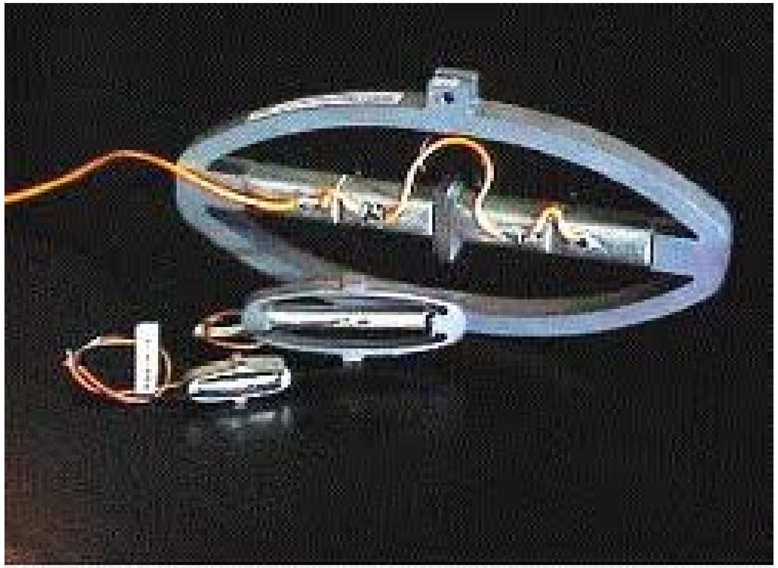
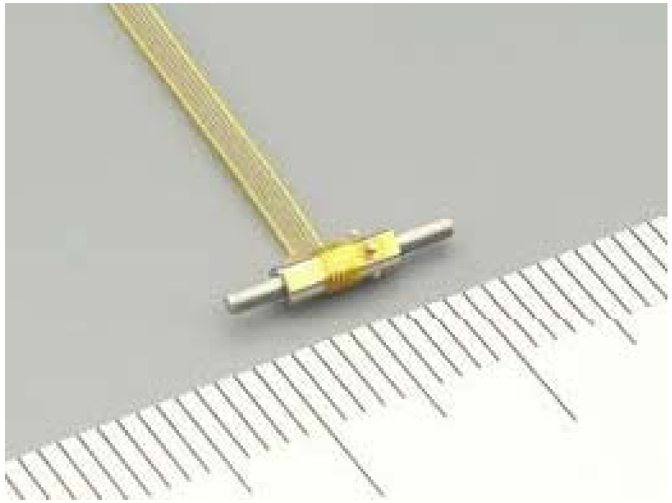


APA230L, APA150M, APA100S

# Module 3: An Introduction to Composite Materials



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# Topics Covered in Module 2

**Induced Strain Actuation (ISA) – Uniform Strain Model**

**ISA – Euler-Bernoulli Model**

**ISA Model for Magnetostrictive Mini Actuator**

**Active Fibre Composite Actuation**

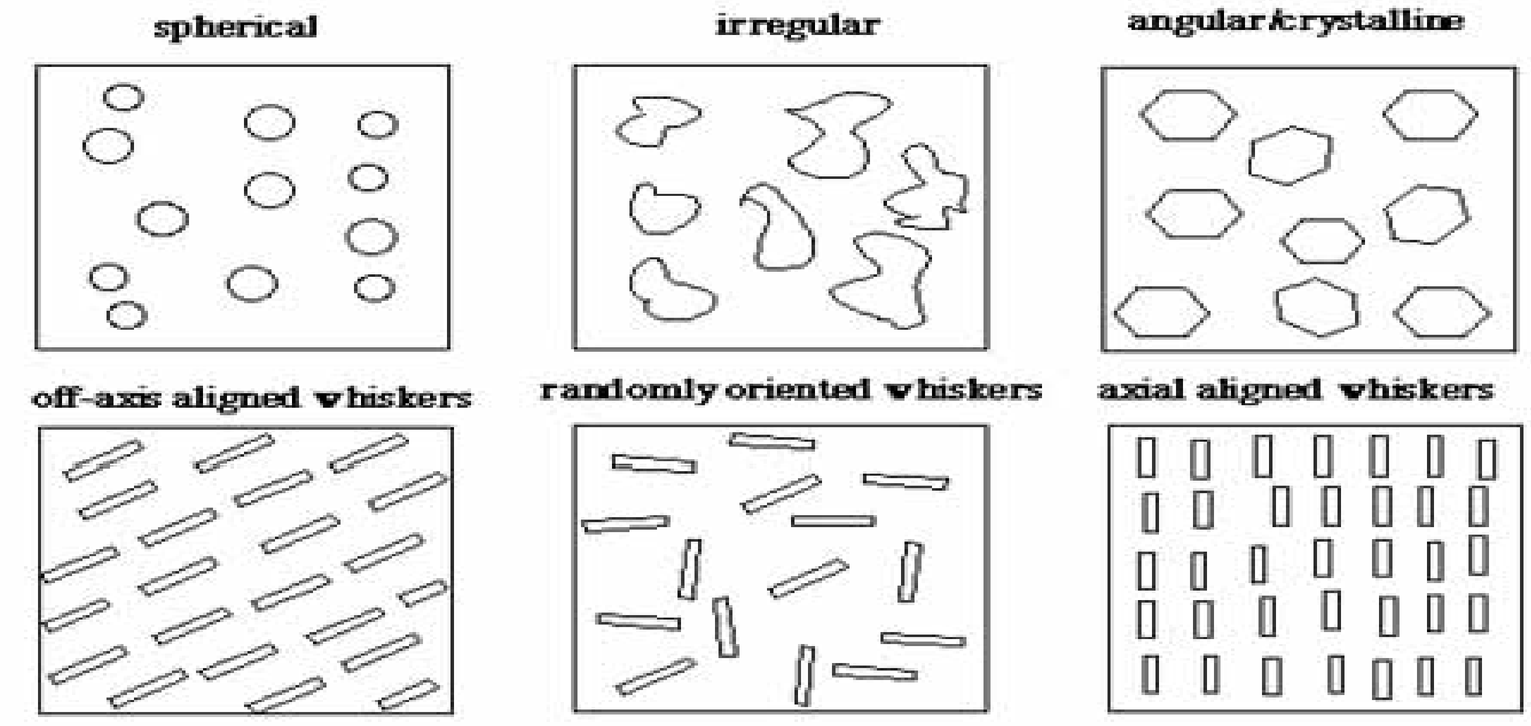
# Organization of this Lecture

- What is Composite Material?
- What are Laminated Composites?
- Various Fibres for Composite Reinforcement.

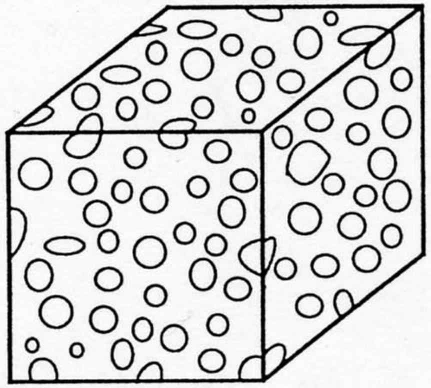
# What is Composite?

- Natural or artificial mixtures of two or more distinct phase/constituents
- Primary engineering goal is to achieve a better balance of properties from the combination of materials
- Mixtures may consist of metals, polymers or ceramics

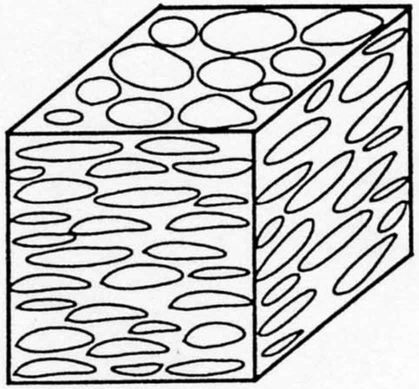
# Types of Particulate/Whisker Reinforcement



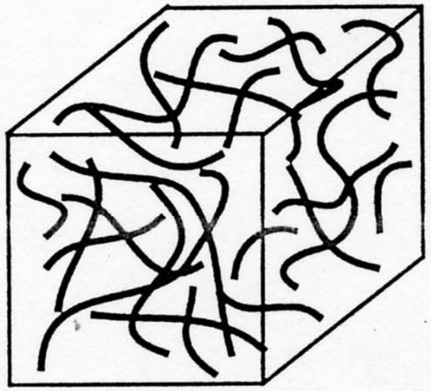
# Types of Composite



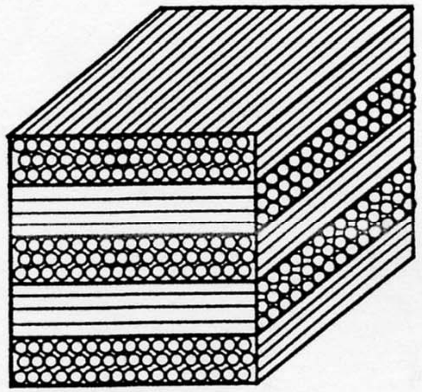
Particulate composite



Flake composite

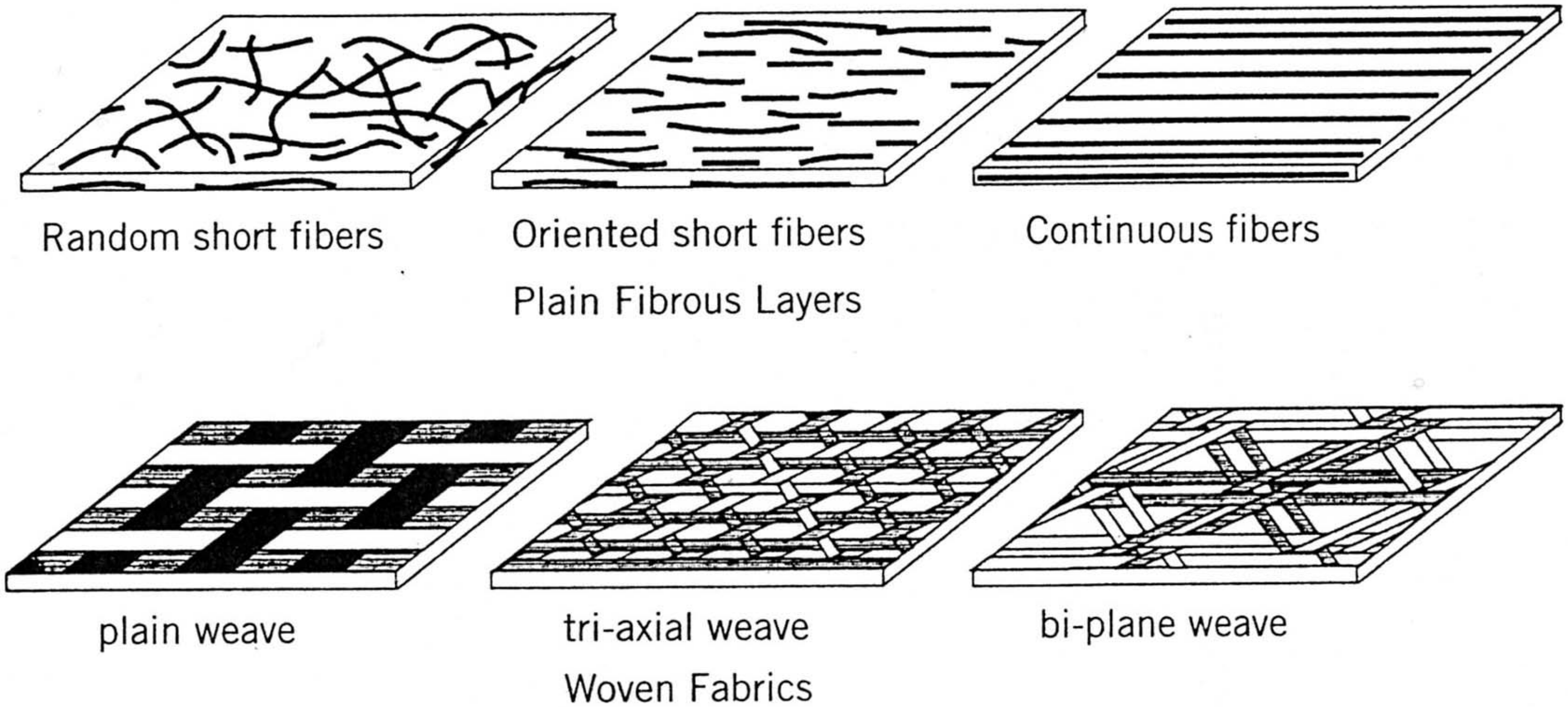


Fiber reinforced composite



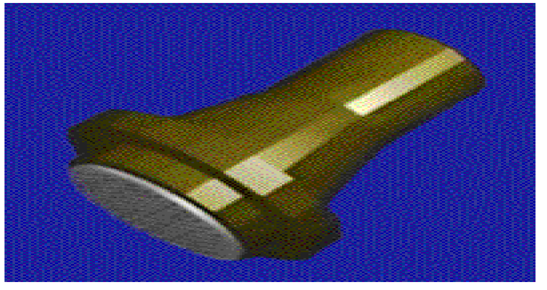
Laminated composite

# Fabrics


Random short fibers
Oriented short fibers
Continuous fibers
Plain Fibrous Layers
plain weave
tri-axial weave
bi-plane weave
Woven Fabrics

# Glass Fibre

- Generic Name, available in three forms: E-Glass (Insulating), C-Glass(Anti corrosive) and S-Glass (High Silica - higher temperature application)
- Major Constituent $SiO_2$ (55-65%) & $Al_2O_3$(8-25%), other constituent: Ca0, $Na_2O$ etc.
- Manufacturing - Molten Glass, fed through Platinum Bushings
- Pure crystalline glass melts at 1800$^o$C breaking Si-O bond, impurities substitute some of the bonds and hence reduce $T_m$.



# Glass Fibre contd..

- Nextel Fibres of 3M uses relatively low-temperature Sol-Gel technique
- Filaments susceptible to surface damage - hence **sizing** is necessary
- E-glass density-2500 kg/$m^3$, Tensile strength - 1750 Mpa,    E-70 Gpa
- susceptible to moisture absorption, strength decreases
- Used in roofing, frames, tanks,  etc.

# Boron Fibre

- Properties borderline between metals and non-metals. A good conductor at high temps. Chemically closer to silicon Crystalline boron is inert chemically .
- First synthetic fibre, used since 1960 (Space Shuttle), very brittle to directly draw.
- Deposited through **CVD** on fine (10-12$\mu$m) Tungsten wire / some times on Carbon core
- Hydrogen Gas used to reduce Boron Trihalide:
- $2BX_3 + 3H_2 \longrightarrow 2B + 6HX$

# Boron fibre contd..

- High temperature around 1000$^{o}$C req. - hence Tungsten base is required - resistive heating of wire.
- Temperature to be controlled during CVD - beyond 1300$^{o}$ C unwanted crystal-form occurs
- Core diffusion forming $WB_4$, $W_2B_5$ etc causes unwanted increase in core thickness - hence SiC coating is used
- Density 2340 Kg/m$^3$, $T_m$-2040$^{o}$C, expensive - used in F14, F15, space shuttle

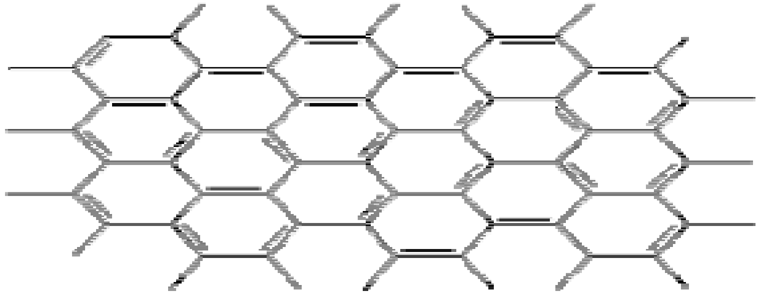
## Carbon Fibre

- Generic Term, Ex-PAN, Ex-Cellulose, Ex-Pitch
- Density -1700-1600 -2200 Kg/m$^3$, E - 230 - 390 - 340,690 Gpa

Manufacturing steps -

- Fibearization - to make a precursor fibre - wet,dry or melt spinning
- Stabilization (to prevent from melting)

# Carbon Fibre contd..



- Carbonisation - to remove impurity
- Graphitisation to enhance strength etc.
- Pan - ladder polymer, Polyethylene with a nitrile CN group in every alternate carbon atom
- PAN stabilisation 250$^{o}$C, carbonisation 1000-1500$^{o}$C, Graphitisation up to 3000$^{o}$ C

# Carbon Fibre ..

- Ex-Cellulose from Cotton, Rayon etc. expensive not commonly used
- Ex-pitch, source PVC, Coal-Tar etc. quite cheap
- Anisotropic, Liquid Crystalline Mesophase could be directly spun
- Due to high alignment /orientation, high E is possible
- Used in shuttle booster, turbine & compressor blades, prosthetics

# Organic Fibre: Kevlar

- Aramid Fibre – Generic Term, commercial form Kevlar & Nomex (Dupont), Technora ( Teijin), Twaron (Akzo)
- Processed from the solution polycondensation of diamines and diacid halides at low temperature
- Mesophase order (random –liquid crystalline – nematic) controls mechanical property

# Kevlar contd ..

- Strong covalent bond axially, weak hydrogen bond transversely
- Density 1440 Kg/m$^3$, Tensile Strength (2.8 Gpa), Modulus ( 65-125 Gpa)
- Negative Coeff. of expansion due to kinks
- UV sensitive – degrades
- Kevlar – rubber reinforcement, K-29 – ropes, cables etc., K-49 aerospace & automotive applications

# Org Fib: Polyethylene

- Molecular chain extension coupled with orientation
- HDPE 90-95% crystalline
- Melt crystalised polyethylene is drawn to a very high ratio (200)
- Surface treatment necessary to for bonding (involving cold gas plasma – Amonia or Argon)
- Density 970 $Kg/m^3$, Tensile Strength 2.7 GPa, Modulus 119 GPa

# Ceramic Fibre

- Alkyl Aluminium or Alkoxy Aluminium polymerised to form Precursor fibre in sol phase
- Extruded and coagulated to form gel fibres
- Dried and Calcined to form final fibre (3-5 micron) **Hazardous for health!**
- Inviscid melt technique is often used to reduce cost and draw fibre at low temperature – trade off high fibre dia >100 micron

# Ceramic Fibres ..

- Density 2000-3000 $Kg/m^3$, Tensile strength – 2Gpa, E- 150-370 Gpa
- Use as refractory materials, reentry vehicle, shuttle etc
- Fine fibres have the best thermal insulation properties and good thermal shock resistance, and do not crumple up when heated and cooled over and over again.

# Basalt Fibre

- Raw material for producing basalt fibre is a rock of the volcanic origin.
- Fibres are received by melting basalt stones down at the temperature of 1400ºC. Melted basalt mass passes through the platinum bushing and is extended into fibres
- Because of its wide range of temperature resistance from –260C to 800C basalt fibre products will outperform GFRP!

# References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- Nguyen, C. and Kornmann, X., A comparison of dynamic piezoactuation of fiber-based actuators and conventional piezo patches, *Journal of Intelligent Material Systems and Structures*, Vol. 17, 45-56, 2006

# END OF LECTURE 12