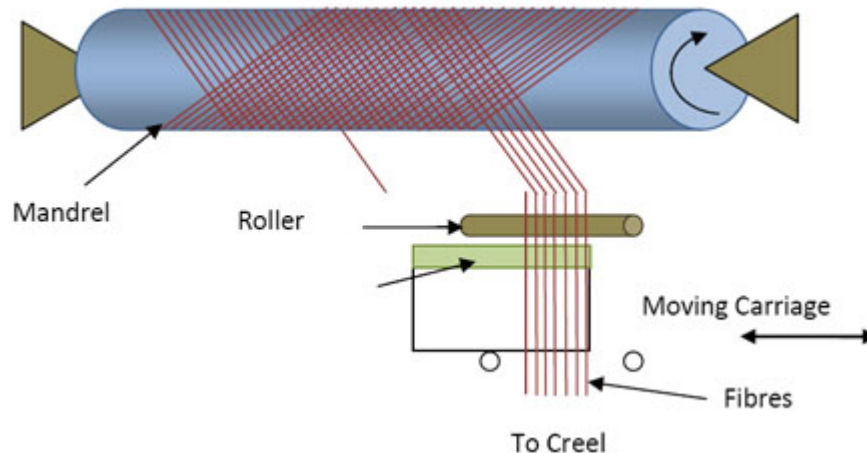


Figure 1.17: Filament winding

Applications:

Pressure bottles, rocket motor casing, chemical storage tanks, pipelines, gas cylinders, fire-fighters, breathing tanks etc.

Module 1: Introduction to Composites

Lecture 7: Fabrication Processes

E. Pultrusion:

It is a continuous process in which composites in the form of fibers and fabrics are pulled through a bath of liquid resin. Then the fibres wetted with resin are pulled through a heated die. The die plays important roles like completing the impregnation and controlling the resin. Further, the material is cured to its final shape. The die shape used in this process is nothing the replica of the final product. Finally, the finished product is cut to length.

In this process, the fabrics may also be introduced into the die. The fabrics provide a fibre direction other 0° . Further, a variant of this method to produce a profile with some variation in the cross-section is available. This is known as **pulforming**.

The resins like epoxy, polyester, vinylester and phenolic can be used with any fibre.

The pultrusion process is shown in Figure 1.18.

Advantages:

- The process is suitable for mass production.
- The process is fast and economic.
- Resin content can be accurately controlled.
- Fibre cost is minimized as it can be taken directly from a creel.
- The surface finish of the product is good.
- Structural properties of product can be very good as the profiles have very straight fibres.

Disadvantages:

- Limited to constant or near constant cross-section components.
- Heated die costs can be high.
- Products with small cross-sections alone can be fabricated.

Applications:

Beams and girders used in roof structures, bridges, ladders, frameworks

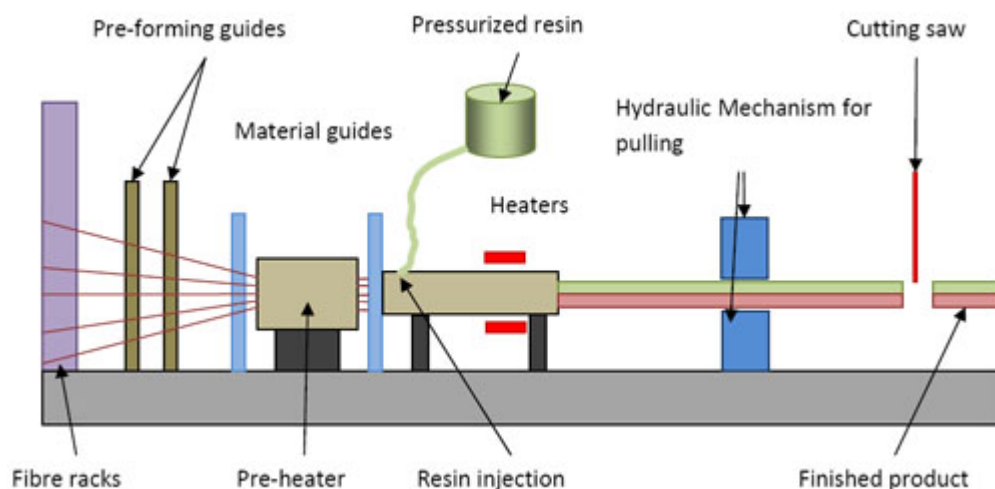


Figure 1.18: Pultrusion

◀ Previous Next ▶

Resin transfer molding process

- Resin transfer molding is a closed molding process. It is also known as liquid transfer molding process.
- As the name indicates, resin is transferred over the already placed reinforcement.
- The process is effective for production of structural parts with low cost in low to medium production quantities.



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Resin transfer molding process

- It is possible to achieve near net shape with controlled fiber orientation. Generally, continuous fibers are used in this method.

Raw materials:-

- Reinforcing materials: Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax etc.)
- Matrix: Epoxy, methyl methacrylate, polyester, polyvinyl ester, phenolic resin



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Resin transfer molding procedure

- Reinforcement in terms of either woven mat or chopped fiber mat form is placed on the surface of lower half mold.
- A release gel is applied on the mold surface for easy removal of the composite.
- The mold is properly closed and clamped.

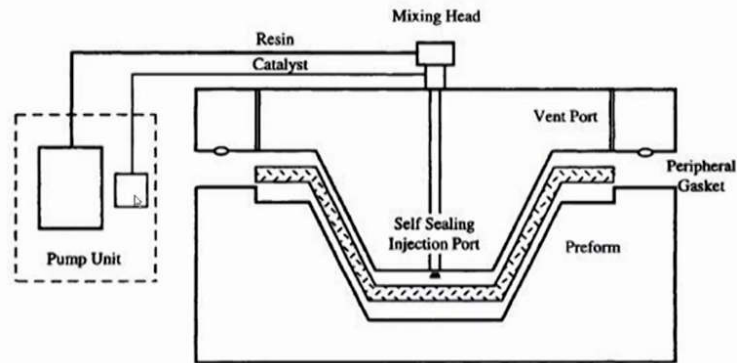


Resin transfer molding procedure

- The resin is pumped into the mold through ports and air is displaced through other vents.
- The uniformity of resin flow can be enhanced by using a catalyst as an accelerator and vacuum application.
- After curing, the mold is opened and composite product is taken out.



Resin transfer molding procedure



Resin transfer molding Setup

Source:- <https://www.google.co.in/search?q=resin+transfer+molding&safe=active&source=lnms&tbm=isch&sa=X&ve>



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Controlling parameters

- Resin viscosity
- Injection time
- Injection pressure
- Temperature in the mold



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Advantages

- Composite parts have good surface finish on both surfaces of the product.
- Any combination of reinforced materials (including 3D) in any orientation can be achieved.
- Fast cycle time can be achieved through temperature control device.
- Process can be manual control, semi-automated or highly automated.
- Ability to incorporate inserts and other attachments into moldi



Disadvantages

- Mold cavity limits the size of the composite.
- High tooling cost.
- There is limitation on reinforcing materials due to the flow and resin saturation of fibers.



Applications

- Complex structures can be produced.
- Automotive body parts, big containers, bathtubs are commonly processed through resin transfer molding technique.



APPLICATIONS:

- Aerospace and automobile parts



- Bathroom fixtures, car body, helmet, etc.



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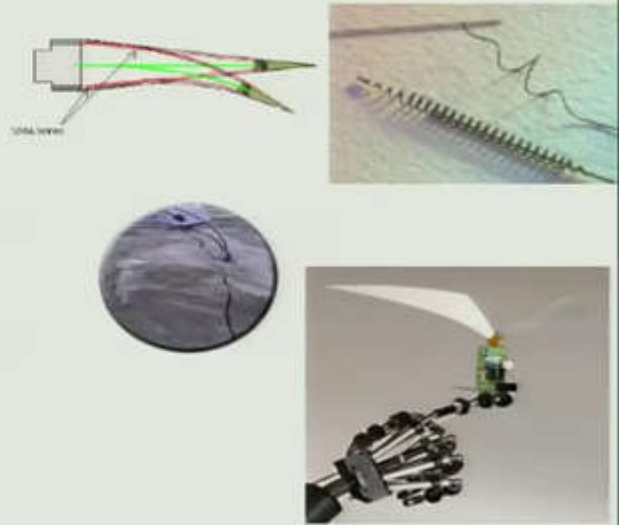
1. Define Shape Memory Effect? List space applications of SMA's?

What is Shape Memory Effect?

- ✓ Certain classes of metallic alloys have a special ability to '**memorize**' their shape at a **high temperature**, and **recover** large deformations imparted at a low temperature on **thermal activation**.
- ✓ The recovery of strains imparted to the material at a lower temperature, as a result of heating, is called the **Shape Memory Effect (SME)**.

Space Application of SMA

- Control of aerodynamic surfaces
- Micro-coils for vibration isolation
- Grasping by robotic fingers
- Space exploration: rock splitting
- Nitinol filter
- Deployment of Solar Array Hinges



1. What are shape memory alloys? Types and Composition of SMA's? Discuss SME with respect to phase transformation?

Shape Memory Alloys (SMAs) refer to a group of materials which have the ability to return to a predetermined shape when heated. The shape memory effect is caused by a temperature dependent crystal structure.

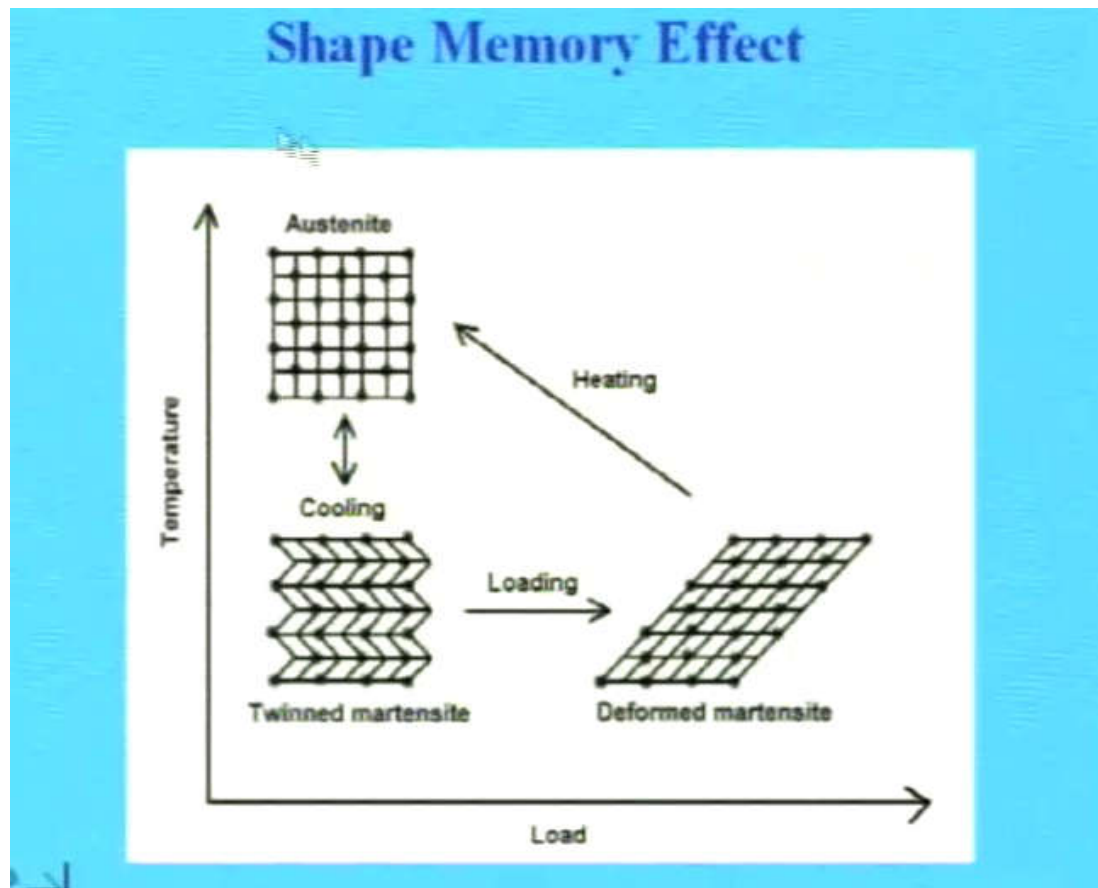
The most widely used shape memory material is an alloy of Nickel and Titanium called Nitinol. This particular alloy has excellent electrical and mechanical properties, long fatigue life, and high corrosion resistance.

Types and composition of SMAs:

System	Composition
Au-Cd	46- 50%
Cu-Zn	38-41 %
Ni-Al	36-38 %
Ni-Si	49-51 %
Ni-Ti	49-51 %

The SME occurs due to a temperature and stress dependent shift in the materials crystalline structure between two different phases, martensite (low temperature phase) and austenite (high temperature phase). The temperature, where the phase transformation occurs, is called the transformation temperature. Figure below is a simplified representation of materials crystalline arrangement during different phases. In austenite phase, the structure of the material is symmetrical; each “grain” of material is a cube with right angles. When the alloy cools, it forms martensite phase and collapse to structure with different shape called twinned martensite. If an external stress is applied, the alloy will yield and deform to an alternate state called deformed martensite. Now, if the alloy is heated again above the transformation temperature, the austenite phase will be formed and the structure of the material

returns to the original “cubic” form, it will generate force/stress and recover the original shape.



Criterion for an alloy to show you the Shape Memory Effect (SME):

- ✓ **Reversibility in transformation**
- ✓ **Thermo- elastic martensite**
- ✓ **Low transformation strains.**

2. Explain functionally graded materials (FGM) with suitable example? List types of FGM's

- A new class of composite materials known as functionally graded materials (FGMs).
- FGMs are composite materials in which the composition or microstructure or both are locally varied so that a certain variation of the local material properties is achieved.
- We have many kinds of materials with functional gradients, in nature

Example: Human bone

- The human bone consists of compact and cancellous bones.
- Compact bone, which is the surface part of human bone. On the other hand, the cancellous bone is sponge- like with many small pores.
- The compact bone with a high bone density contributes to the hardness and strength of the human bone. The cancellous bone is light weighted because of its honeycomb structure. This is a graded structure.

VARIOUS TYPES OF FGMs

Ceramic-Metal

TiC-Ni, Mullite-Mo, Al-AlB₂

Metal-Metal/Intermetallic

W-Cu, W-Mo, Al-Al₃Fe

Metal-Polymer

Al-Polycarbonate

Others:

Single material (variation in porosity)

Glass - Ceramic

Ceramic - Ceramic

Functionally Graded Materials

Fabrication process:

There are many kinds of processes applied to FGM fabrication. The processes are classified into three based on the starting materials: gaseous processes, liquid processes, and solid processes.

(1) Gaseous processes

Chemical vapor deposition (CVD), Physical vapor deposition (PVD), and Plasma spraying are included.

(a) CVD process

CVD is a process for depositing metal or ceramics on the substrate by the thermal decomposition of halide gases including metals or semimetals. The composition or structure of deposits can be controlled by deposition parameters such as the kind of gas, gas flow rate, and thermal decomposition temperature.

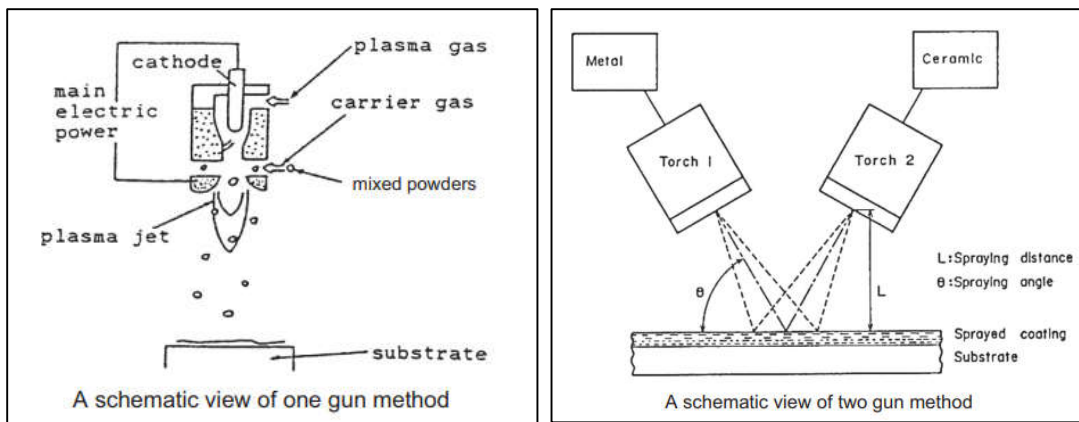
(b) PVD process

PVD is a process for depositing metals or ceramics on the substrate by evaporating the source metal. When reaction gases such as C_2H_2 , N_2 , and O_2 are introduced into the deposition chamber during the deposition process, metal carbide, nitride, and oxide are formed. For example, the reaction products of Ti vapor with C_2H_2 are TiC, Ti, and their mixtures according to the C_2H_2 flow rate. The TiC/Ti FGM can be obtained by changing the flow rate of C_2H_2 during the deposition process.

(c) Plasma spraying process

Plasma spraying is a process for depositing semisolid metals or ceramics on the substrate by plasma jet. There are two methods: the one – gun method and two – gun method. Figure below shows a schematic view of one – gun method. The

mixture of metal and ceramic powders is fed into the one plasma gun and sprayed on the substrate. The FGM can be obtained by changing the mixing ratio of metal and ceramic powders during the spraying process. Figure below shows the schematic view of the two – gun method. Metal and ceramic powders are fed into different plasma guns, and the two plasma sprayings are performed simultaneously. The FGM can be obtained by increasing the feed rate of ceramics powders and decreasing that of metal powders during the spraying process.



(2) Liquid processes

Electro deposition, and centrifugal casting are included.

(a) Electro deposition process

Electro deposition is a process for depositing a mixed film of metals and ceramics on the electrode from a plating solution containing ceramics powders. The volume fraction of ceramics in the deposited film is controlled in the range from 0 % to approximately 25% by concentration of ceramic powders in the plating solution. The FGM can be obtained by changing the concentration of the ceramic powders in the solution during the deposition process.

(b) Centrifugal casting process

Centrifugal casting is a process for solidifying the mixture of molten metal and ceramic powders in a die under centrifugal force. When the relative density of

ceramic powders move in the centrifugal direction in the die under centrifugal force. In the opposite case, the powders move against the centrifugal direction. The gradation profile of ceramic powders in the FGM can be controlled by the difference in the relative density between molten metal and ceramic powders and the intensity of centrifugal force.

(3) Solid processes

Powder configuration and self-propagating high temperature synthesis (SHS) are included.

(a) Powder configuration process

The powder configuration process is used to fill the mixtures of metal and ceramic powders in a die as a preceding process of sintering. Sintering is achieved by hot pressing, hot isostatic pressing (HIP) and cold isostatic pressing (CIP). FGMs can be obtained by changing the mixing ratio of metal and ceramic powders in the depth direction of die. When the mixing ratio is changed step by step or continuously, the compositional gradient of the FGM is stepwise or continuous, respectively.

(b) Self – propagating high temperature synthesis (SHS)

SHS is a process for forming compounds of boride, carbide; or nitride from the mixtures of metal powders and boron powders, nitrogen gas, or carbon powders by their exothermic formation reaction. The formation energy of boride, carbide, and nitride is > 40 kcal/mol. When one part of mixture is ignited, the compound formation starts. The formation reaction heats the neighboring mixtures and then self-propagates in the mixtures. Because the compounds obtained by SHS are generally powder like or porous, HIP or CIP is sometimes applied to the mixtures during the SHS process. The FGM can be obtained by preparing mixtures with a compositional gradient using the powder configuration process.

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Introduction to Nano Science and Nano Technology

Nano science is the scientific study at the atomic and molecular scale of molecular structures with at least one dimension measuring between 1 and 100 nanometers in order to understand their physic-chemical properties and identify ways to manufacture, manipulate, and control them.

In the nano world we cannot see objects with our naked eyes, we cannot touch or manipulate them by our hands or any of the tools that we generally use. The objects that we deal with the nano world are very tiny and are close to the size of the atoms and molecules. Comparing an object with diameter

of nanometer to that of meter is like comparing the size of the marble to the size of the earth. A single strand of human hair around 20000 nanometers diameter. Bulk materials properties are independent of its size, whereas when particles are reduced to nano size it depends on its size.

In nano materials

- ✓ Large fraction of surface atoms
- ✓ High surface energy
- ✓ Spatial confinement
- ✓ Reduced number imperfections that do not exist in the corresponding bulk materials

A few properties in which differences between nano materials and bulk materials are summarized below.

- The melting point (m.p) drastically falls when the particle size is much reduced to nano size. The m.p depression is most evident in nano wires nanotubes and nano particles, which all melt at lower temperature than bulk from the same materials. The change in m.p is because, nano scale materials have much larger surface to volume ratio than bulk materials.

- All nano materials possess high mechanical strength than bulk. The cutting tools should be harder than the materials which is to be cut are made of nano materials. These cutting tools are higher erosion- resistant and durable than their bulk materials.
- Electrical conductivity may decrease or increase when particles are in nano scale
- Optical properties of nano materials are much different from their bulk materials. This is because of effect on the Plasmon resonance. In addition, the increased energy level spacing is another criteria for this behavior. Due to increased band gap for semiconductor nano particles absorption edge shift towards shorter wave lengths.
- Chemical properties of the materials are changed when they are in nano range, due to the increase of exposed surface area of the nano particles compared with bulk materials.

From the detailed study of nano materials it has been realized that materials in nano dimensions exhibit properties that are different from their bulk materials. These materials in nano dimensions will revolutionized the industries and daily lives. This is becoming more and more evident in the form of potential applications which extend to wide ranging areas such as catalysis, biosensors, diagnostic, cell labeling, solar cells, fuel cells. Photonic band gap materials, single electron transistors, non-linear optical devices, information storage, refrigeration, chemical/optical computers, harder metals, self-cleaning paints, improved national security.

Preparation of Nano materials

The methods of producing nanoparticles are classified into two main categories, “top-down” and “bottom-up” approaches.

Top down Approach:

The top-down method involves the systematic breakdown of a bulk material into smaller units using some form of grinding mechanism. This is

beneficial and simple to execute and avoids the use of volatile and poisonous compounds frequently found in the bottom-up techniques. However, the quality of the nanoparticles formed by grinding is accepted to be poor in comparison with the material produced by modern bottom up methods. The main drawbacks include defect problems from grinding equipment, low particle surface areas, asymmetrical shape and size distributions and high energy needed to produce relatively small particles. Apart from these disadvantages, it must be distinguished that the nano-material produced from grinding still finds use, due to the simplicity of its manufacture, in applications including magnetic, catalytic and structural properties.

Bottom up Approach:

The bottom-up approach uses atomic or molecular feed-stocks as the source of the material to be chemically transformed into larger nanoparticles. This has the advantage of being potentially much more convenient than the top down approach. By controlling the chemical reactions and the environment of the growing nanoparticle, then the size, shape and composition of the

nanoparticles may all be affected. For this reason nanoparticles produced by bottom up, chemically based and designed, reactions are normally seen as being of higher quality and having greater potential applications. This has led to the growth of a host of common bottom up strategies for the synthesis of nanoparticles. Many of these techniques can be tailored to be performed in gas, liquid, solid states, hence the applicability of bottom-up strategies to a wide range of end products. Most of the bottom up strategies requires suitable organometallic complexes or metal salts to be used as chemical precursors, which are decomposed in a controlled manner resulting in particle nucleation and growth.

Nanomaterials are divided into three category

One dimension – It has only one parameter either length (or) breadth (or) height (example: very thin surface coatings)

1 Dimension <100nm



Example: Thin Films ,Layers and Coatings



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Nanomaterials are divided into three category

Two dimensions- it has only length and breadth (for example, nanowires and nanotubes)

2 Dimension <100nm



Example: Nanotubes , Nano fibers and Nanowires



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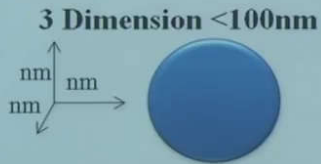


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Nanomaterials are divided into three category

Three dimensions -it has all parameter of length, breadth and height. (for example, Nano Particles).



Example: Nanoparticles, Nano shells, Nano rings etc.



CLASSIFICATION

- 0-dimensional: nanoparticles and nanocrystals
- 1-dimensional: nanotubes, nanowires, and nanobelts
- 2-dimensional: nanosheets
- Dimensionless: nanostructured materials and nanopores

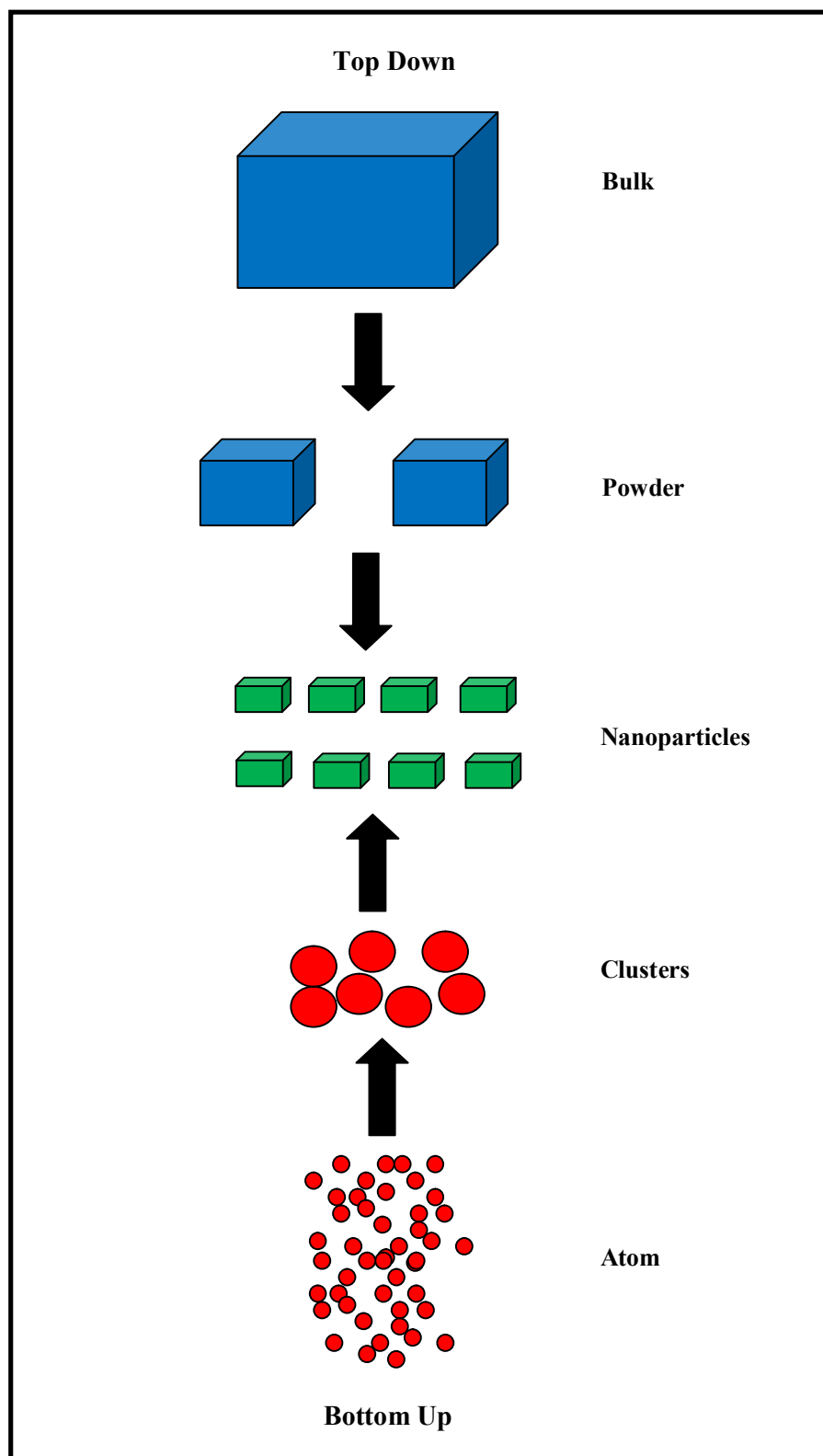
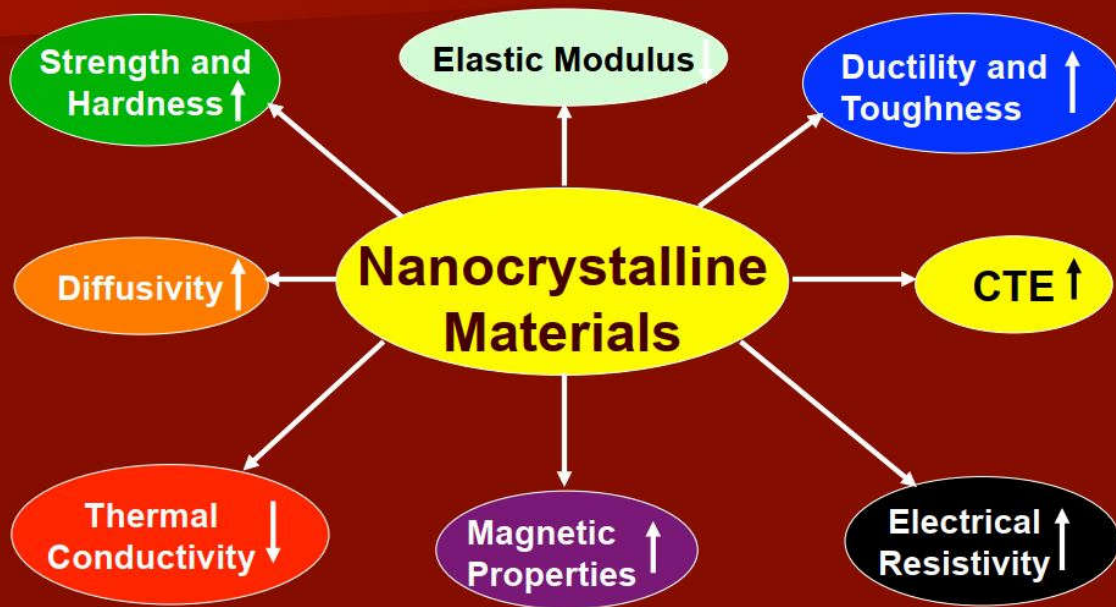


Fig. 1.1: Schematic Representation of the Building up of Nanomaterials

PROPERTY CHANGES



1. Nanotechnology Applications in Medicine

- Because of their small size, nanoscale devices can readily **interact with biomolecules** on both the surface of cells and inside of cells.
- By gaining access to so many areas of the body, they have the potential to **detect disease and the deliver treatment**.

- Nanoparticles can **deliver drugs directly** to diseased cells in your body.
- **Nanomedicine** is the medical use of molecular-sized particles to deliver drugs, heat, light or other substances to specific cells in the human body.

- **Quantum dot**- that identify the location of cancer cells in the body.
- **Nano Particles** - that deliver chemotherapy drugs directly to cancer cells to minimize damage to healthy cells.
- **Nanoshells** - that concentrate the heat from infrared light to destroy cancer cells with minimal damage to surrounding healthy cells.
- **Nanotubes**- used in broken bones to provide a structure for new bone material to grow.

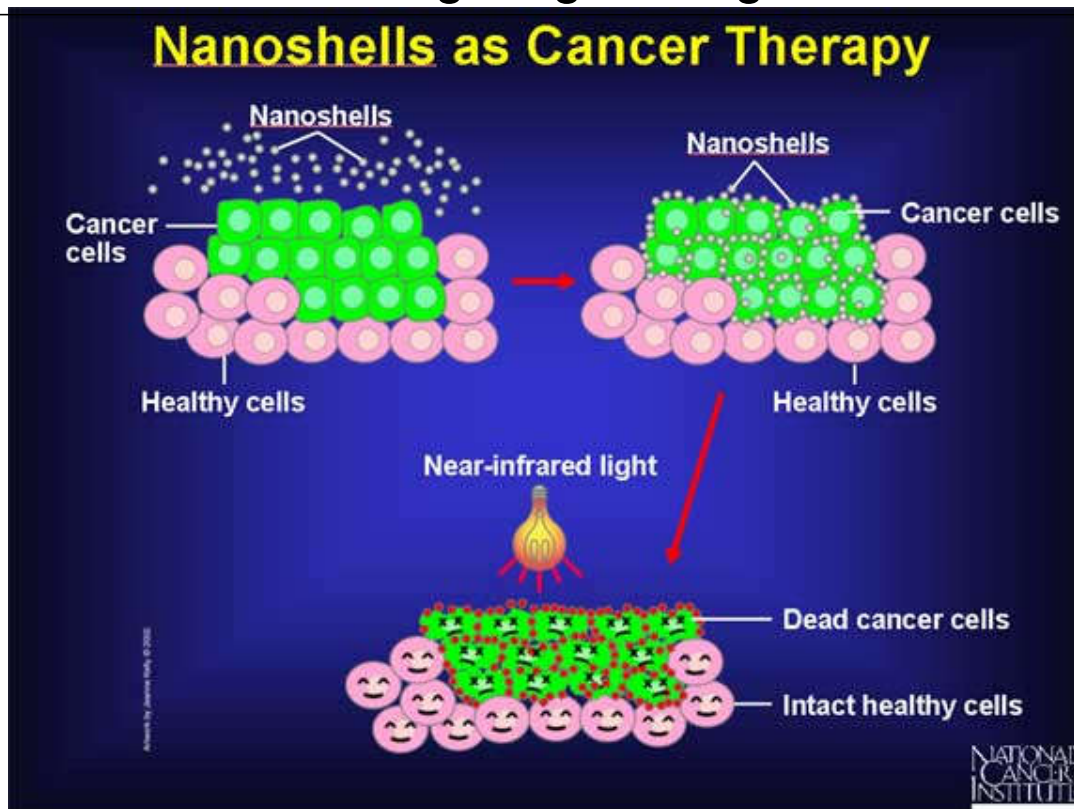
Nanoshells



Nanoshells kill tumor cells selectively

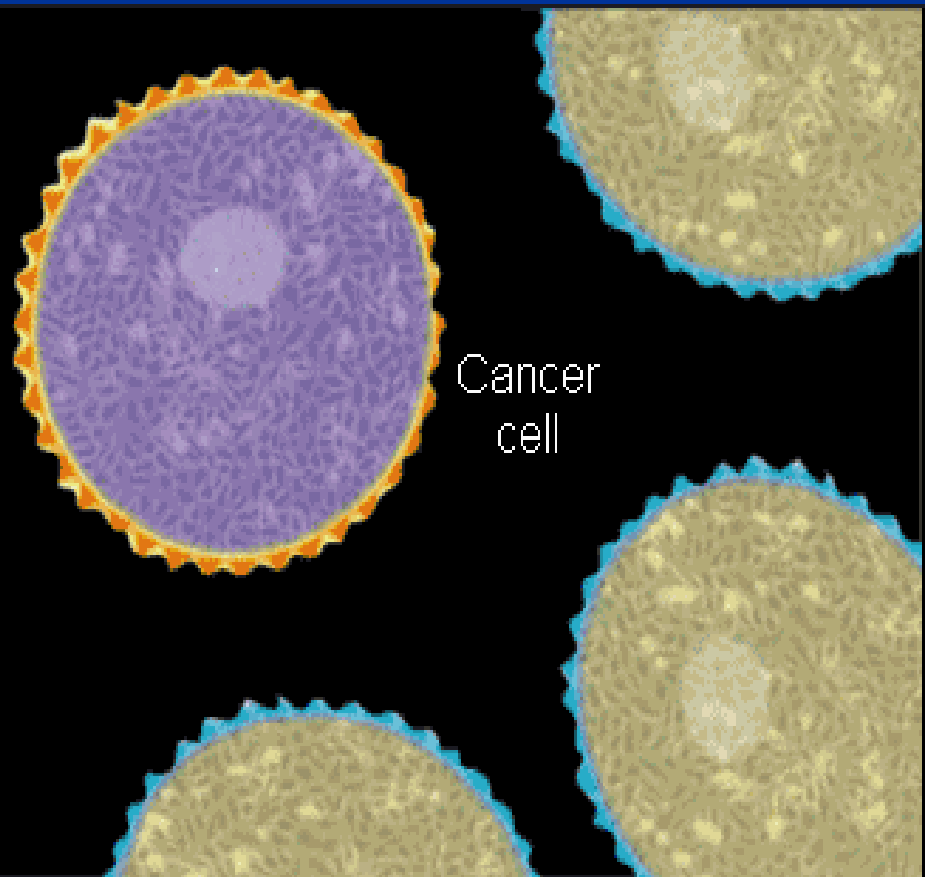
Nano shells as Cancer Therapy

Nano shells are injected into cancer area and they recognize cancer cells. Then by applying near-infrared light, the heat generated by the light-absorbing Nano shells has successfully killed tumor cells while leaving neighboring cells intact.



Nanoparticles

***Nanoparticles used
for molecular imaging
of malignant lesions***



3. Sunscreens and Cosmetics

- Nanosized titanium dioxide and zinc oxide are currently used in some sunscreens, as they absorb and reflect ultraviolet (UV) rays.
- Nanosized iron oxide is present in some lipsticks as a pigment.

4. Fuel Cells

The potential use of nano-engineered membranes to intensify catalytic processes could enable higher-efficiency, small-scale fuel cells.

5. Displays

- Nanocrystalline zinc selenide, zinc sulphide, cadmium sulphide and lead telluride are candidates for the next generation of light-emitting phosphors.
- CNTs are being investigated for low voltage field-emission displays; their strength, sharpness, conductivity and inertness make them potentially very efficient and long-lasting emitters.

6. Batteries

- With the growth in portable electronic equipment (mobile phones, navigation devices, laptop computers, remote sensors), there is great demand for lightweight, high-energy density batteries.
- Nanocrystalline materials are candidates for separator plates in batteries because of their foam-like (aerogel) structure, which can hold considerably more energy than conventional ones.
- Nickel–metal hydride batteries made of nanocrystalline nickel and metal hydrides are envisioned to require less frequent recharging and to last longer because of their large grain boundary (surface) area.

7. Catalysts

In general, nanoparticles have a high surface area, and hence provide higher catalytic activity.

8. Magnetic Nano Materials applications

- It has been shown that magnets made of nanocrystalline yttrium–samarium–cobalt grains possess unusual magnetic properties due to their extremely large grain interface area (high coercivity can be obtained because magnetization flips cannot easily propagate past the grain boundaries).
- This could lead to applications in motors, analytical instruments like magnetic resonance imaging (MRI), used widely in hospitals, and microsensors.
- Nanoscale-fabricated magnetic materials also have applications in data storage.
- Devices such as computer hard disks storage capacity is increased with Magnetic Nano materials

9. Medical Implantation

- Unfortunately, in some cases, the biomedical metal alloys may wear out within the lifetime of the patient. But Nano materials increases the life time of the implant materials.
- Nanocrystalline zirconium oxide (zirconia) is hard, wear resistant, bio-corrosion resistant and bio-compatible.
- It therefore presents an attractive alternative material for implants.
- Nanocrystalline silicon carbide is a candidate material for artificial heart valves primarily because of its low weight, high strength and inertness.

10. Water purification

- Nano-engineered membranes could potentially lead to more energy-efficient water purification processes, notably in desalination process.

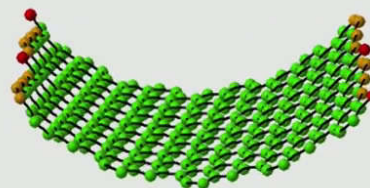
11. Military Battle Suits

- Enhanced nanomaterials form the basis of a state-of-the-art ‘battle suit’ that is being developed.
- A short-term development is likely to be energy-absorbing materials that will withstand blast waves;
- longer-term are those that incorporate sensors to detect or respond to chemical and biological weapons (for example, responsive nanopores that ‘close’ upon detection of a biological agent).

Carbon nanotubes (CNT)

- CNT can be described as a sheet of graphene rolled into a cylinder
- Constructed from hexagonal rings of carbon
- Can have one layer or multiple layers
- *Can have caps at the ends making them look like pills*

Graphene sheet



<http://www.photon.t.u-tokyo.ac.jp/~maruyama/agallery/agallery.html>



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Structure and morphology

- The bonding in carbon nanotubes is sp^2 , with each atom joined to three neighbours, as in graphite.
- The tubes can therefore be considered as rolled-up graphene sheets (graphene is an individual graphite layer)
- This bonding structure, which is stronger than the sp^3 bonds found in diamond, provides the molecules with their unique strength.
- Under high pressure, nanotubes can merge together, giving the possibility of producing strong, unlimited length wires through high-pressure nanotube linking.



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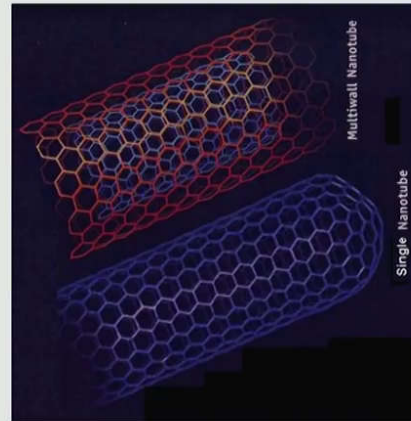
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Classification of carbon nanotubes

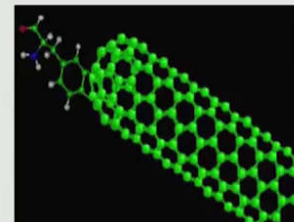
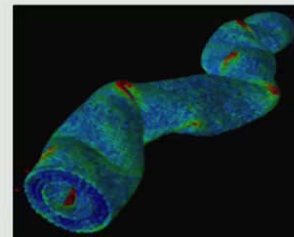
Carbon nanotubes are classified in following two types,

- SWNTs- Single walled carbon nanotubes
- MWNTs- Multiple walled carbon nanotubes



CNT properties

- The strongest and most flexible molecular material because of C-C covalent bonding and hexagonal network architecture
- Strength to weight ratio ~500 times greater than Al, steel, titanium
- Maximum strain ~10%; much higher than any material
- Very high current carrying capacity
- Other chemical groups can be attached to the tip or sidewall (called 'functionalization')



CNT properties

- “CNT is 100 times stronger than stainless steel but six times lighter...”
- “CNT is as hard as diamond and its thermal capacity is twice that of pure diamond...”
- “CNT’s current-carrying capacity is 1000 times higher than that of copper...”
- “CNT is thermally stable up to 4000 K...”
- “CNT can be metallic or semiconducting, depending on their diameter and atomic arrangement...”



Limitations of CNTs

- Difficulty of mass production for industrial purposes.
- Secondly is the solubility of CNTs in the water
- The production of structurally and chemically reproducible batches of CNTs with identical characteristics.
- Difficulty in maintaining high quality and minimal impurities.

