Composites and Applications

Session delivered by:

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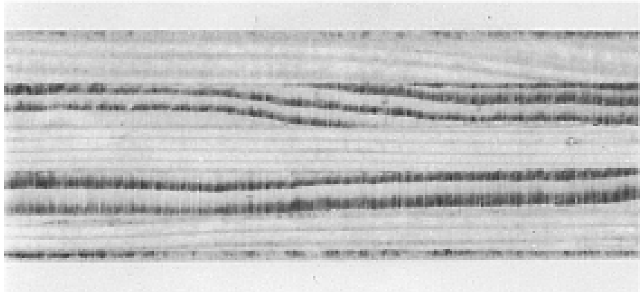
Session Objectives

At the end of the session the delegates will be able to understand

- What are composites?
- Classification
- Properties
- Applications of composites

What are Composites?

- ***Composite*** is a combination of two or more chemically distinct and insoluble phases
- Constituent materials or phases must have significantly different properties for it to combine them: thus metals and plastics are not considered as composites although they have a lot of fillers and impurities
- The properties and performance of ***composites*** are far superior to those of the constituents
- Composites consist of one or more discontinuous phases (reinforcement) embedded in a continuous phase (matrix)
- Examples:
  - Cemented carbides (WC with Co binder)
  - Rubber mixed with carbon black
  - Wood (a natural composite as distinguished from a synthesized composite)



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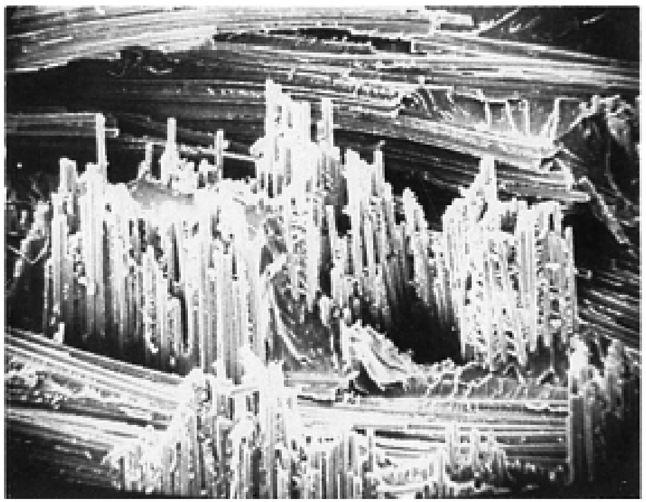

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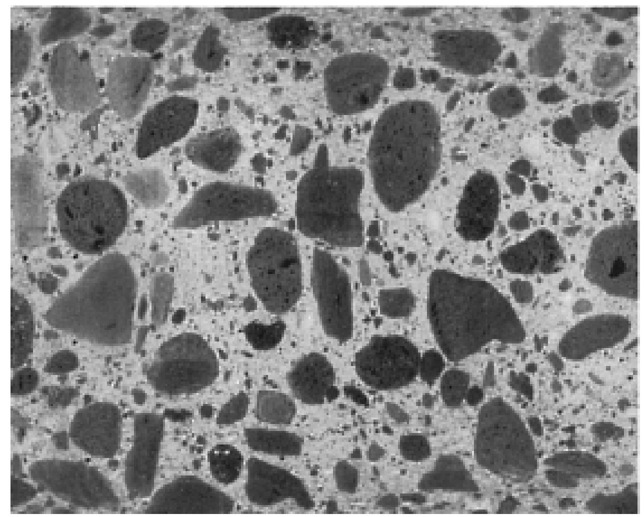

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Some examples of composite materials: (a) plywood is a laminar composite of layers of wood veneer, (b) fiberglass is a fiber-reinforced composite containing stiff, strong glass fibers in a softer polymer matrix (× 175), and (c) concrete is a particulate composite containing coarse sand or gravel in a cement matrix (reduced 50%).

Merits of Composite Materials

Composites can be very strong and stiff, yet very light in weight, so ratios of strength-to-weight and stiffness-to-weight are several times greater than steel or aluminum

- High specific strength and
- High specific stiffness Long fatigue life
- High creep resistance
- Low coefficient of thermal expansion
- Low density
- Low thermal conductivity
- Better wear resistance
- Improved corrosion resistance
- Better temperature dependent behavior

Disadvantages and Limitations of Composite Materials

- Properties of many important composites are anisotropic - the properties differ depending on the direction in which they are measured – this may be an advantage or a disadvantage
- Many of the polymer-based composites are subject to attack by chemicals or solvents, just as the polymers themselves are susceptible to attack
- Composite materials are generally expensive
- Manufacturing methods for shaping composite materials are often slow and costly

Functions of the Matrix Material (Primary Phase)

- Provides the bulk form of the part or product made of the composite material
- Holds the imbedded phase in place, usually enclosing and often concealing it
- When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent
- Cermets
  - Ceramic (up to 90%) contained in a metallic matrix
  - Cemented Carbides (tungsten, titanium, chromium)
  - Cutting Tools, Dies, Indenters

Classification

Based on the type of matrix material

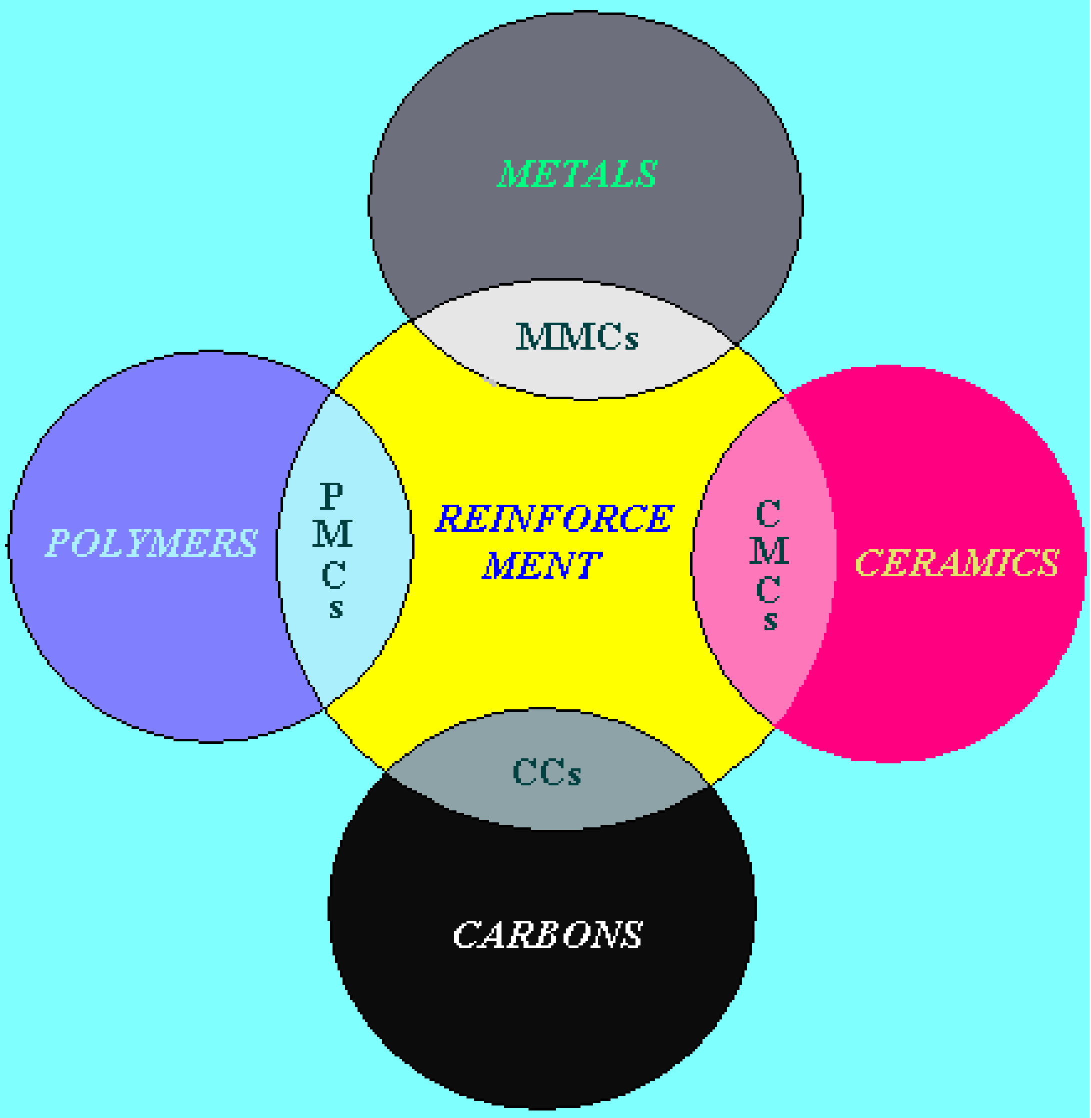
- Polymer Matrix Composites (PMCs)
- Metal Matrix Composites (MMCs)
- Ceramic Matrix Composites (CMCs)
- Carbon/Carbon Composites (C/Cs)

Based on the geometry of reinforcement

- Particulate reinforced Composites
- Whisker/Flakes reinforced composites
- Fiber reinforced composites

Hybrid: A composite laminate comprising of laminae of two or more composite material systems or a combination of two or more different fibers such as C and glass or C and aramid into a structure

Based on the Type of Matrix



Polymer Matrix Composites (PMCs)

Are prominent class of composites compared to other composite materials in commercial applications

Fiber Materials: Boron, Graphite, Carbon

Most of the PMCs use either carbon-graphite or aramid fibers, which are the main commercial fibers

Matrix Materials:

Thermoplastic, Epoxy and Thermo-set materials.

•Thermoplastics offer the advantages of good mechanical and tribological properties.

•Epoxy resin remains the most important matrix polymer.

Metal Matrix Composites (MMCs)

•MMCs are advanced class of structural materials consisting of nonmetallic reinforcements incorporated into the metallic matrix.

•MMCs are widely used in engineering applications where the operating temperature lies in between 250 ^{o}C to 750 ^{o}C.

Matrix materials: Aluminum, Titanium, Copper, Magnesium and Super alloys.

Reinforcement materials: Silicon carbide, Boron, Molybdenum and Alumina

Ceramic Matrix Composites (CMCs)

CMCs are advanced class of structural materials consisting of metallic/non-metallic reinforcements incorporated into the ceramic matrix

CMCs are widely used in engineering applications where the operating temperature lies in between 800ºC to 1650ºC

Carbon/Carbon Composites (C/Cs)

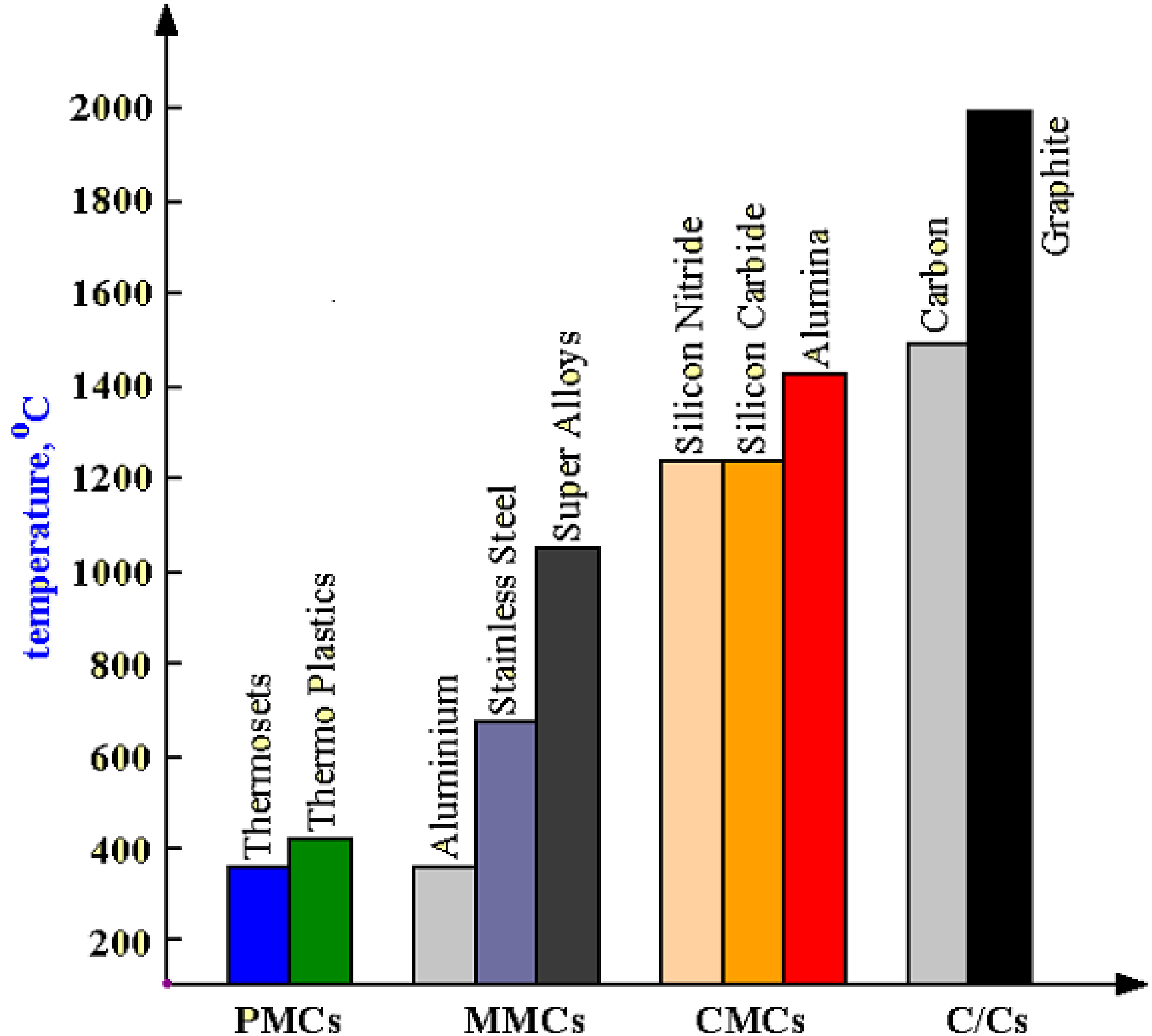
C/Cs are developed specifically for parts that must operate in extreme temperature ranges.
Composed of a carbon matrix reinforced with carbon yarn fabric, 3-D woven fabric, 3-D braiding, etc.

Applications: C/C composites meet applications ranging from *rockets to aerospace* because of their ability to maintain and even increase their structural properties at extreme temperatures.

Advantages:

- Extremely high temperature resistance (1930°C – 2760°C).
- Strength actually increases at higher temperatures (up to 1930°C).
- High strength and stiffness.
- Good resistance to thermal shock.

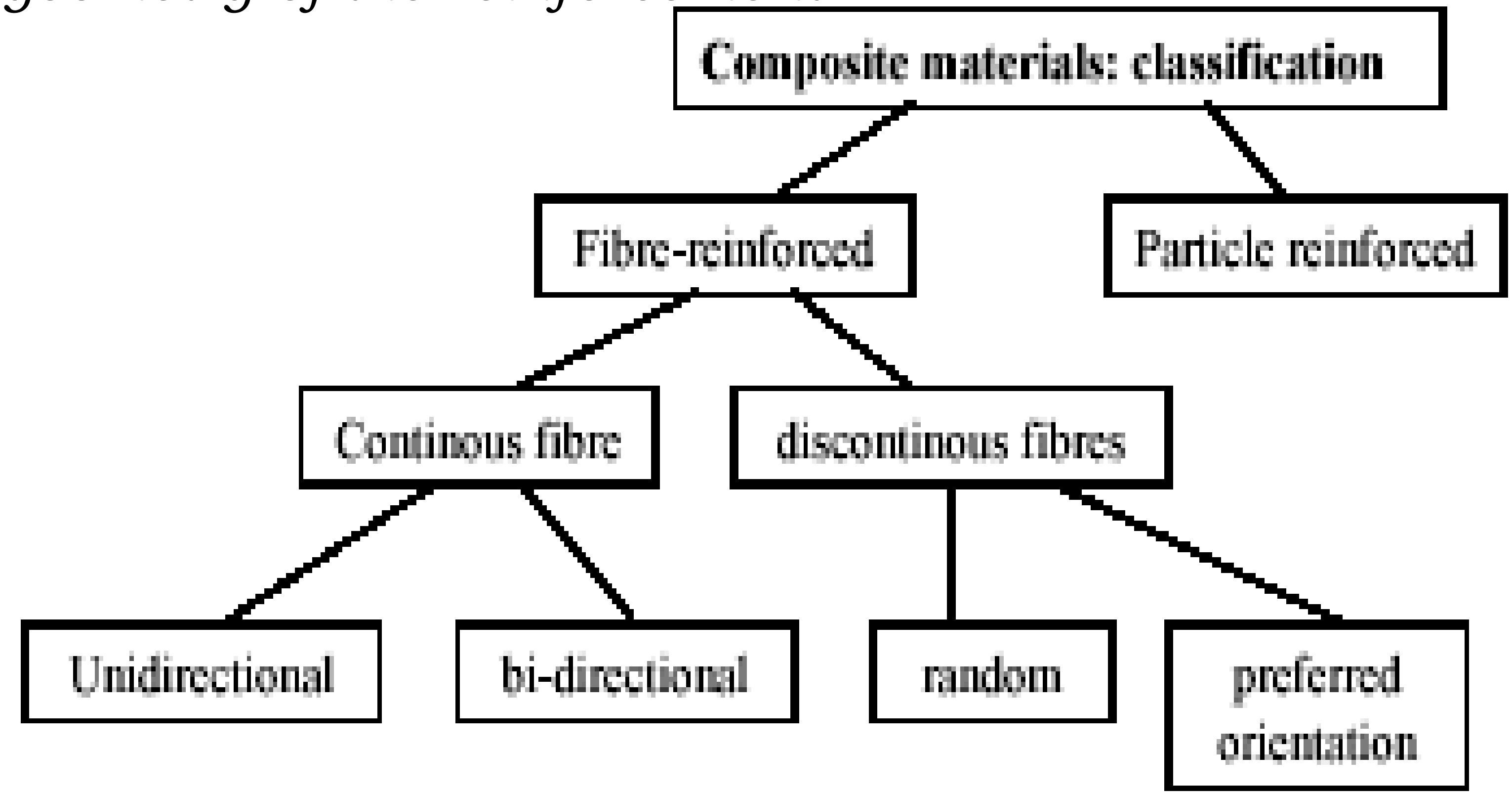
Operating Temperatures



Service temperature ranges for different types of composites

Classification Based on Reinforcement

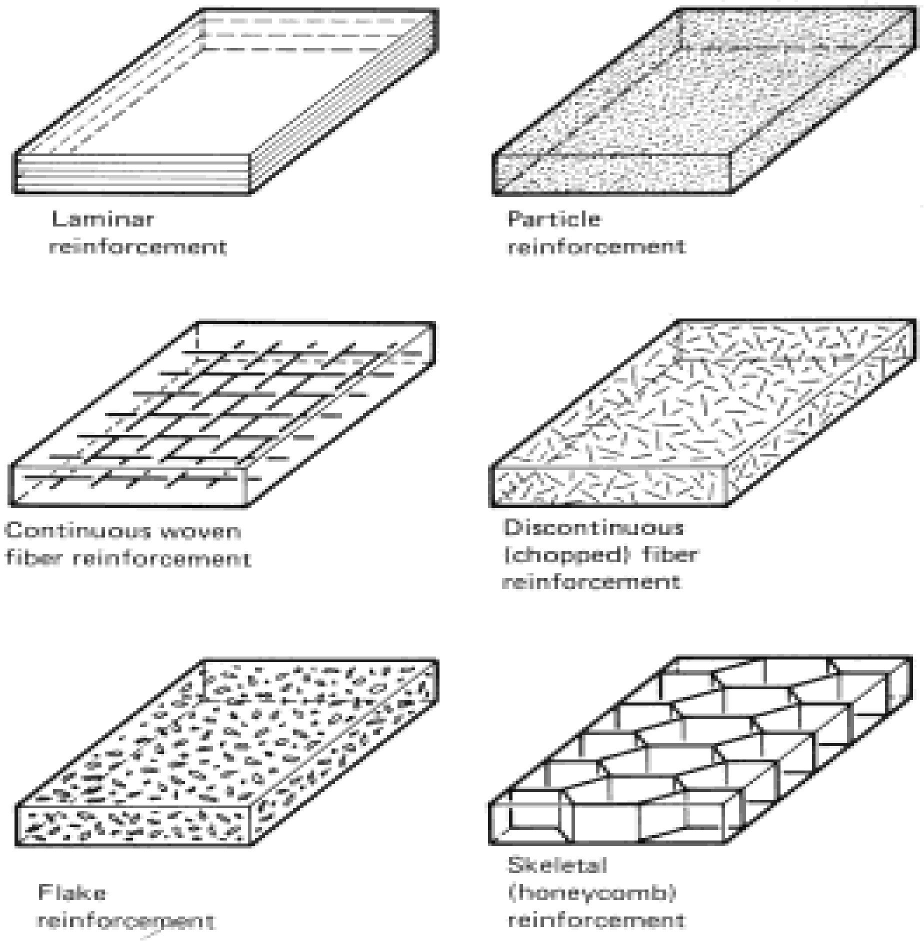
Strengthening mechanism depends strongly on the geometry of the reinforcement



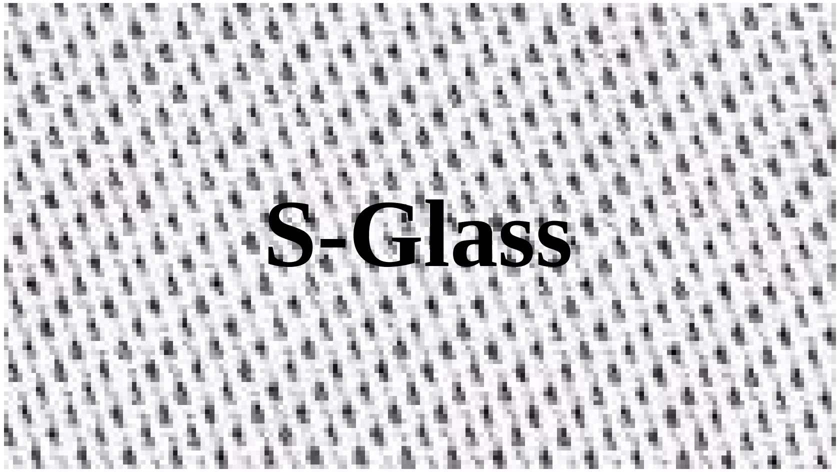
Types of Reinforcements

- *Fibers*
  - Cross-section can be circular, square or hexagonal
  - Diameters -- 0.0001” - 0.005 ” (0.00025-0.0125cm)
  - Lengths -- L/D ratio
    - 100 -- for chopped fiber
    - Much longer for continuous fiber
- *Particulate*
  - Small particles that impede dislocation movement (in metal composites) and strengthens the matrix
  - For sizes > 1 μm, strength of particle involved in load sharing with matrix
- *Flakes*
  - Flat platelet form

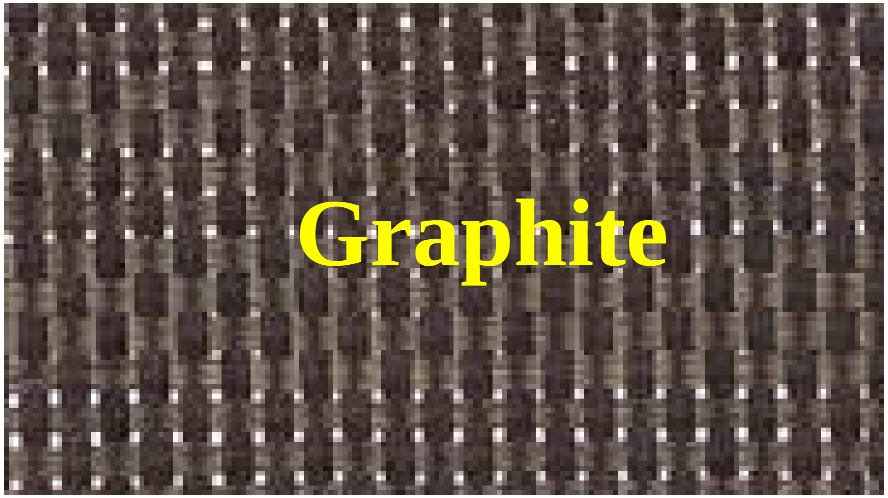
Types of Reinforcement




E-Glass

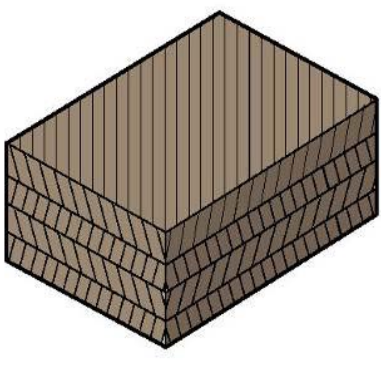

S-Glass

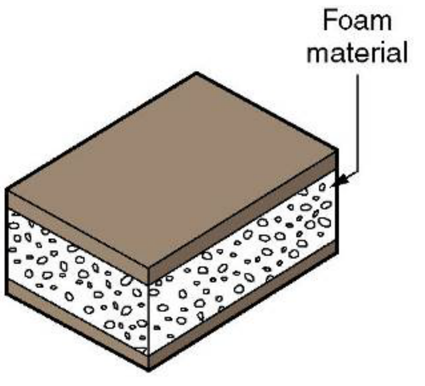

Kevlar

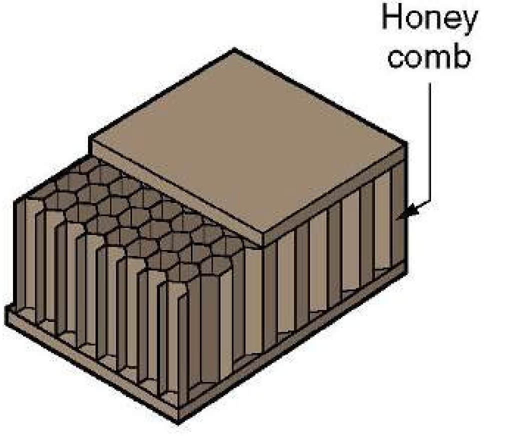

Graphite

Other Composite Structures

- Laminar composite structure – conventional
- Sandwich structure
- Honeycomb sandwich structure







Laminate:

A laminate is a layered construction of a number of lamine arranged in a proper sequence.

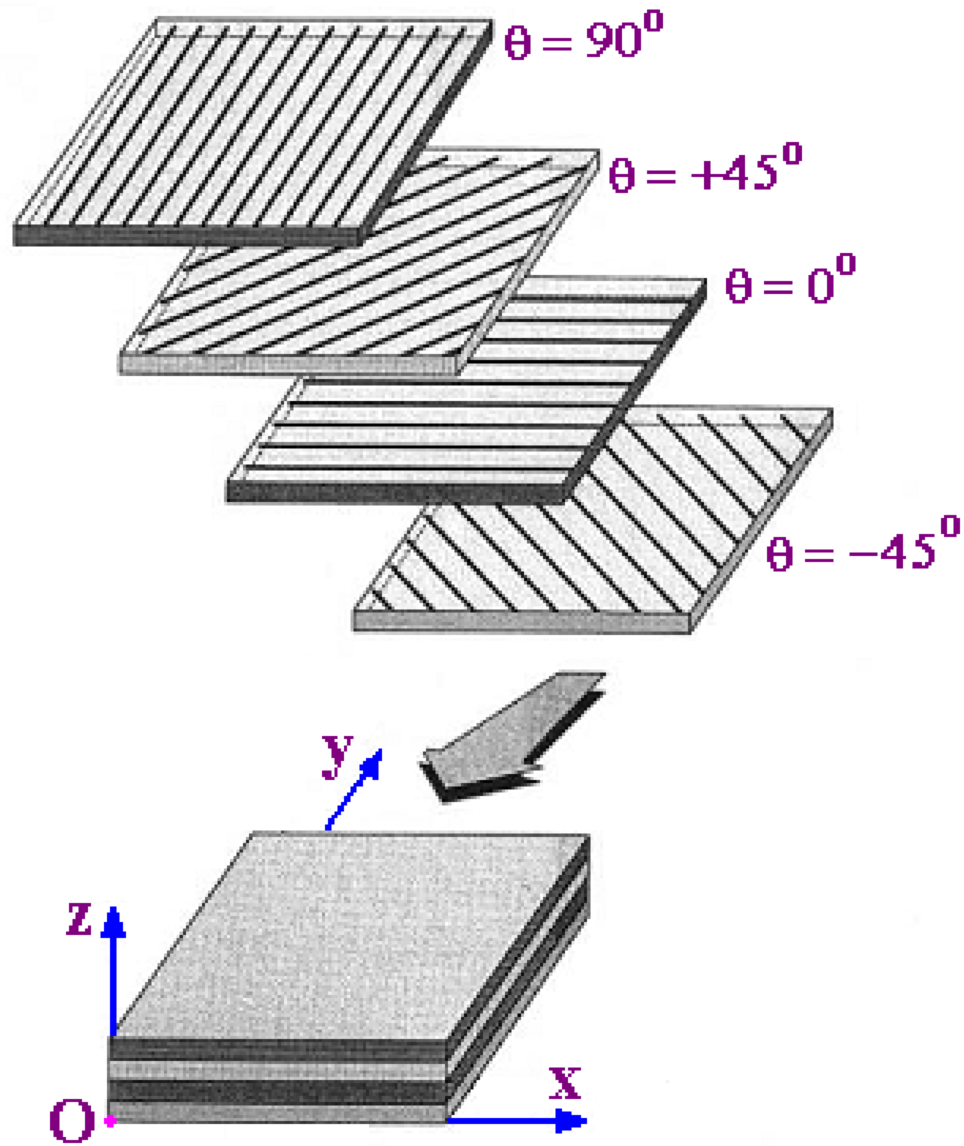
The layers are stacked and subsequently cemented together such that the orientation of fiber direction (θ) varies with each successive layer.

Lamine

Stacking sequence

Laminate

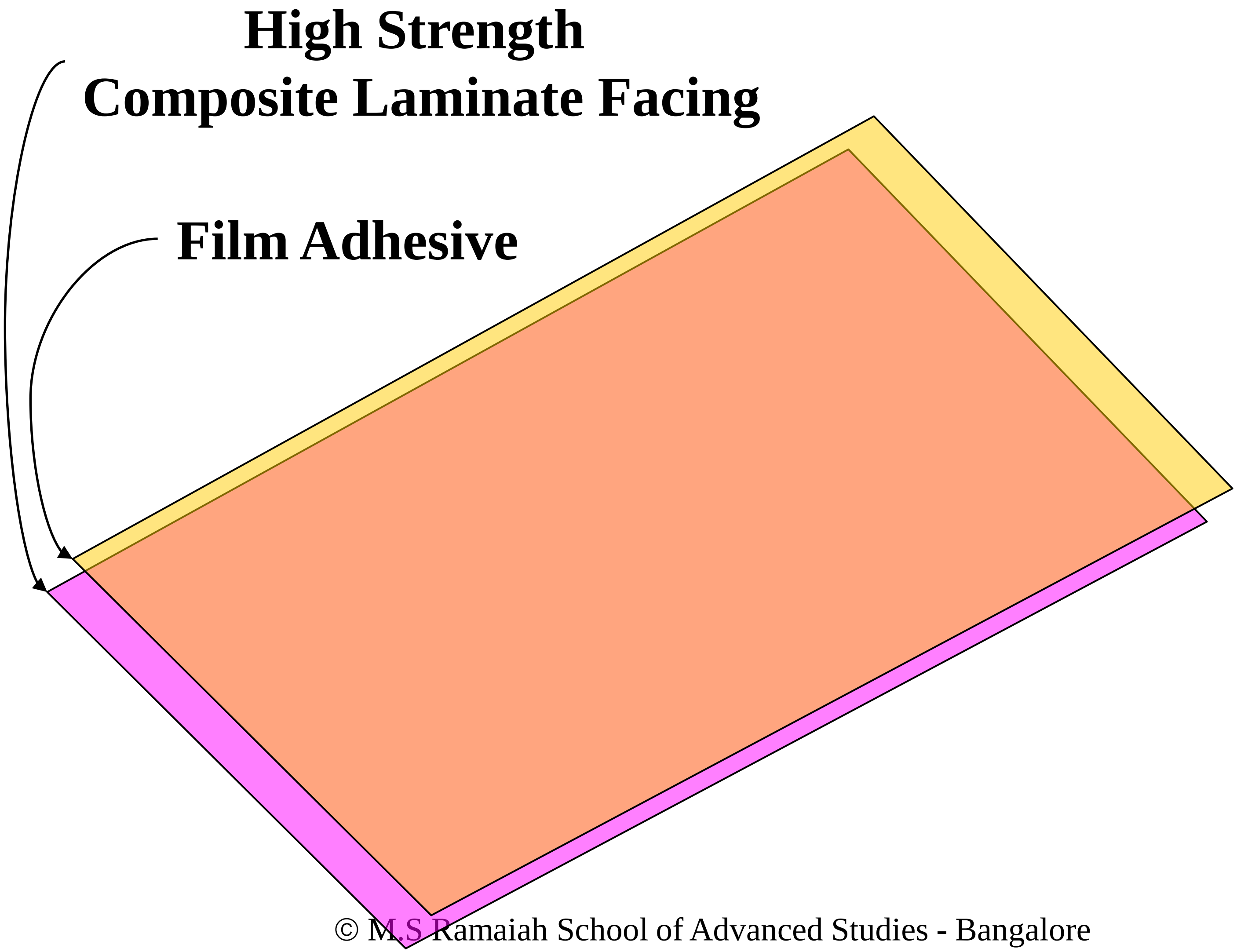
[26]

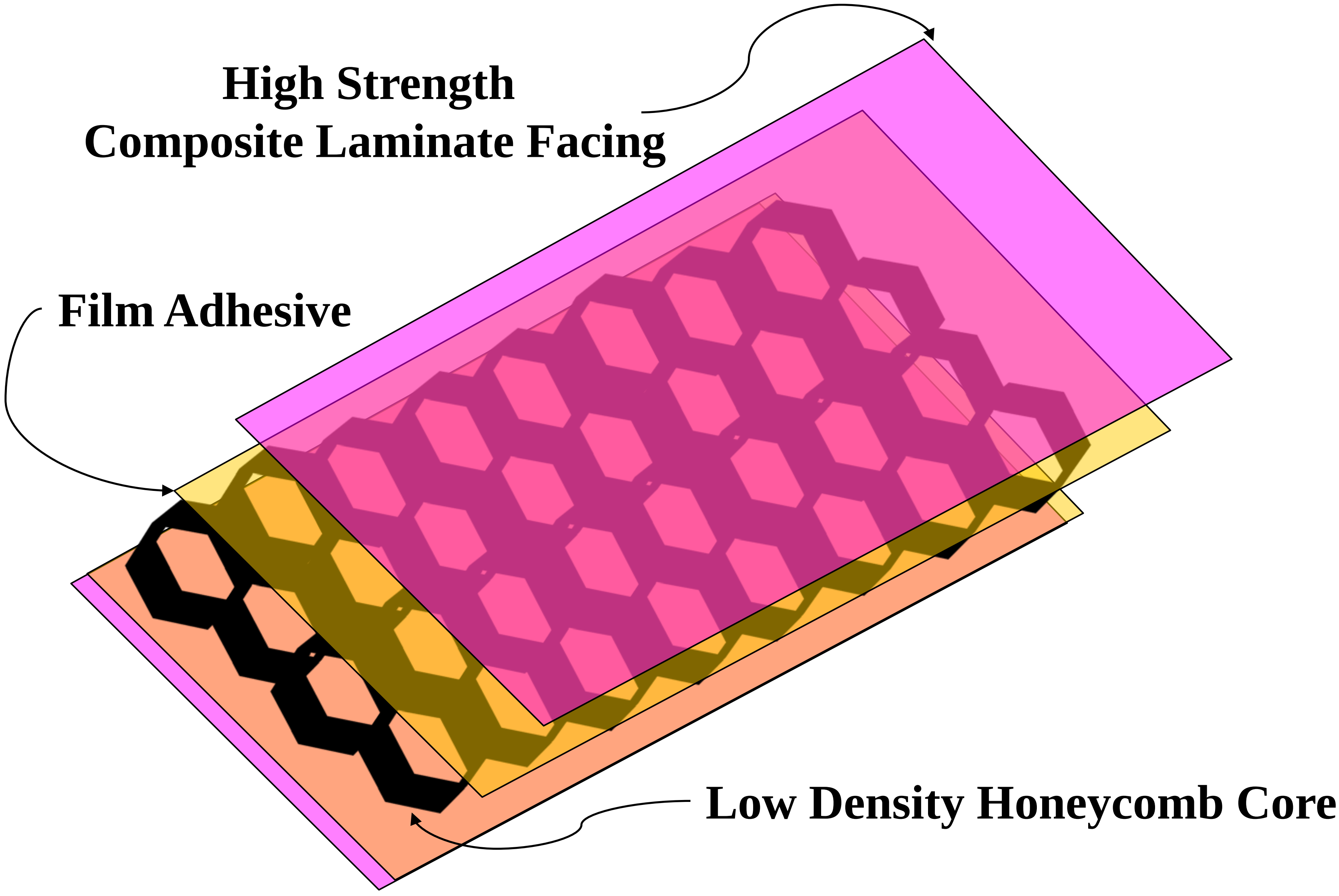


Other Laminar Composite Structures

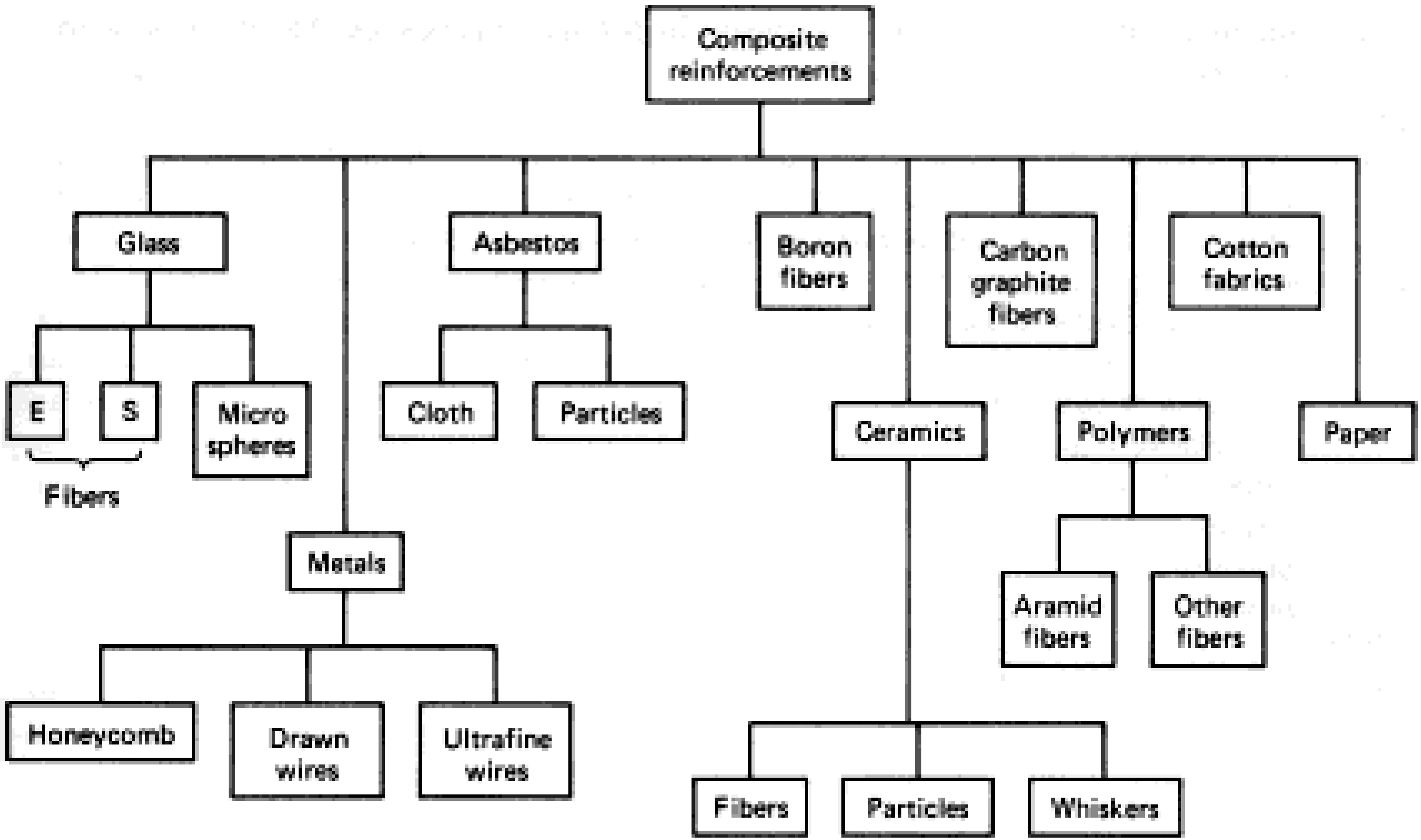
- Automotive tires - consists of multiple layers bonded together
- FRPs - multi-layered fiber-reinforced plastic panels for aircraft, automobile body panels, boat hulls
- Printed circuit boards - layers of reinforced plastic and copper for electrical conductivity and insulation
- Snow skis - composite structures consisting of layers of metals, particle board, and phenolic plastic
- Windshield glass - two layers of glass on either side of a sheet of tough plastic

Sandwich Panel



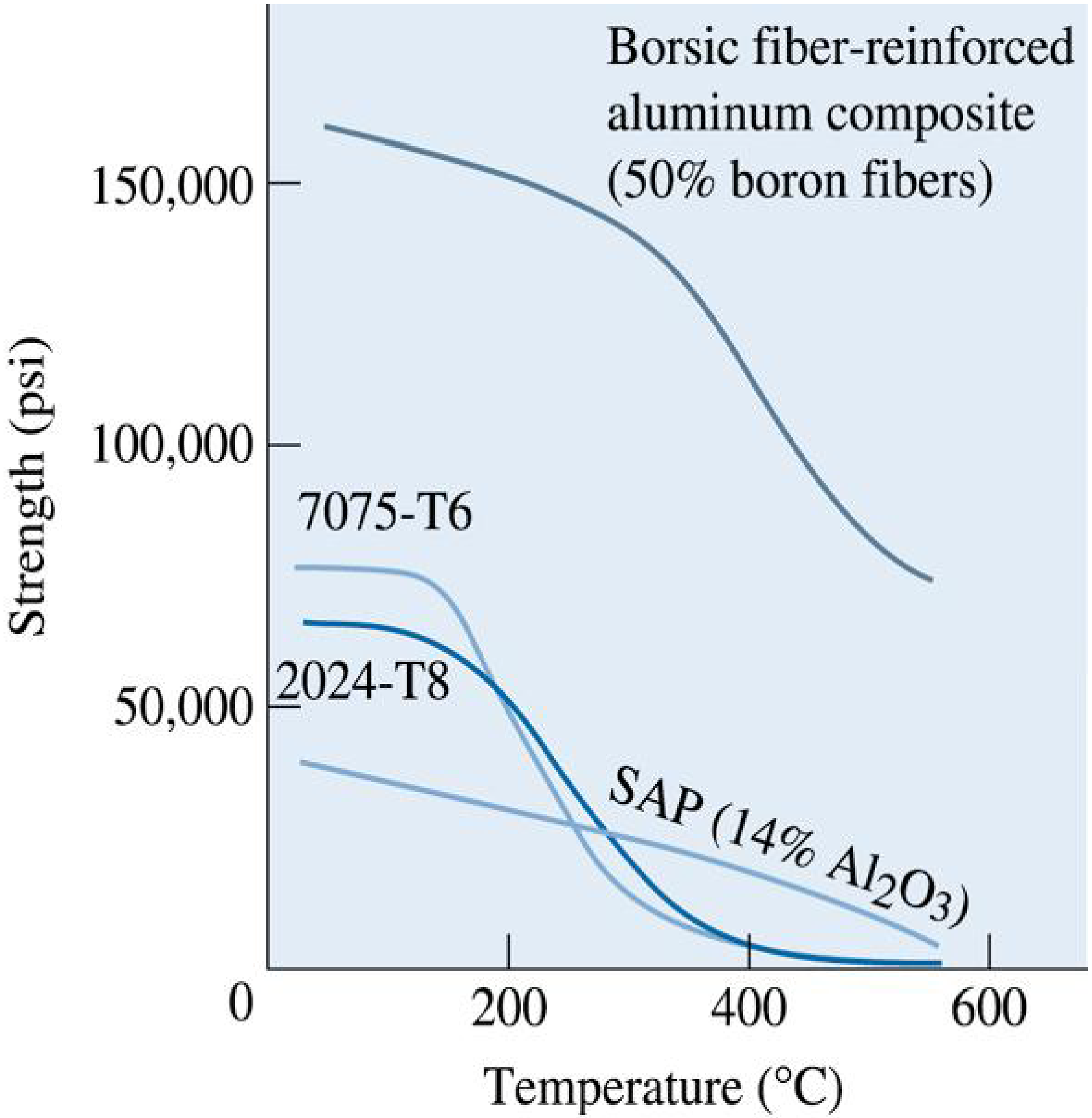

High Strength
Composite Laminate Facing
Film Adhesive
Low Density Honeycomb Core

Types of Reinforcement Materials for Composites



Properties of Composite Materials

- In selecting a composite material, an optimum combination of properties is usually sought, rather than one particular property
  - Example: fuselage and wings of an aircraft must be lightweight and be strong, stiff, and tough
    - Several fiber-reinforced polymers possess this combination of properties
  - Example: natural rubber alone is relatively weak
    - Adding significant amounts of carbon black to NR increases its strength dramatically

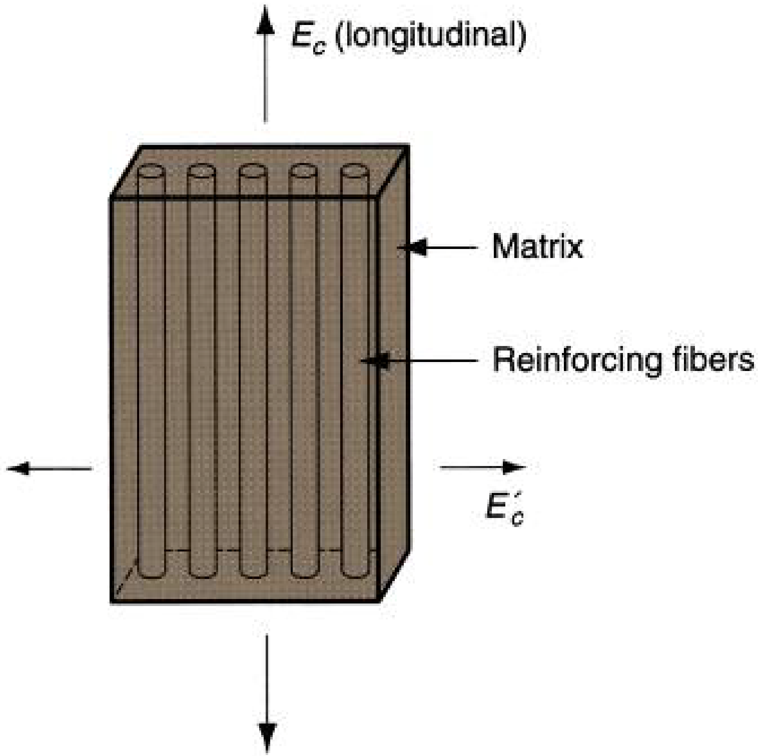


Comparison of the yield strength of dispersion-strengthened sintered aluminum powder (SAP) composite with that of two conventional two-phase high-strength aluminum alloys. The composite has benefits above about 300°C. A fiber-reinforced aluminum composite is shown for comparison.

Properties of Composites

- Particles and flakes usually enhance properties less effectively than chopped fibers.
- Continuous fibers are the most effective, although the properties vary with direction and are the strongest in the longitudinal direction of the fiber -To reduce directionality, woven mats and different plies are used
- A strong bond between the matrix and reinforcement phases.
- Properties are determined by three factors
  - The materials used as component phases in the composite
  - The geometric shapes of the constituents and resulting structure of the composite system
  - The manner in which the phases interact with one another

Rule of Mixtures



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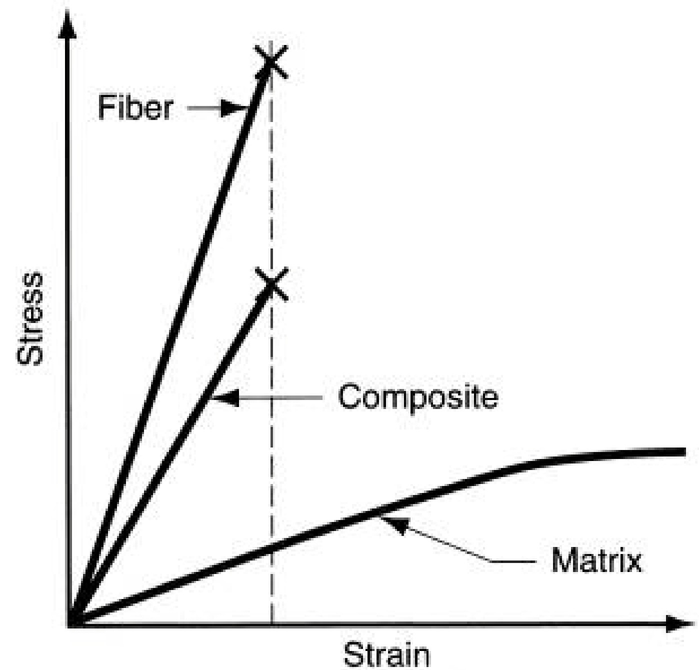

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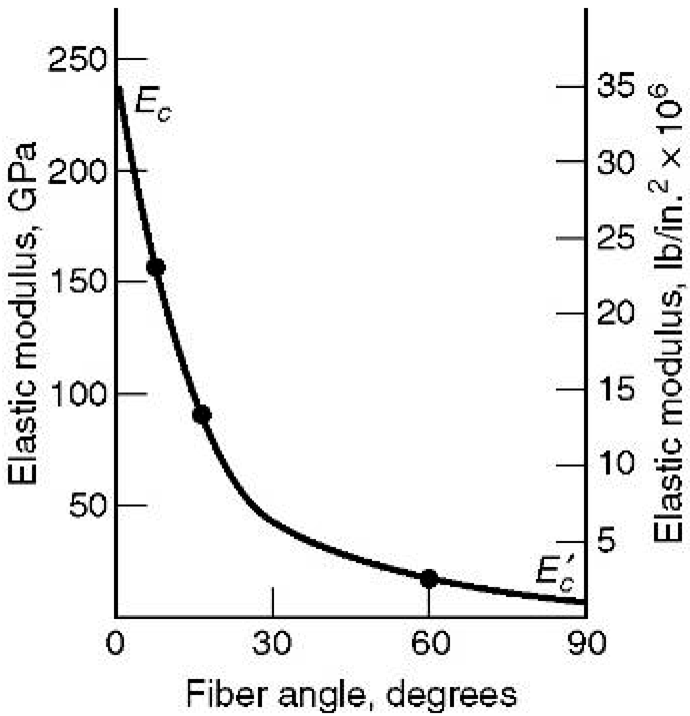
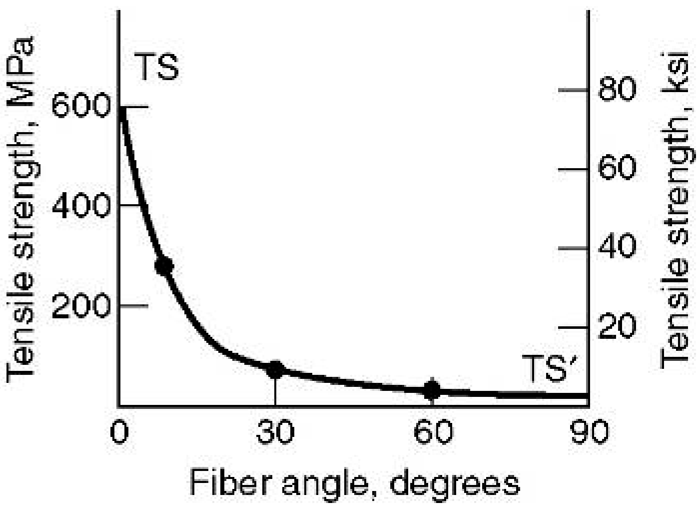
$E_c = E_m V_m + E_p V_p$

Or $E_c = E_m E_p / (E_m V_m + E_p V_p)$

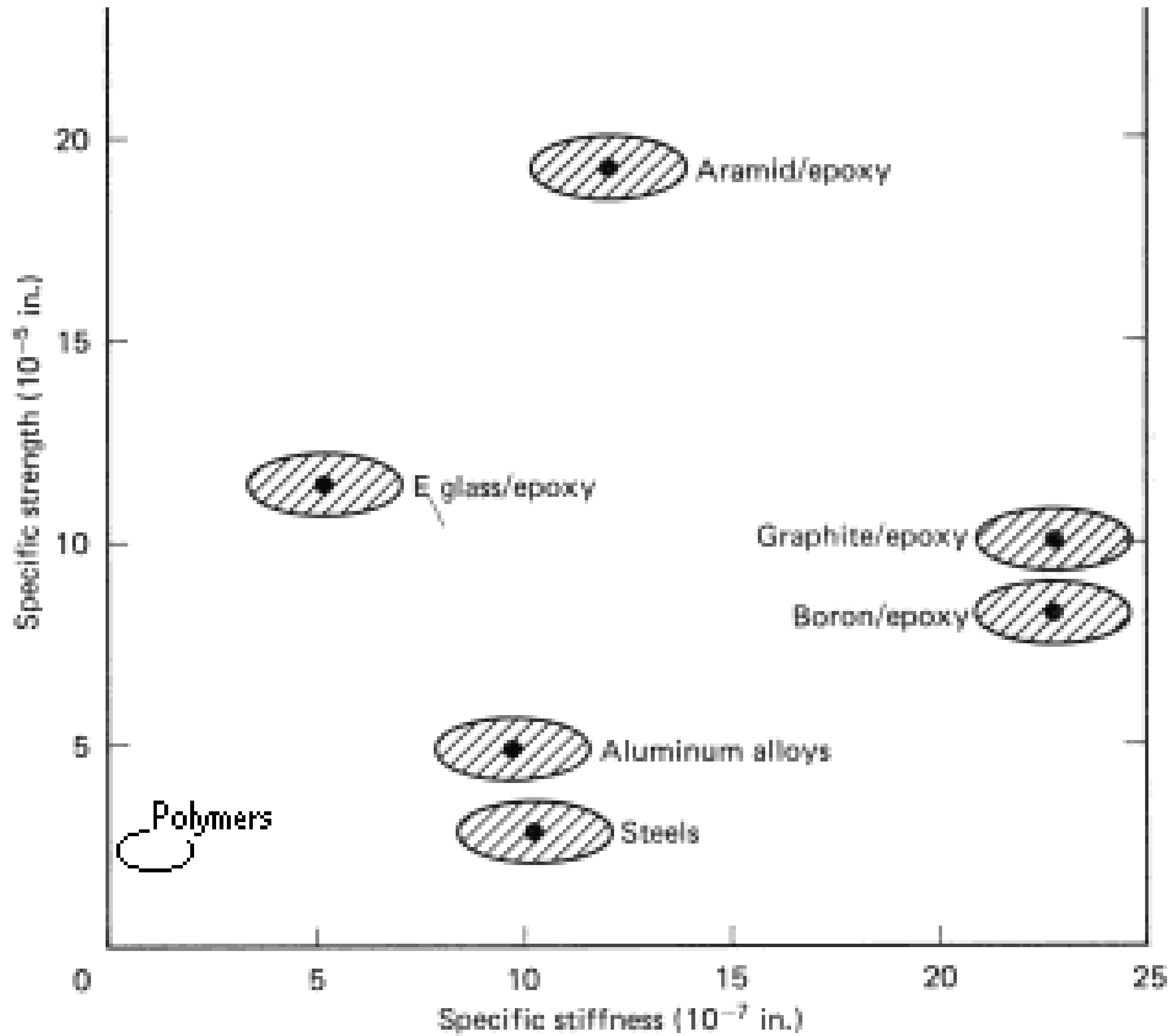
where V_m & V_p are the volume fraction of matrix and reinforcement respectively and E_m & E_p are elastic modulus of matrix and reinforcement

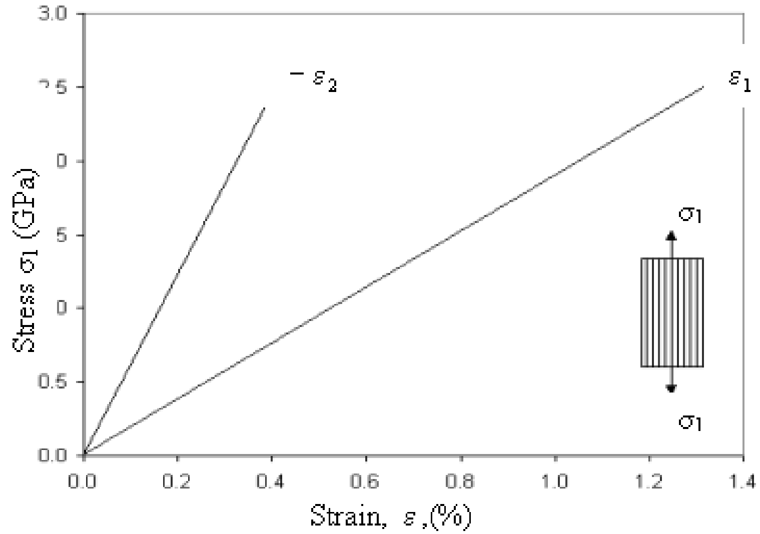
Variation in elastic modulus and tensile strength as a function of direction of measurement relative to longitudinal axis of carbon fiber-reinforced epoxy composite



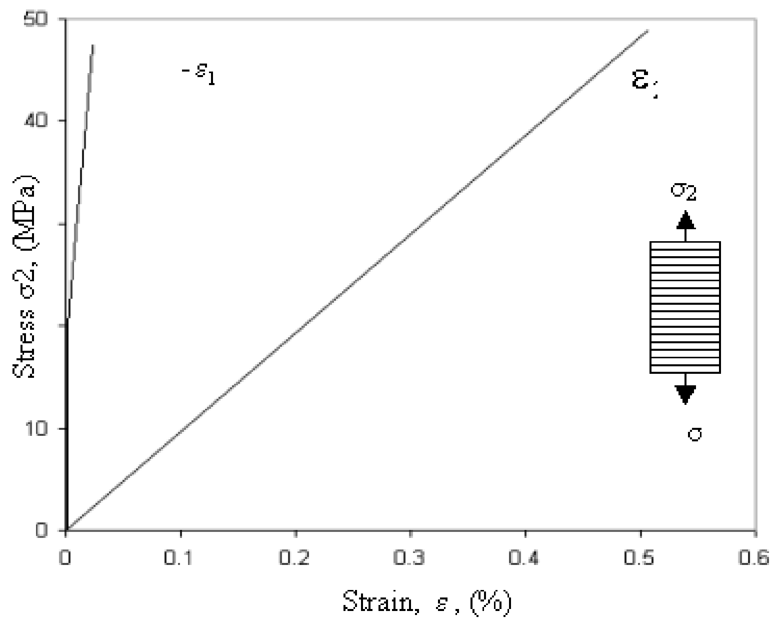


Specific Strength and Modulus of Composites





Stress-strain curves for $[0_6]$ carbon/epoxy specimen under uniaxial tensile loading.



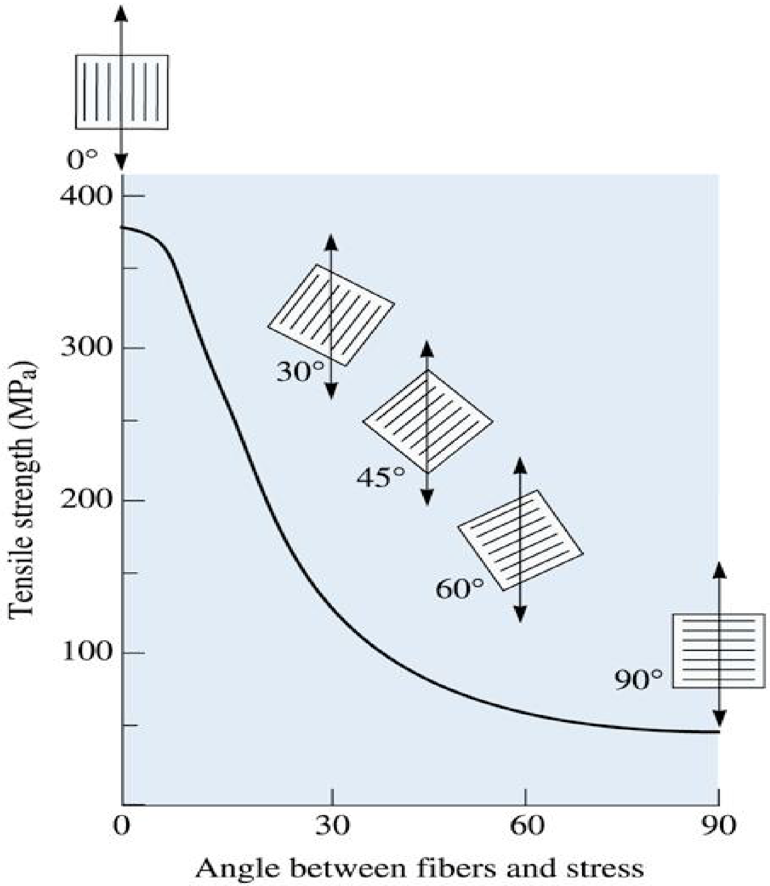
Stress-strain curves for $[90_8]$ carbon/epoxy specimen under uniaxial tensile loading.

Longitudinal properties of carbon/epoxy specimen

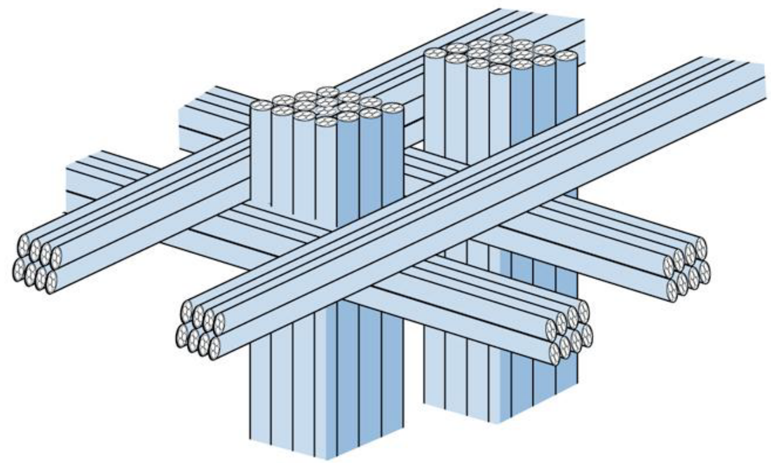
Properties	Values
E_1	177 GPa
F_{1t}	2530 MPa
ε_{1t}^{u}	0.0137
ν_{12}	0.29

Transverse properties of carbon/epoxy specimen

Properties	Values
E_2	9.2 GPa
F_{2t}	49.7 MPa
ε_{2t}^{u}	0.0055
ν_{21}	0.015



Effect of fiber orientation on the tensile strength of E-glass fiber-reinforced epoxy composites.



A three-dimensional weave for fiber-reinforced composites.

Applications of PMCs

- Most widely used form of FRP is a laminar structure, made by stacking and bonding thin layers of fiber and polymer until desired thickness is obtained
- By varying fiber orientation among layers, a specified level of anisotropy in properties can be achieved in the laminate
- Applications: parts of thin cross-section, such as aircraft wing and fuselage sections, automobile and truck body panels, and boat hulls
  - Aerospace Industries (Carbon/Epoxy PMCs)
  - Automobile Industry (Epoxy based PMCs)
  - Springs and bumper systems (Reinforced Thermosets)
  - Tooling (Epoxy based PMCs)
  - Fiberglass reinforced plastic has been used for boat hulls, fishing rods, tennis rackets, golf club shafts, helmets, skis, bows and arrows

Applications

Space craft: Antenna structures, Solar reflectors, Satellite structures, Radar, Rocket engines, etc.

Aircraft: Jet engines, Turbine blades, Turbine shafts, Compressor blades, Airfoil surfaces, Wing box structures, Fan blades, Flywheels, Engine bay doors, Rotor shafts in helicopters, Helicopter transmission structures, etc.

Miscellaneous: (1) Bearing materials, Pressure vessels, Abrasive materials, Electrical machinery, Truss members, Cutting tools, Electrical brushes, etc.

(2) Automobile: Engines, bodies, Piston, cylinder, connecting rod, crankshafts, bearing materials, etc.

Examples of fiber-reinforced materials and applications

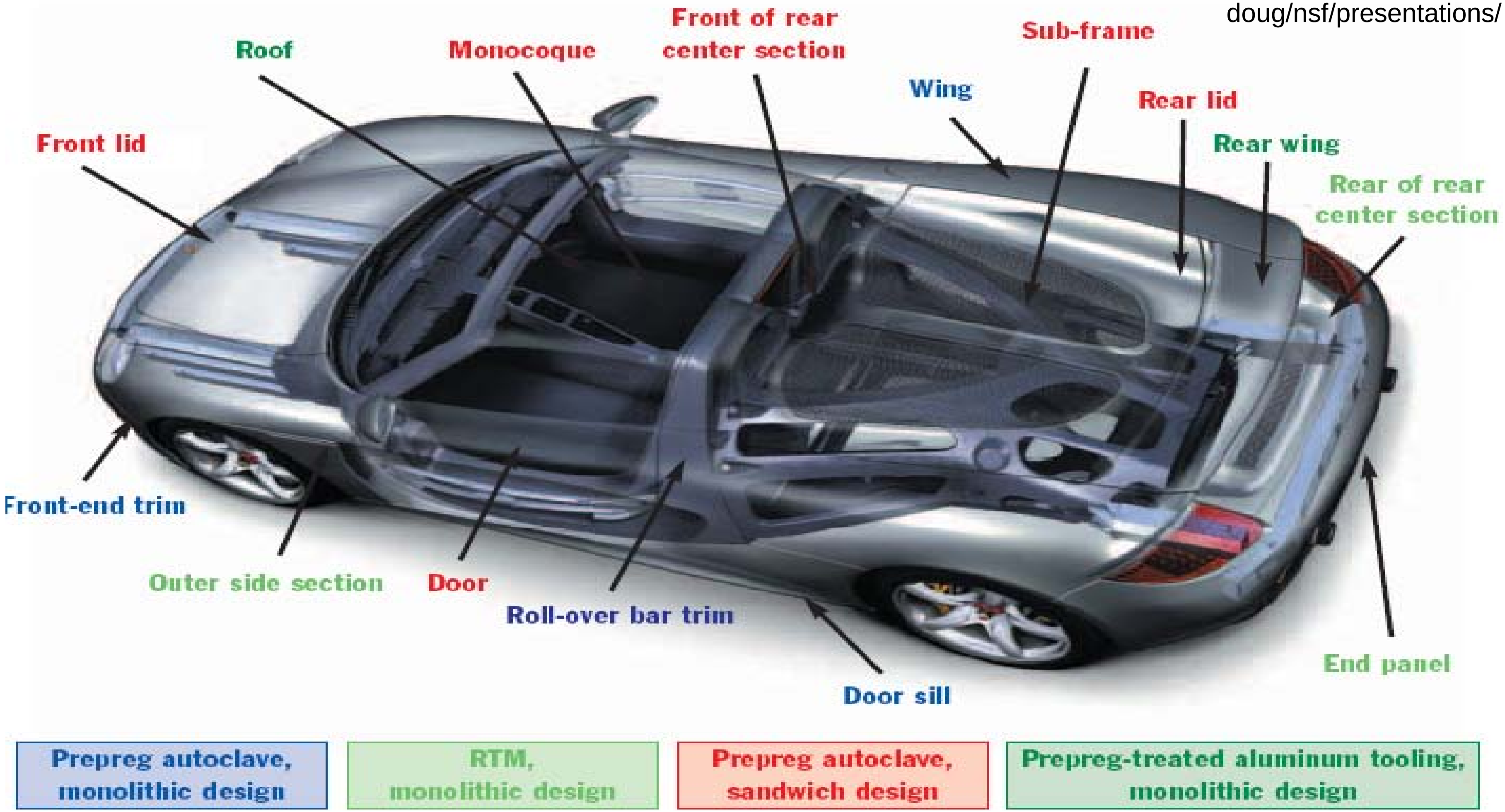
Material	Applications
Borsic aluminum	Fan blades in engines, other aircraft and aerospace applications
Kevlar^{TM}-epoxy and Kevlar^{TM}-polyester	Aircraft, aerospace applications (including space shuttle), boat hulls, sporting goods (including tennis rackets, golf club shafts, fishing rods), flak jackets
Graphite-polymer	Aerospace and automotive applications, sporting goods
Glass-polymer	Lightweight automotive applications, water and marine applications, corrosion-resistant applications, sporting goods equipment, aircraft and aerospace components

Light Weight Application

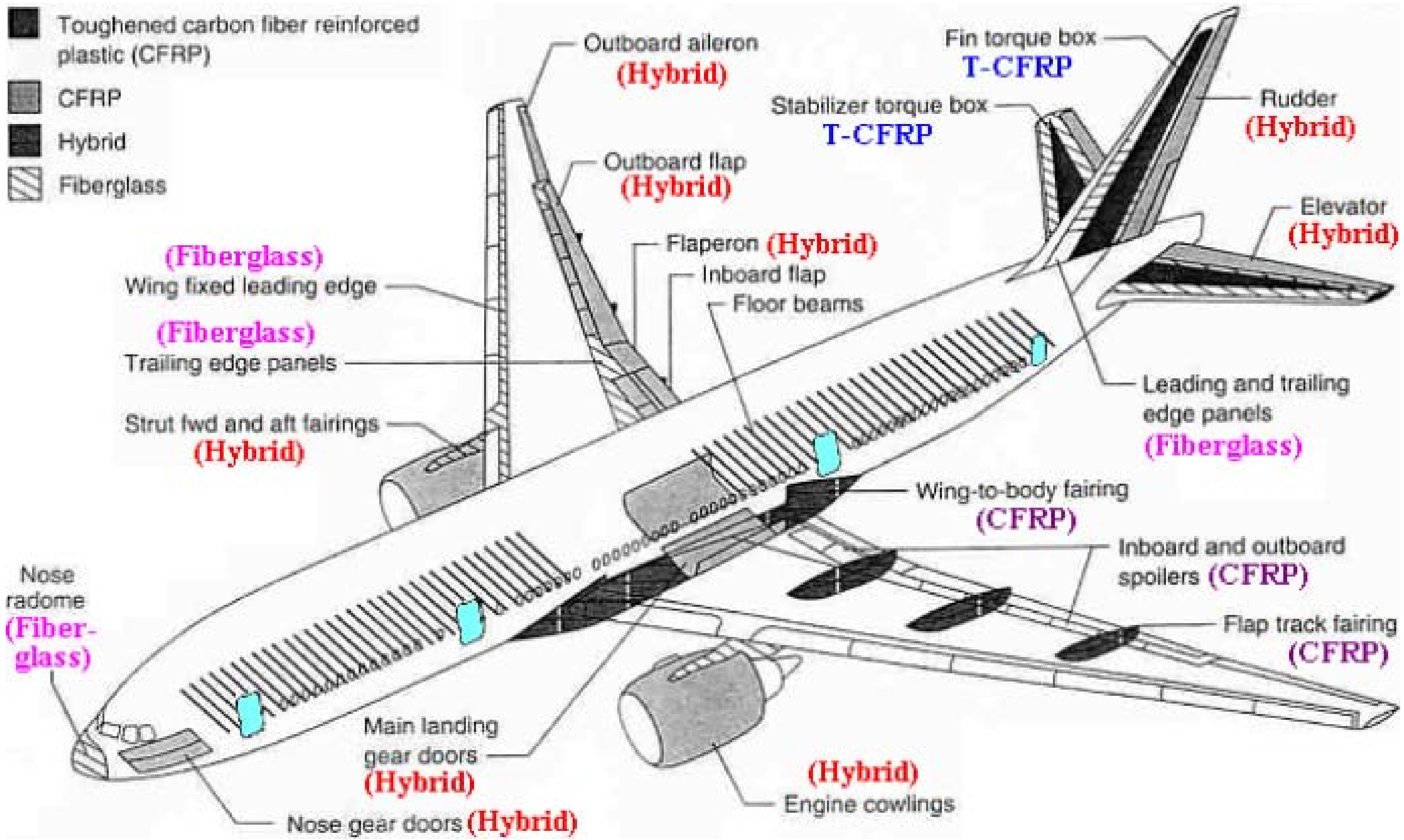
- Composites are the candidate materials
- Automotive body parts by composites mainly CFRP and GFRP
- GFRP, CFRP, SMC, C/C for seat structures
- Formula one uses CFRP extensively
- CFRP is used in road and mountain bikes and also in road bikes made of Al the seat posts handle bars, and forks
- CFRP and Honeycomb composites for Chassis
- Fuel tanks made up of Kevlar reinforced rubber

CFRP Application

web.missouri.edu/~smith doug/nsf/presentations/



Composites in a Boeing 777



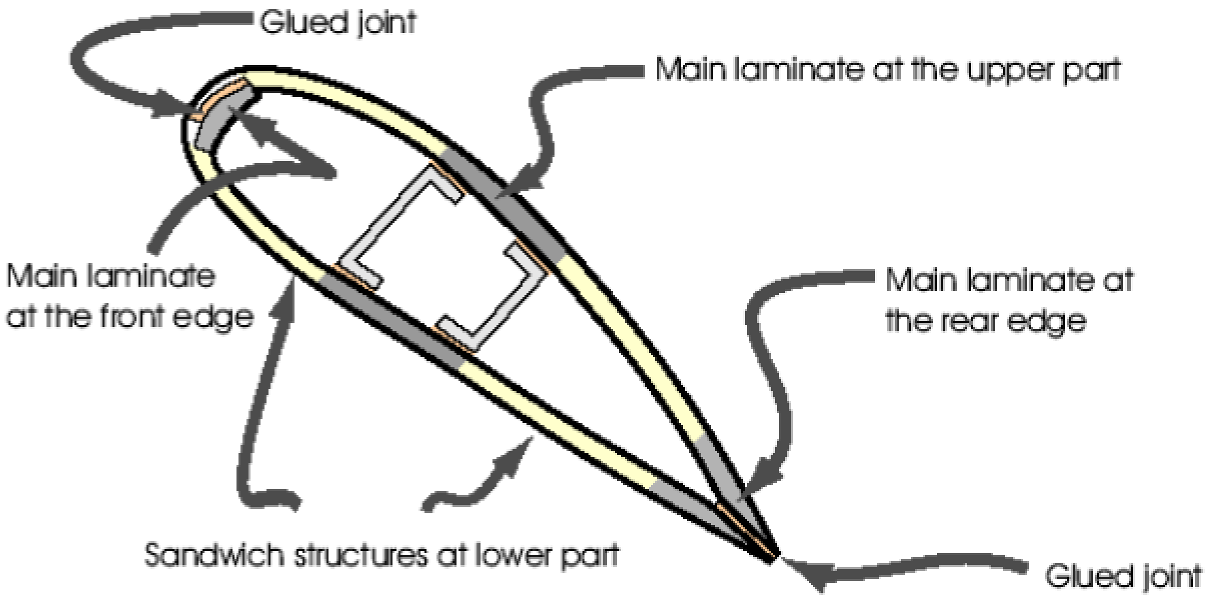
Composite Materials for Wind Turbine Blades

CFRP Sonar Dome

The NEG-Micon 40 m radius AL40 carbon-wood epoxy wind turbine blade: Resin infusion manufacturing process

www.tech.plym.ac.uk/sme/mats324

Typical Cross section of a Wind Turbine Blade



Examples and applications of selected dispersion-strengthened composites

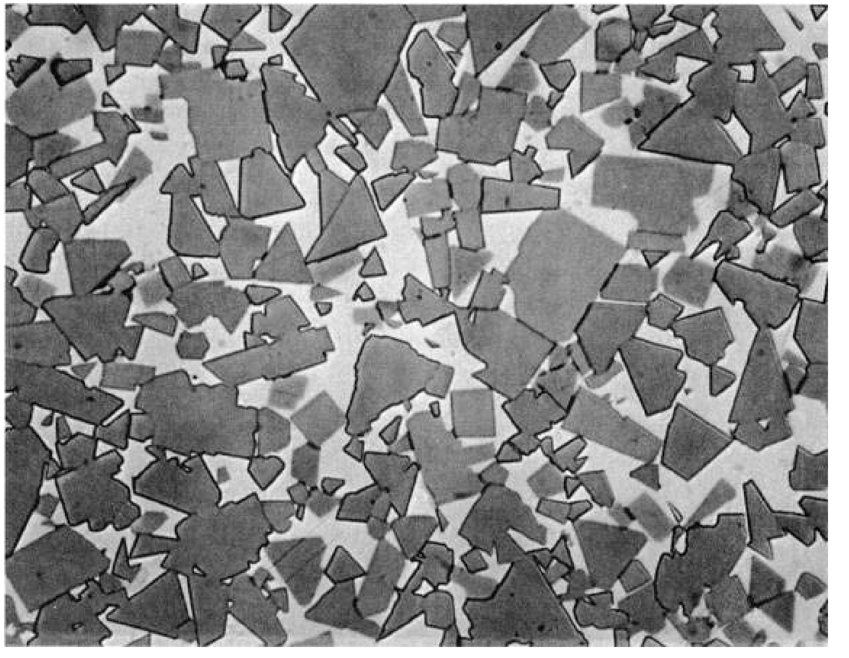
System	Applications
Ag-CdO	Electrical contact materials
$Al\text{-}Al_2O_3$	Possible use in nuclear reactors
Be-BeO	Aerospace and nuclear reactors
$Co\text{-}ThO_2$, Y_2O_3	Possible creep-resistant magnetic materials
$Ni\text{-}20\%\ Cr\text{-}ThO_2$	Turbine engine components
Pb-PbO	Battery grids
$Pt\text{-}ThO_2$	Filaments, electrical components
$W\text{-}ThO_2$, ZrO_2	Filaments, heaters

MMCs

www.youtube.com/watch?v=xbPxVws5Ty4&feature=related

Cemented Carbide

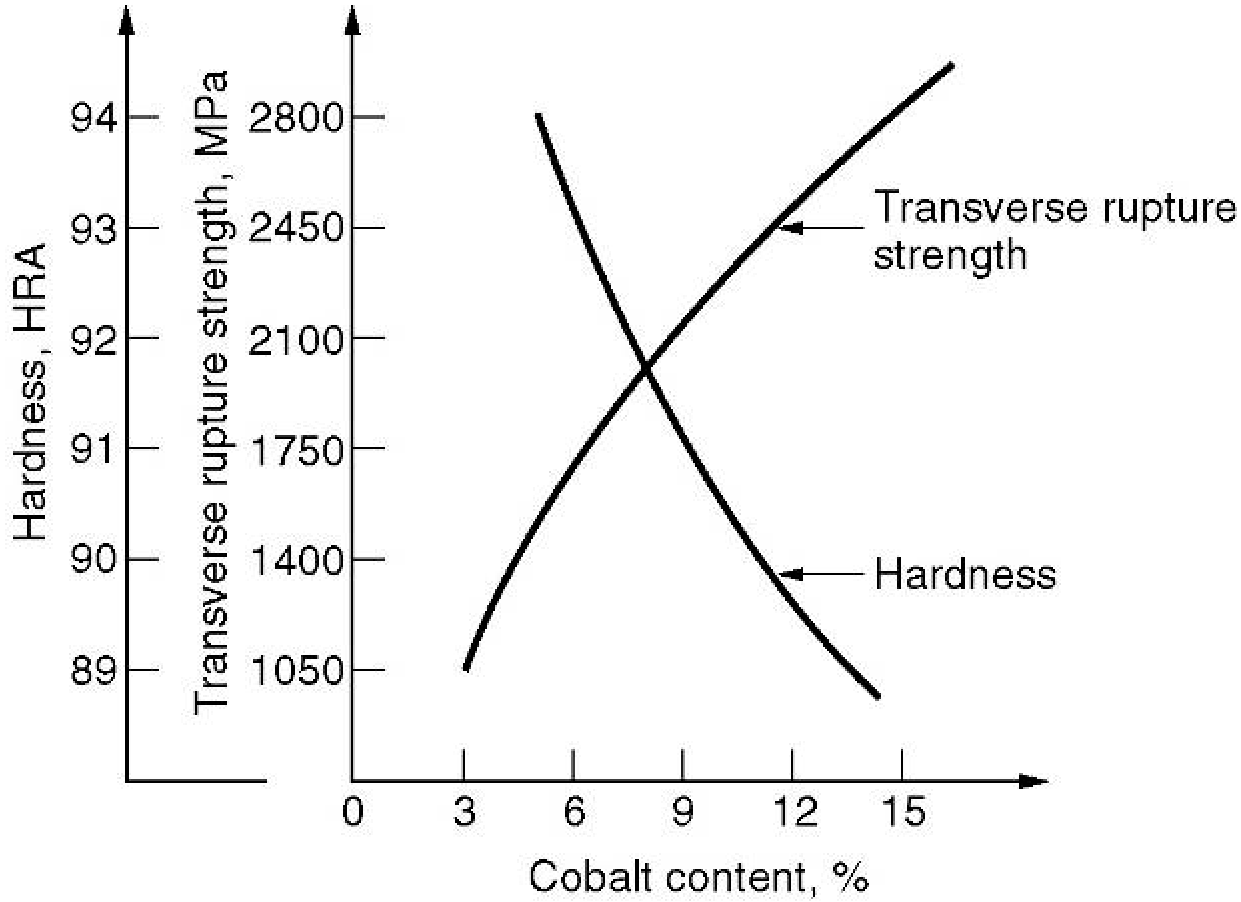
- One or more carbide compounds bonded in a metallic matrix
- Common cemented carbides are based on tungsten carbide (WC), titanium carbide (TiC), and chromium carbide (Cr3C2)
- Tantalum carbide (TaC) and others are less common
- Metallic binders: usually cobalt (Co) or nickel (Ni)



Photomicrograph (about 1500X) of cemented carbide with 85% WC and 15% Co

Hardness vs. Transverse Rupture Strength

Typical plot of hardness and transverse rupture strength as a function of cobalt content



Applications of Cemented Carbides

- Tungsten carbide cermets (Co binder) - cutting tools are most common; other: wire drawing dies, rock drilling bits and other mining tools, dies for powder metallurgy, indenters for hardness testers
- Titanium carbide cermets (Ni binder) - high temperature applications such as gas-turbine nozzle vanes, valve seats, thermocouple protection tubes, torch tips, cutting tools for steels
- Chromium carbides cermets (Ni binder) - gage blocks, valve liners, spray nozzles, bearing seal rings

Summary

- Classification of composites have been studied.
- The variation of mechanical properties with reinforcement composition and direction is addressed
- Advantages of composites are discussed.
- Applications of composite materials have been addressed