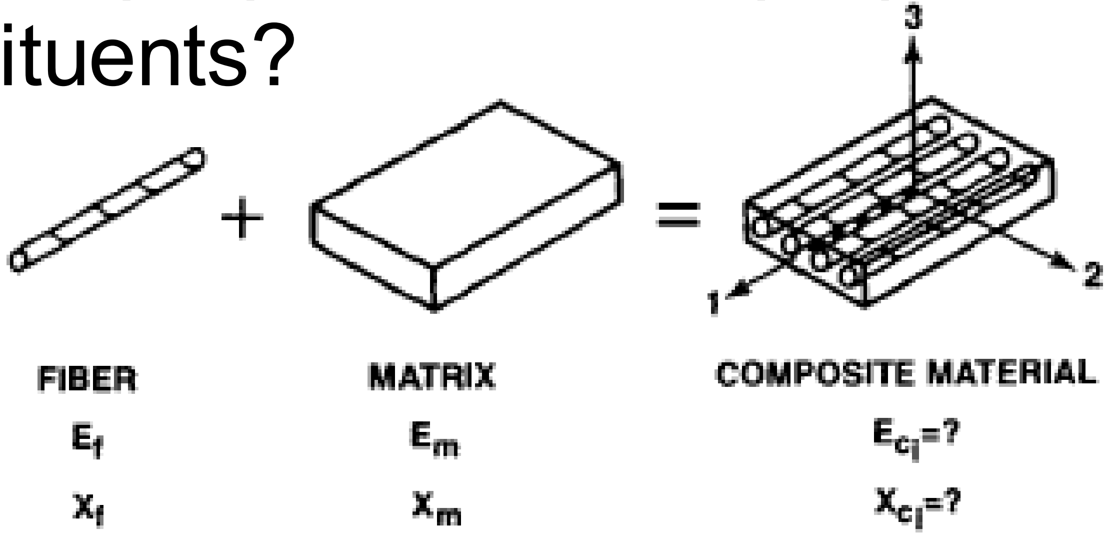
Rule of mixture

jyotiprakash

Micromechanics

- The basic question of micromechanics is: what is the relationship of the composite material properties to the properties of the constituents?



The Design Question!

- How can the percentages of the constituent materials be varied so as to arrive at the desired composite stiffness and strength?

Definitions

- Macromechanics: The study of composite material behavior wherein the material is assumed homogeneous and the effects of the constituent materials are detected only as averaged apparent properties of the composite material.

Definitions

- **Micromechanics:** The study of composite material behavior wherein the interaction of the constituent materials is examined in detail as part of the definition of the behavior of the heterogeneous composite material.

Approaches to Micromechanics

- Mechanics of Materials
- Elasticity

Micromechanics Objective

- To answer the questions set by micromechanics, the objective becomes:
  - Determine the elastic moduli or stiffness or compliances of a composite material in terms of the elastic moduli of the constituent materials

$$P_i = P_i\left(P_{if}, V_f, P_{im}, V_m\right)$$

Micromechanics Objective

$$P_i = P_i\left(P_{if}, V_f, P_{im}, V_m\right)$$

$$V_f = \frac{Volume\ of\ \ Fibres}{Volume\ of\ Composite\ Material}$$

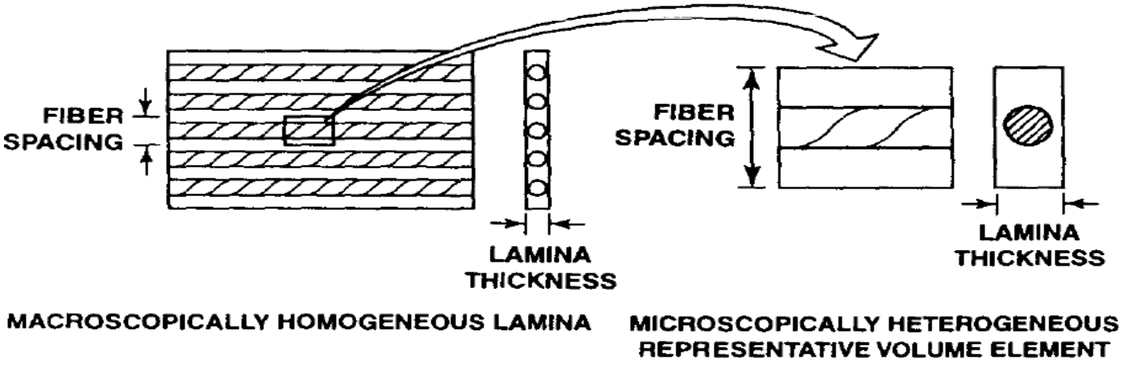
$$V_m = 1 - V_f$$

Basic Assumptions

- The lamina:
  - Initially stress-free, macroscopically homogeneous, linearly elastic, macroscopically orthotropic
- The fibers:
  - Homogeneous, regularly spaced, linearly elastic, perfectly aligned, Isotropic, perfectly bonded
- The matrix:
  - Homogeneous, Isotropic, linearly elastic, void-free

Representative Volume

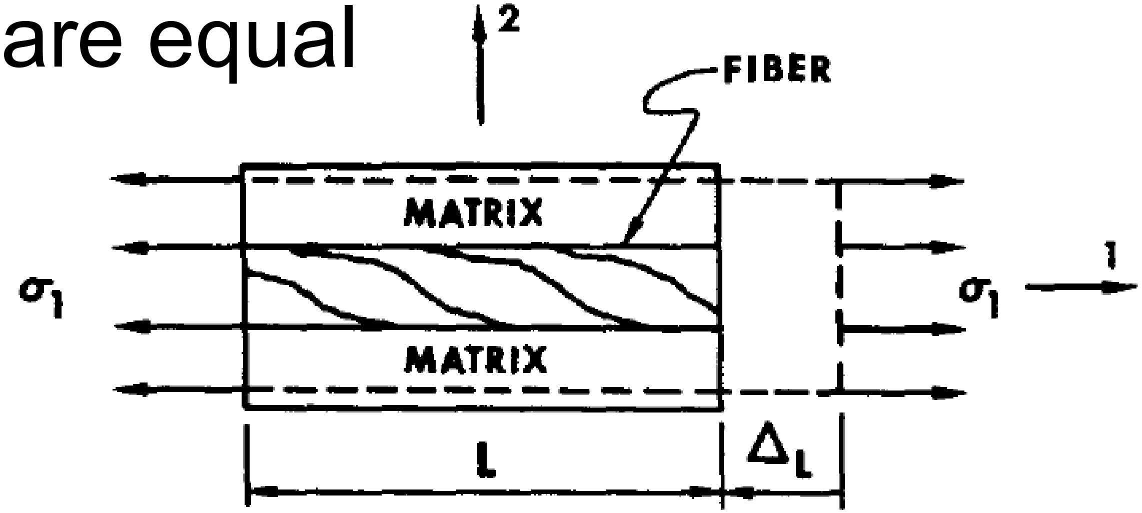
- The smallest region or piece of material over which the stresses and strains can be regarded as macroscopically uniform and yet the volume still has the correct proportions of fiber and matrix



Mechanics of Materials Approach

Most Prominent Assumptions

- In fibre direction, strain in fibres and matrix are equal
- Normal to fibre direction, stresses in matric and fibre are equal



Determination of E1

$$\varepsilon_1 = \frac{\Delta_L}{L}$$

$$\sigma_f = E_f \varepsilon_1 \qquad \sigma_m = E_m \varepsilon_1$$

$$\sigma_1 A = \sigma_f A_f + \sigma_m A_m$$

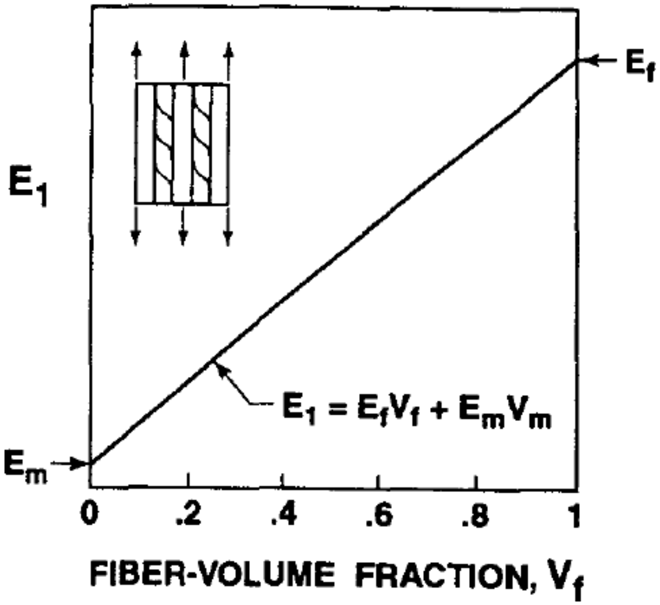
$$\sigma_1 = E_1 \varepsilon_1$$

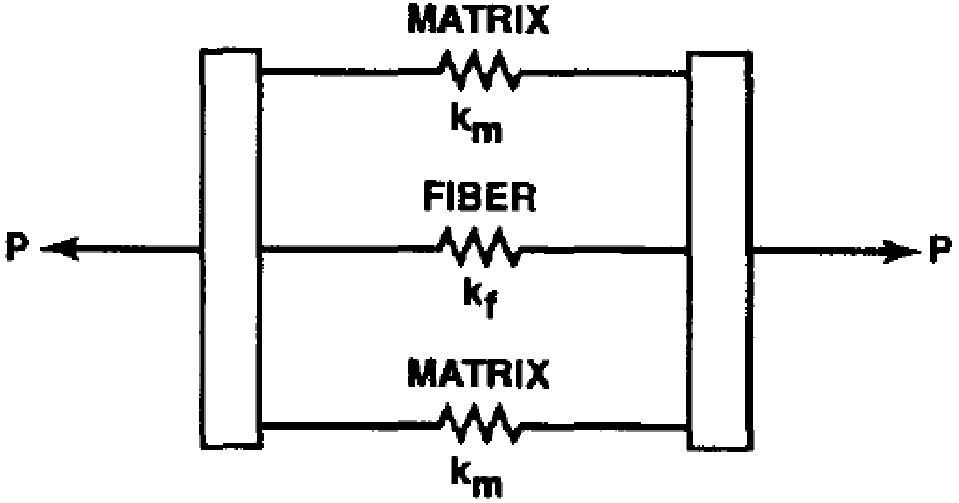
$$E_1 = E_f \frac{A_f}{A} + E_m \frac{A_m}{A}$$

$$\boxed{E_1 = E_f V_f + E_m V_m}$$

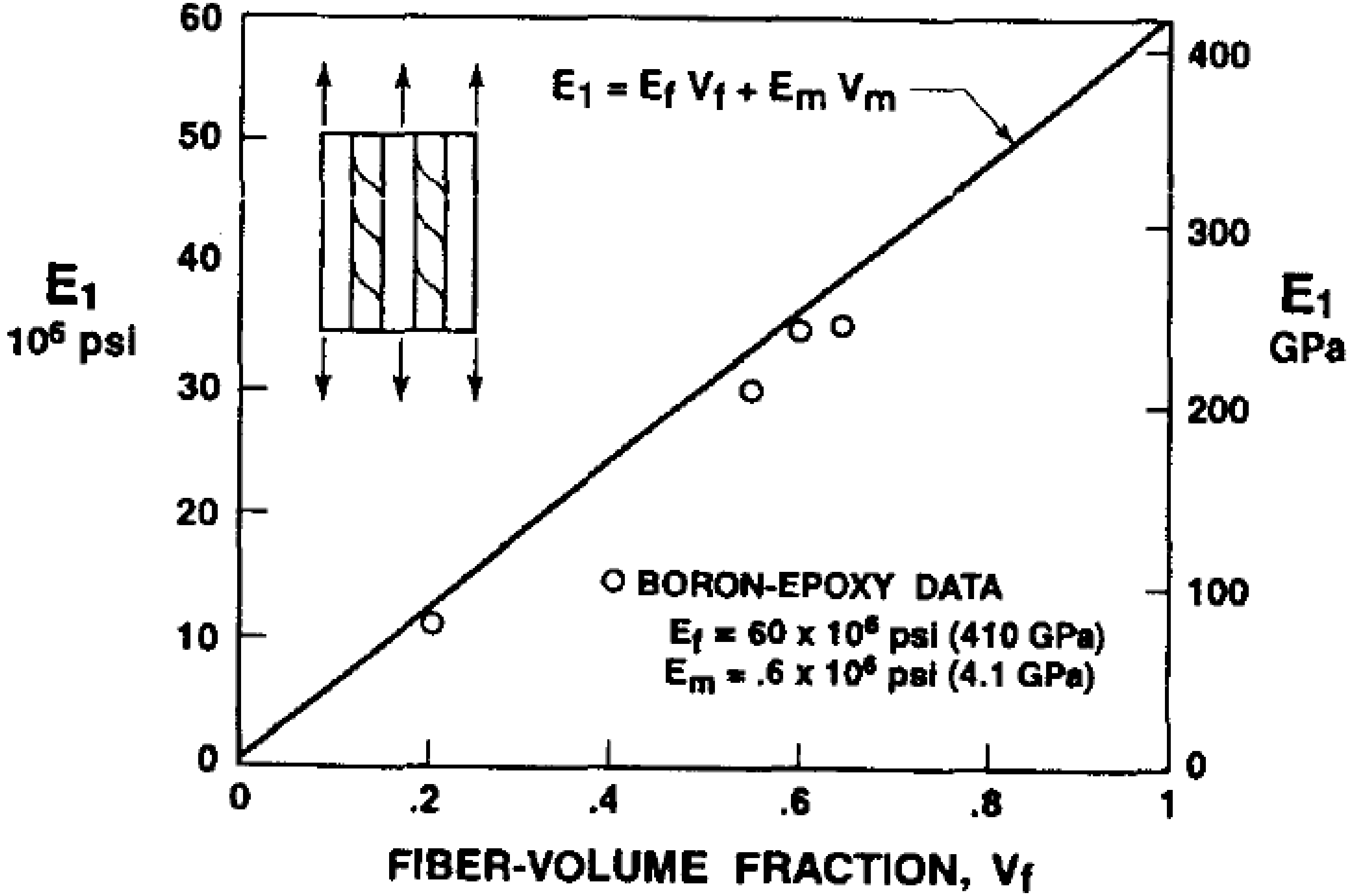
Rule of Mixture

Rule of Mixture





Experimental Results

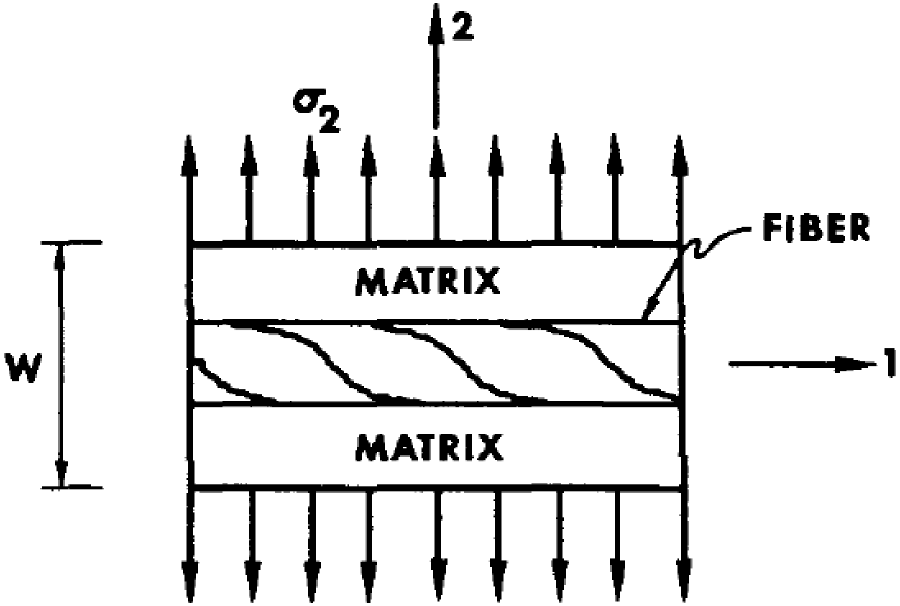


Determination of E2

$$\varepsilon_f = \frac{\sigma_2}{E_f} \qquad \varepsilon_m = \frac{\sigma_2}{E_m}$$

$$\varepsilon_2 = V_f\,\varepsilon_f + V_m\varepsilon_m$$

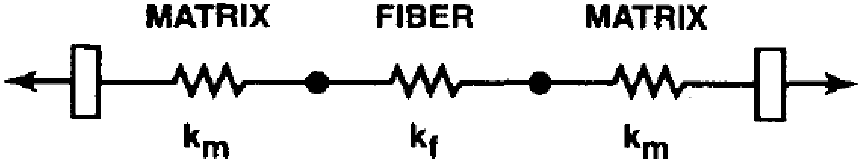
$$\varepsilon_2 = V_f\,\frac{\sigma_2}{E_f} + V_m\,\frac{\sigma_2}{E_m}$$



$$\sigma_2 = E_2\varepsilon_2 = E_2\left[\frac{V_f\,\sigma_2}{E_f} + \frac{V_m\sigma_2}{E_m}\right]$$

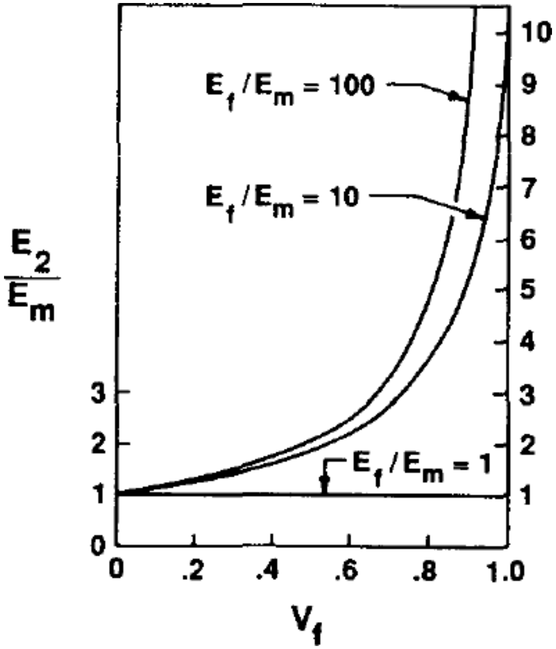
$$\boxed{E_2 = \frac{E_f\,E_m}{V_mE_f + V_f\,E_m}}$$

Determination of E2

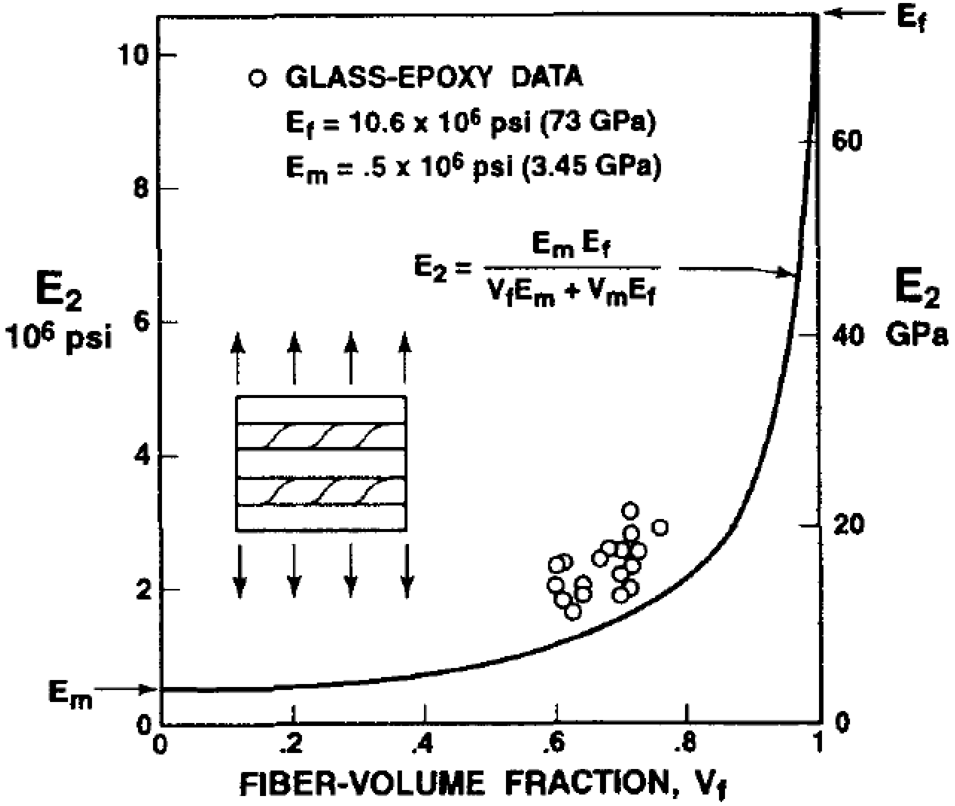


- Nondimensionalizing:

$$\frac{E_2}{E_m} = \frac{1}{V_m + V_f\,(E_m/E_f)}$$

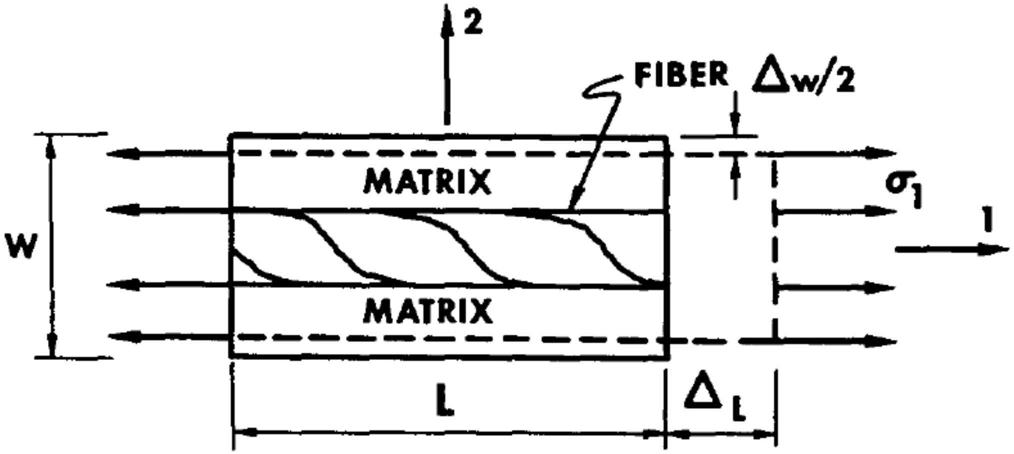


Experimental Results



Determination of Poisson's Ratio

- We have two values for the Poisson's Ratio ν12 & ν21 .



$$\nu_{12} = -\frac{\varepsilon_2}{\varepsilon_1}$$

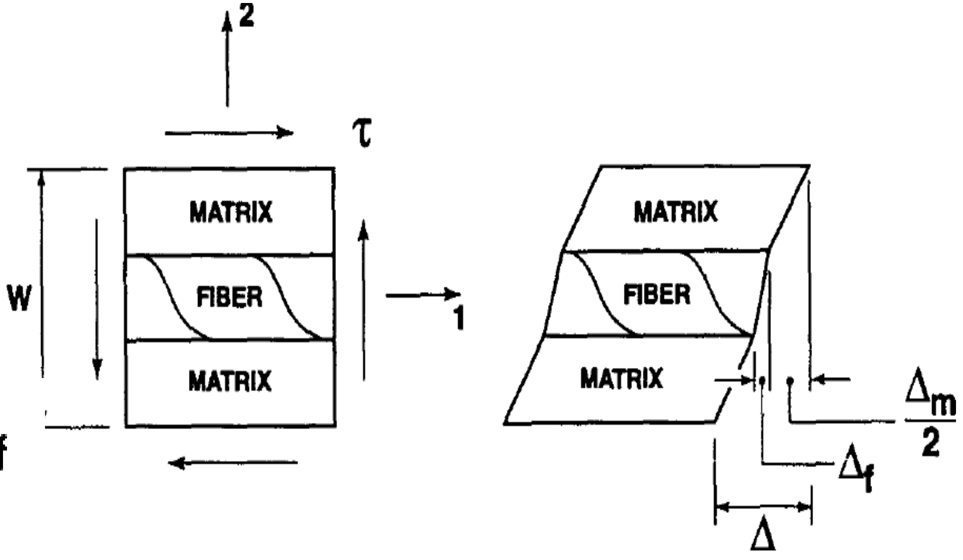
$$\Delta_W = -W\varepsilon_2 = W\nu_{12}\varepsilon_1$$

$$\Delta_W = \Delta_{mW} + \Delta_{fW}$$

$$\Delta_{mW} = WV_m\nu_m\varepsilon_1 \qquad \Delta_{fW} = WV_f\nu_f\varepsilon_1$$

$$\boxed{\nu_{12} = \nu_m V_m + \nu_f V_f}$$

Determination of G12



a Shear Stress Loading

b Shear Deformation

$$\gamma_m = \frac{\tau}{G_m} \qquad \gamma_f = \frac{\tau}{G_f}$$

$$\Delta = \gamma W$$

$$\Delta_m = V_m W \gamma_m \qquad \Delta_f = V_f W \gamma_f$$

$$\gamma = V_m \gamma_m + V_f \gamma_f$$

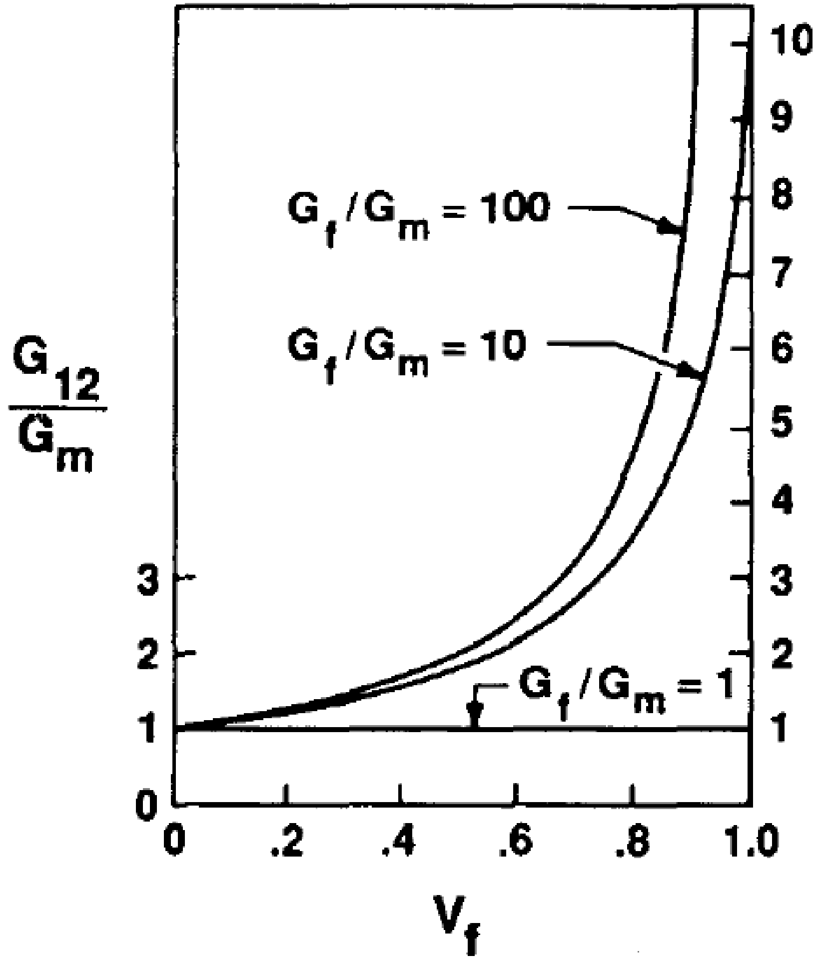
$$\gamma = \frac{\tau}{G_{12}}$$

$$\frac{\tau}{G_{12}} = V_m \frac{\tau}{G_m} + V_f \frac{\tau}{G_f}$$

$$\boxed{G_{12} = \frac{G_m G_f}{V_m G_f + V_f G_m}}$$

Determination of G12

$$\frac{G_{12}}{G_m} = \frac{1}{V_m + V_f(G_m/G_f)}$$



Strength

Strength

- “A chain is as strong as its weakest link”
- When the composite material gets loaded, all its components get loaded with different stresses
- Nevertheless, strength prediction of the composite materials have not yet reached the accuracy level of the stiffness prediction. i.e. Open research area!

Longitudinal Tensile Strength

- Main assumptions:
  - All fibres have the same strength
  - Fibres and matrix behave linearly
  - Fibres are brittle when compared to matrix
  - Fibres are stiffer than matrix

Longitudinal Tensile Strength

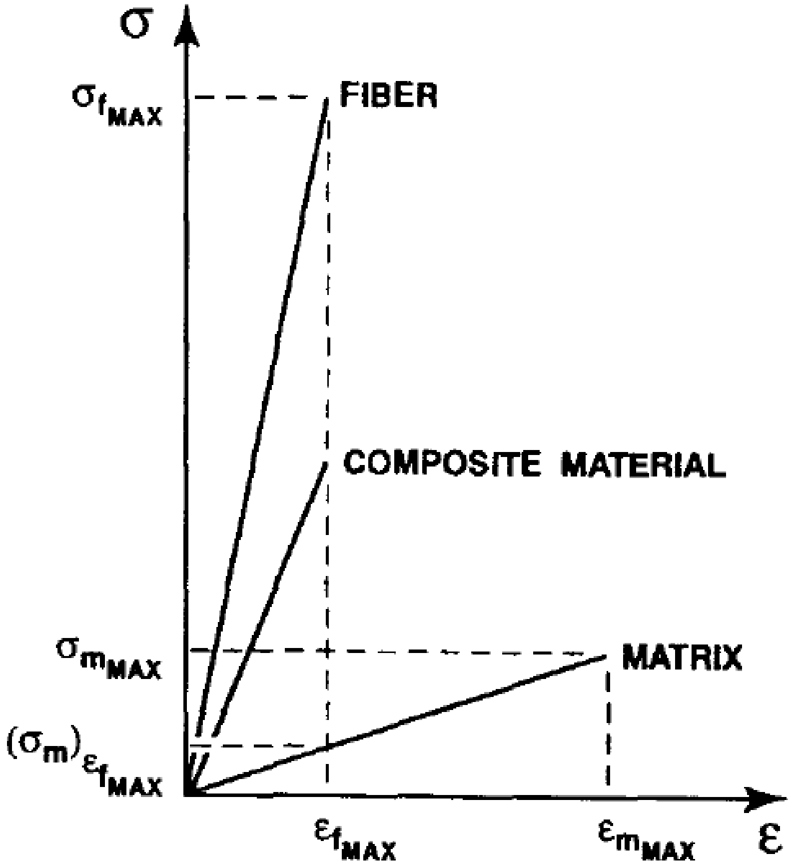
- The stress that will cause the fibres to fail:

$$\sigma_{1t} = \sigma_{fu} V_f + \sigma_m^* V_m$$

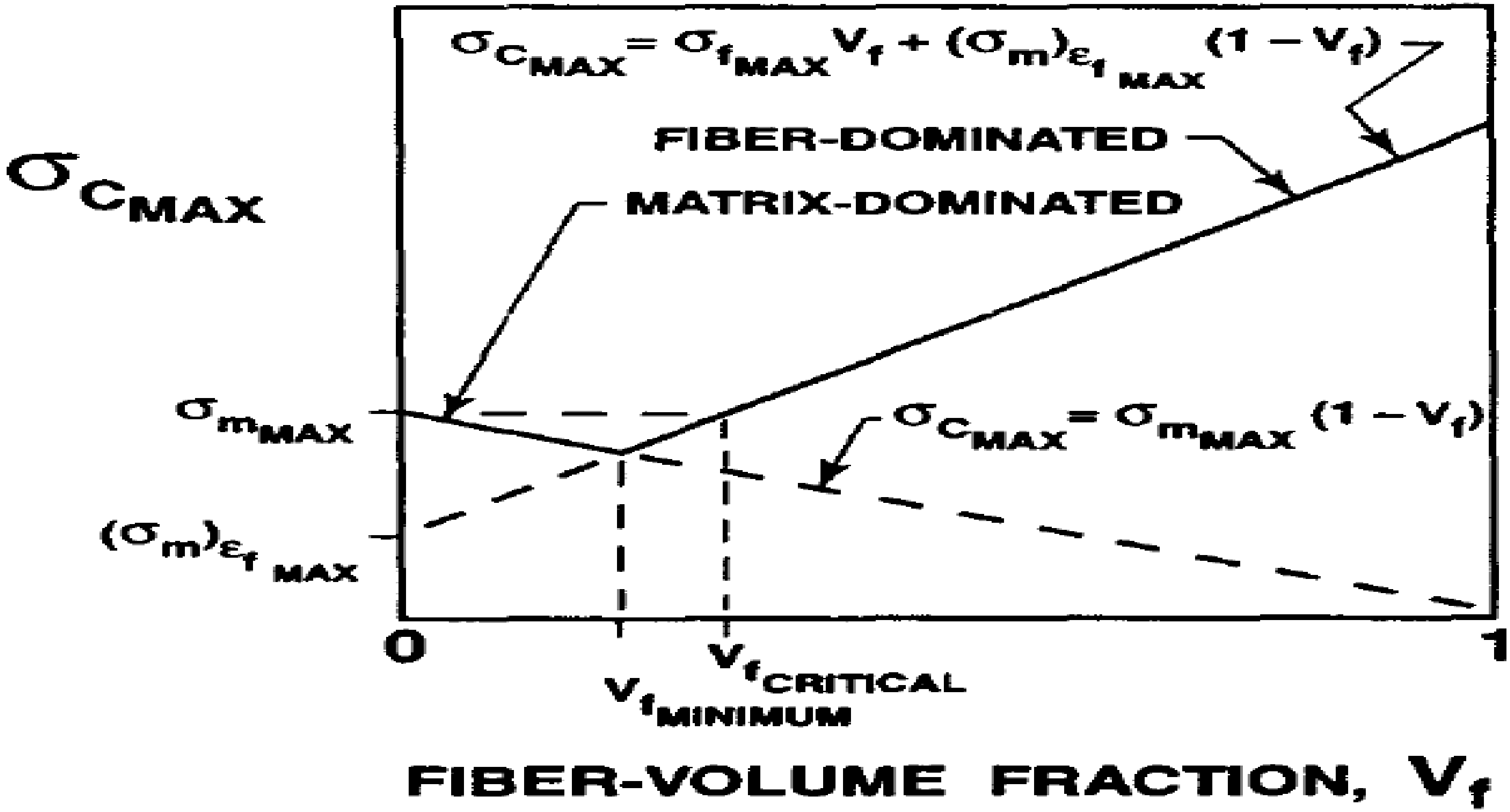
$$\sigma_m^* = \sigma_{fu} \frac{E_m}{E_f}$$

- Where is the stress in the matrix as the fibres reach their ultimate stress.
- From that: $\sigma_{1t} = \sigma_{fu} \left(V_f + \frac{E_m}{E_f} V_m \right)$

Longitudinal Tensile Strength



Longitudinal Tensile Strength



Minimum and Critical Vf

- From the graphs, and using the previous equations, we may calculate:

$$V_{f-critical} = \frac{\sigma_{mu} - \sigma_m^*}{\sigma_{fu} - \sigma_m^*}$$

$$V_{f\,\max} = \frac{\sigma_{mu} - \sigma_m^*}{\sigma_{fu} + \sigma_{mu} - \sigma_m^*}$$

Longitudinal Compressive Strength

- In compression, the failure is dominated by buckling of the fibres!
- Long fibres that are supported by softer matrix material tend to buckle causing what is called Microbuckling
- Microbuckling causes great reduction in the compression stiffness of the composite material

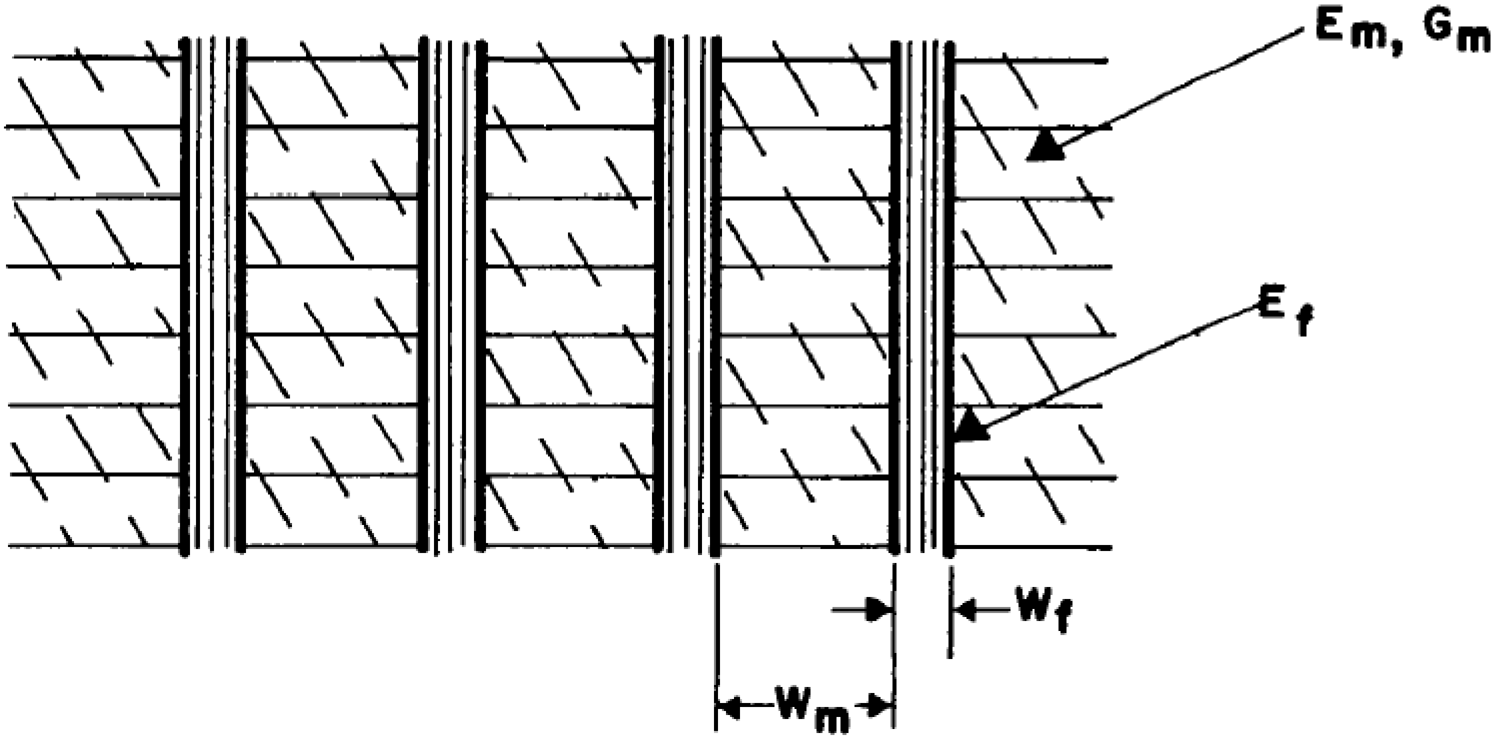


Figure 1

Idealized Composite Geometry

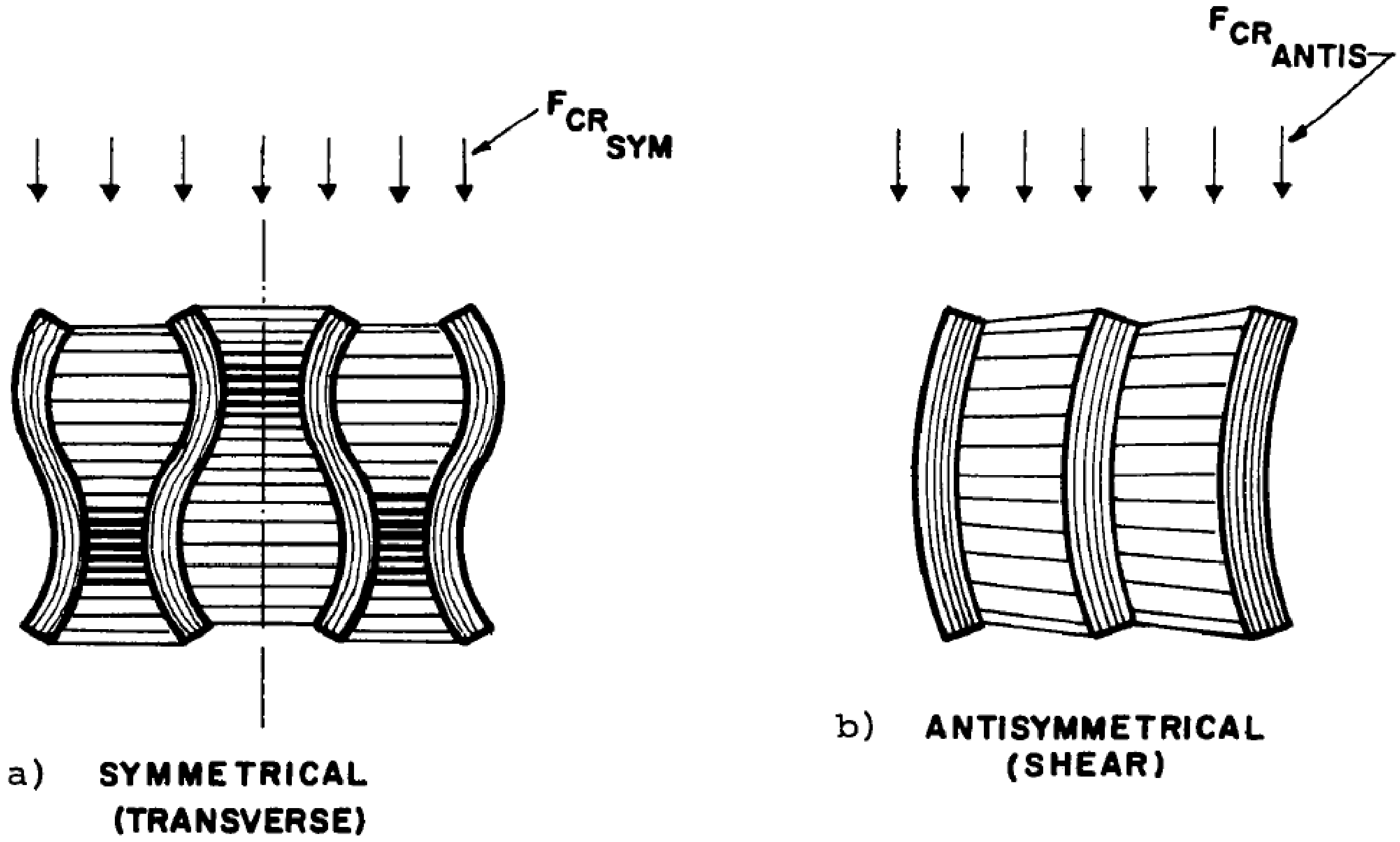


Figure 2

Micro-Stability Failure Modes

Compressive Strength

- The compressive strength is greatly affected by:
    - Buckling modes
    - Initial misalignment
    - Curing procedure

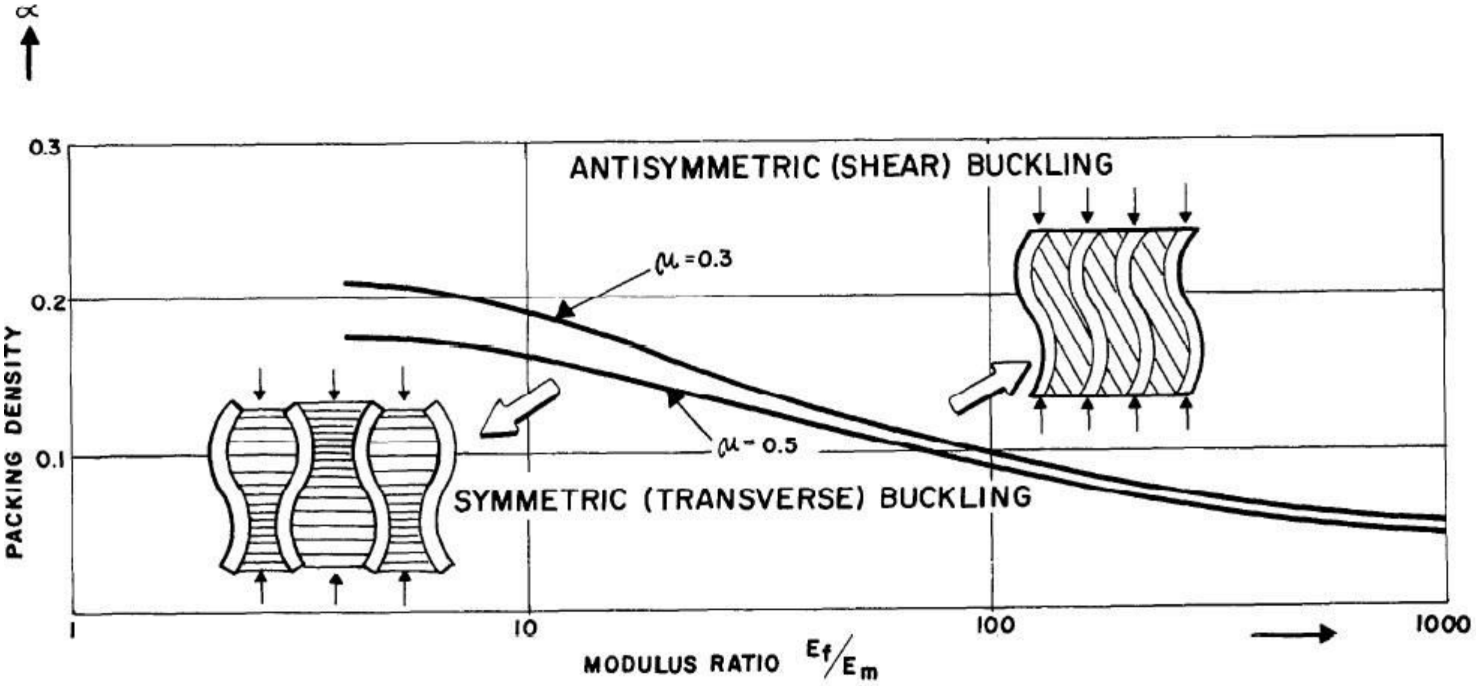


Figure 3

Micro-Stability Failure Domains

ENVIRONMENTAL EFFECTS

Introduction

The foregoing chapters deal, for the most part, with the mechanical response of composite materials under what might be called 'normal' conditions, that is, under a variety of régimes of loading, but with no consideration of possible interactions between the applied stress system and environments that differ appreciably from ordinary laboratory conditions. This is naturally limiting, and yet this 'normal' performance must always be established before the effects of other more aggressive environments can be distinguished. By and large, it is the effects of temperature, ultra-violet radiation, and chemical environments, including oxidising atmospheres, that first come to mind when considering practical applications of composites in general. But, ironically, it is moist environments that are likely to be the major source of trouble to designers in most applications.

The combined effect of temperature and moisture is frequently observed to be more damaging than the effect of either separately. The differing responses of cross-plied epoxybased composites reinforced with glass, aramid, and carbon fibres to combined temperature/humidity cycling are illustrated by some results of Dickson et al (1984).

Water diffuses readily through many of the thermoset and thermoplastic polymers that are commonly used as matrix materials. And where the environment has access to the fibre/matrix interface, at the cut edges of a component, for example, water may be 'wicked in' by capillarity along the interface. Moisture therefore has ready access to those parts of the composite from whence it derives its load bearing properties, to a greater or lesser extent, depending on the nature of the matrix polymer concerned, and in the long term this can result in deterioration of composite properties.

Most forms of high-energy radiation are damaging to polymers because of the relatively low energies required to cause chemical damage. The most obvious effect in long-chain polymers is the degradation associated with scission of the main chains, which results in a reduction in the average molecular weight, and additional cross-linking between chains, resulting in network formation. Scission often causes a lowering of the polymer viscosity and softening temperature and reduction of mechanical strength, and it may also lead, in some cases, to an increase in the degree of crystallinity.Cross-linking, on the other hand, leads to an increase in strength and ductility up to some limiting cross-link density beyond which the strength is again reduced and the polymer embrittled. These are therefore opposing effects which nevertheless occur simultaneously. But the long-term effect of irradiation is almost always serious embrittlement of the polymer. Internal stresses are also developed which, in the presence of an external stress and an aggressive environment, may result in rapid

Disintegration. Exposure of thermoset resin composites to ultra-violet radiation can promote additional cross-linking in the surface resin which may result in surface micro cracks. Most practical reinforcing fibres, with the exception of the aromatic polyamides and high-stretch polyolefins, are unlikely to be affected by uv radiation, and since the bulk of the reinforcing fibres in a composite will largely be screened from the uv by the surface layers of resin and fibre or by pigmented paint coatings, the response of a reinforced plastic laminate to uv will be largely dominated by what happens to the resin.

This kind of damage, which is perhaps likely to be a result of the combined effects of ultraviolet, regular wetting and drying, and diurnal temperature cycling, is particularly serious in the case of glass-fibre- or polymer-fibre-reinforced resins since it leaves the reinforcing elements totally bare of protection against both mechanical damage and further environmental attack useful illustration of the difficulties facing a designer in relation to environmental effects is that of the application of composites in space vehicles. Many of the requirements are the same as those for aeronautical structures, since there is a need to have low weight and high stiffness in order to minimize loads and avoid the occurrence of buckling frequencies. But the environmental effects are special. Service temperatures range from cryogenic to many hundreds of degrees, and the temperature changes are therefore very great: consequently, severe thermal stresses may arise which may cause serious distortion. Dimensional stability is at a premium, for stable antennae and optical platforms, for example, and materials need to be transparent to radio-frequency waves and stable towards both uv radiation and moisture. Many of these effects lead to residual strains, micro cracking, and thermal distortion. Porosity and internal deboned also give problems with moisture, so a high degree of perfection and high-quality adhesive bonding procedures are needed to ensure dimensional stability.Similar corrosion problems may be expected when carbon-fibrereinforced plastics are used in conjunction with metallic components in the presence of the almost inevitable aqueous environment.

Hydrothermal Sensitivity of Reinforced Plastics

Fibre Effects

Although reinforcing fibres like carbon, boron, and other ceramic reinforcements are insensitive to the effects of moisture, others, particularly glass and aramid fibres like Kevlar49, are affected by moisture even at low exposure levels. Glass and Kevlar-49 fibres are known to have mechanical properties that are dependent on time and temperature. The resulting alkaline environment then attacks the normally-stable $SiO2$ network and reduces the strength of the glass fibre. Stress-corrosion essentially results from the conjoint effects of the corrosive environment and the applied stress. The effect occurs more rapidly in acid or alkaline environments than in water alone, but even in pure water the rate of loss of strength is high and the extent of the weakening is substantial. The loss of strength of ordinary E-glass fibres in the alkaline environment of a damp concrete matrix seriously limited the effective use of glass-fibrereinforced cement products (GRC) in the building industry.

Resin effects

The open molecular structure of glassy thermoplastic and thermoset polymers permits relatively rapid diffusion of moisture. Depending on the nature of the polymer, considerable quantities of moisture may be absorbed into the material, and both the rate of absorption and the saturation absorption level will depend on the conditions of exposure (ie. temperature and relative humidity). The wetting and drying of a resin are accompanied by dimensional changes which generate residual stresses in a resin containing rigid reinforcement. Solvent attack on resins can cause both physical and chemical effects, the latter usually being either hydrolysis (of the ester linkages in a polyester, for example) and oxidation, although these processes are slow at ambient temperatures. Chemical attack naturally reduces the mechanical properties of the common resins.

Composite effects

In a normal composite material, moisture will enter by diffusion through the bulk resin, by capillary flow through pores in the resin, and also along the fibre/resin interface. Fickian kinetics again often appear to apply, but deviations from Ficking behaviour are frequently observed, such as where accelerated moisture pick-up occurs as a result of the presence of micro-voids or cracks in the resin. The moisture diffusion in an anisotropic composite lamina is of course also likely to be anisotropic, the rate of diffusion being more rapid in the direction of fibre alignment because of the continuity of the resin diffusion path.

Time-Dependent Effects

Their surprise, that the situation was not improved when the strands were impregnated with resin. The apparent strengths of the impregnated strands fell to one sixth of the normal value, regardless of whether the impregnating resin was epoxy or polyester (although the epoxy resin appeared to delay the onset of the strength reduction somewhat) presumably because of the lower moisture permeability of the epoxy resin.

Composite Material Applications

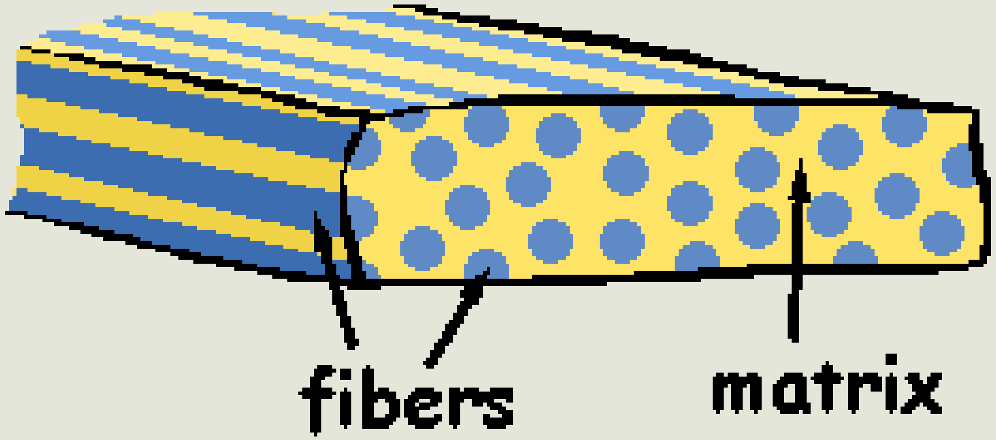
Content

- Carbon fiber & Applications
- Fiber Glass & Applications
- Fiber Reinforced Concrete (FRC) & Applications
- Laminated Floors
- Bullet Proof Glass
- Modern Light Armor
- Aerospace Applications
- Construction Applications

Carbon Fiber

Other Names

- Carbon fiber reinforced polymer (CFRP)
- Carbon fiber reinforced plastic



Carbon Fiber

- Matrix:
  - Epoxy
  - Polyester
  - Vinyl Ester
  - Nylon

Carbon Fiber : Reinforcement

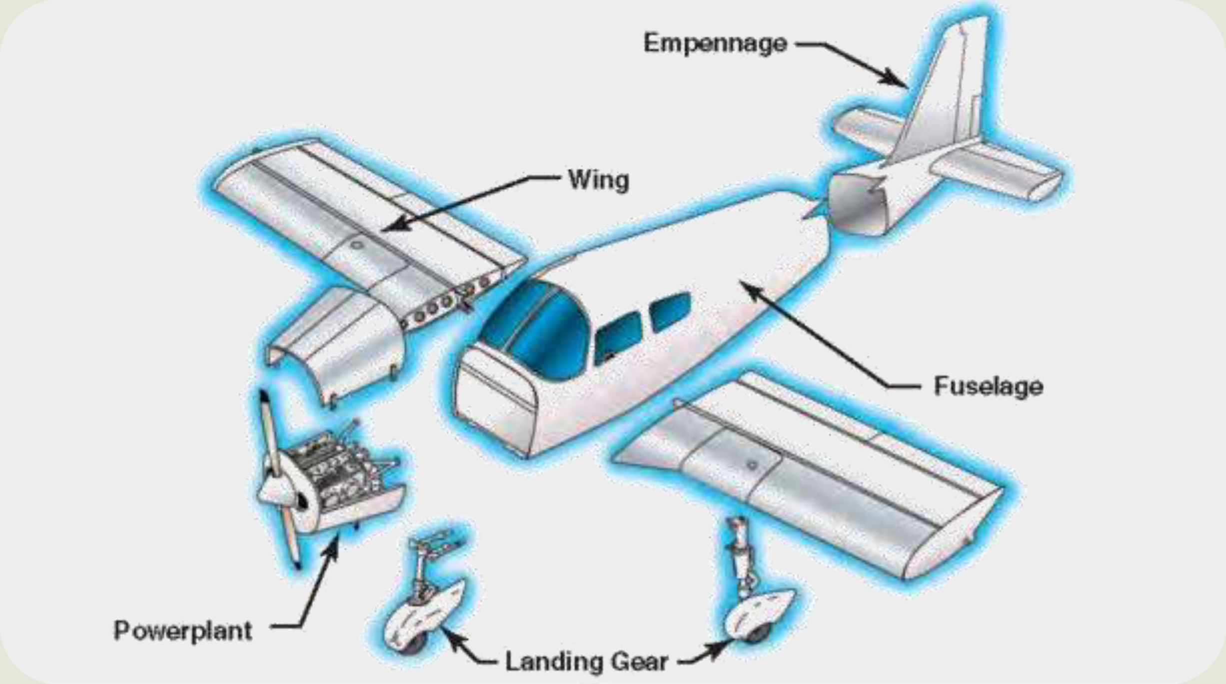
Reinforcement

- Carbon Fiber
- Aramid
- Aluminum
- Ultra-High Molecular Weight Polyethylene (UHMWPE)

Carbon Fiber : Applications

Carbon Fiber : Applications

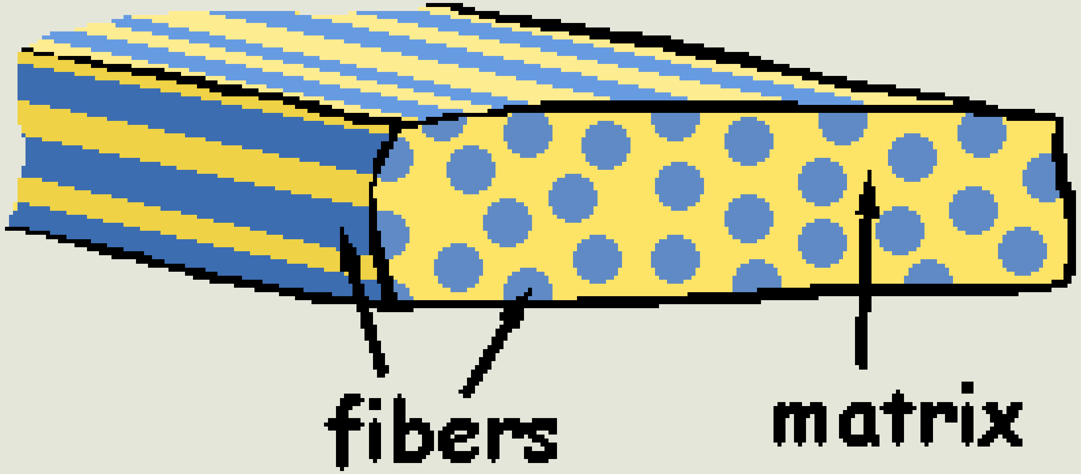
Carbon Fiber : Applications



Fiberglass

Other Names

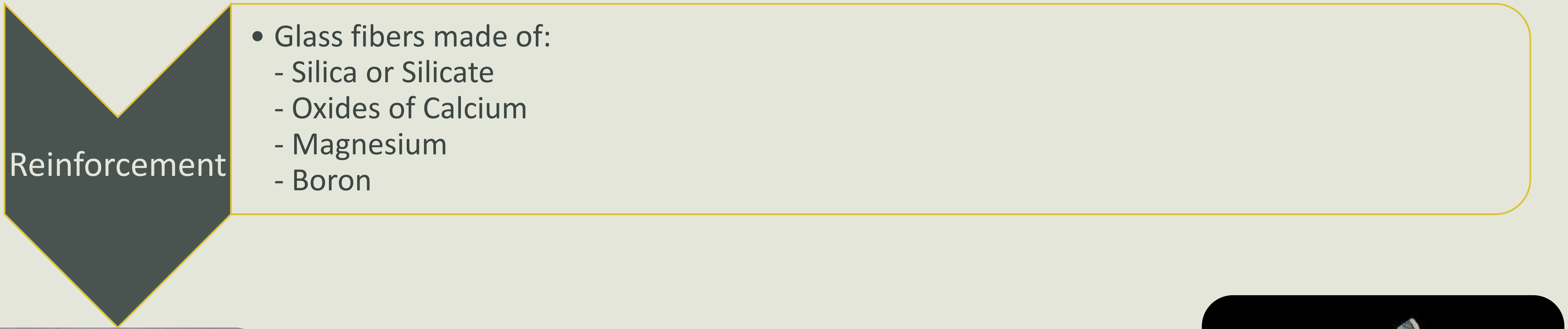
- Fiber reinforced polymer (FRP)



Fiberglass

- Matrix:
  - Epoxy
  - Polyester
  - Vinyl Ester
  - Nylon

Fiberglass



Reinforcement

- Glass fibers made of:
  - Silica or Silicate
  - Oxides of Calcium
  - Magnesium
  - Boron

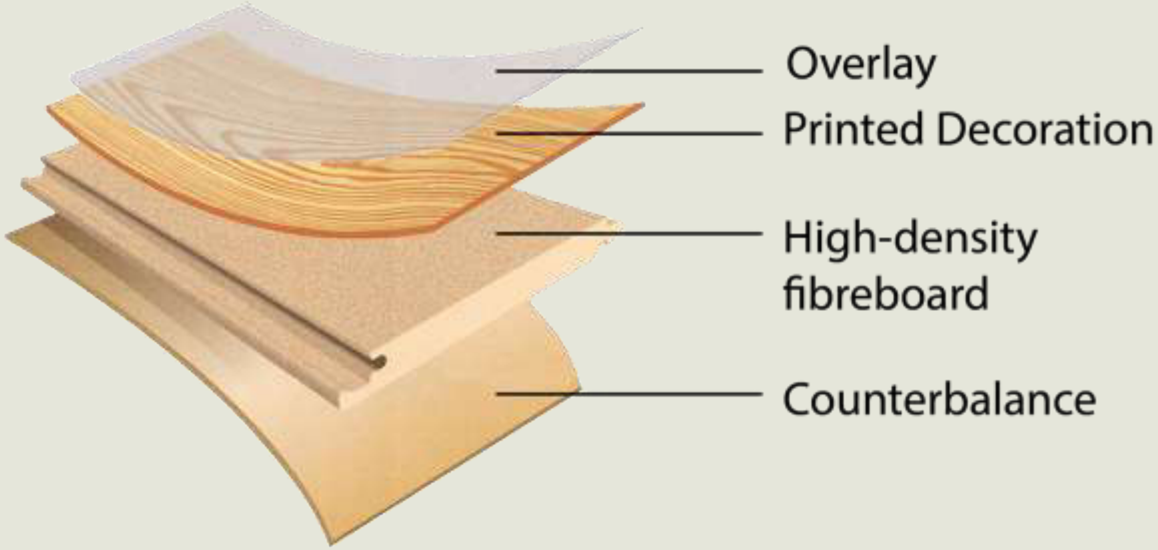
Fiberglass : Applications - Storage Tanks

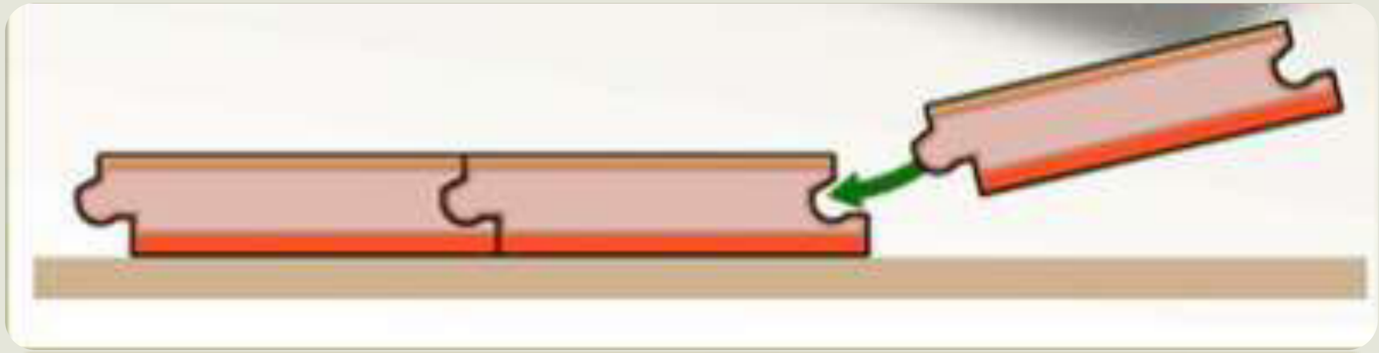
Fiberglass : Applications - Bathtubs

Fiberglass : Applications – Piping Systems

Fiberglass : Applications – Sports Masks & Helmets

Laminate Floors





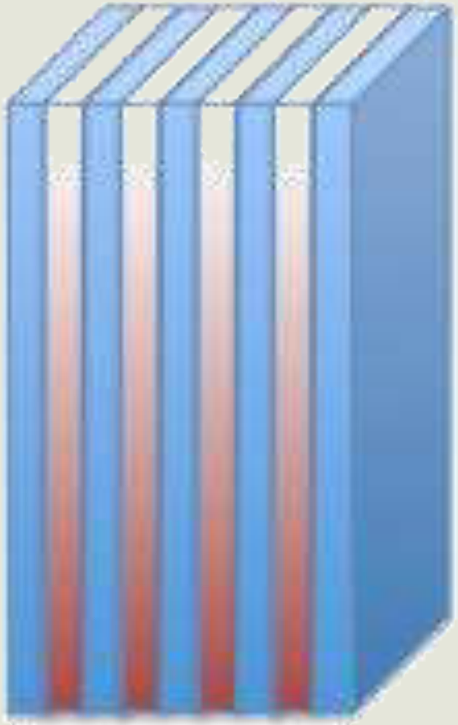
Laminate Floors

Laminate Floor

Hardwood

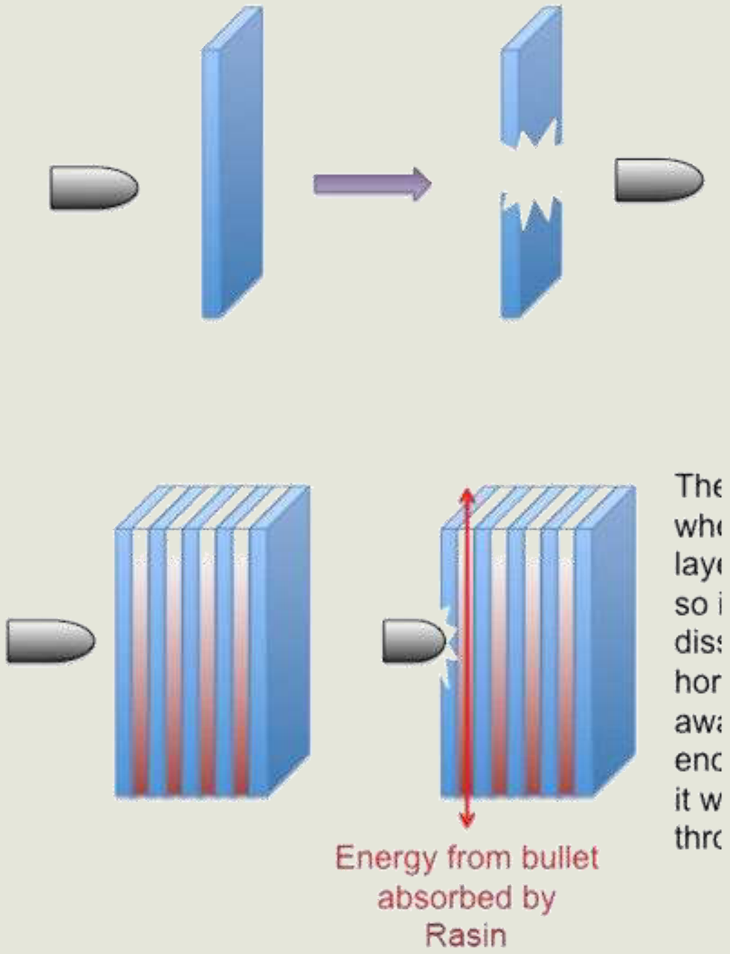
Bulletproof Glass

Normal Glass



Bullet proof glass consisting of normal glass (blue) and polycarbonate (red) layers

Bulletproof Glass



Army Applications : Bullet Proof Vest

Raw Materials :

- A bulletproof vest consists of a panel, a vest-shaped sheet of advanced plastics polymers that is composed of many layers of either Kevlar, Spectra Shield
- The layers of woven Kevlar are sewn together using Kevlar thread, while the nonwoven Spectra Shield is coated and bonded with resins such as Kraton

Army Applications : Bullet Proof Vest

The Manufacturing Process :

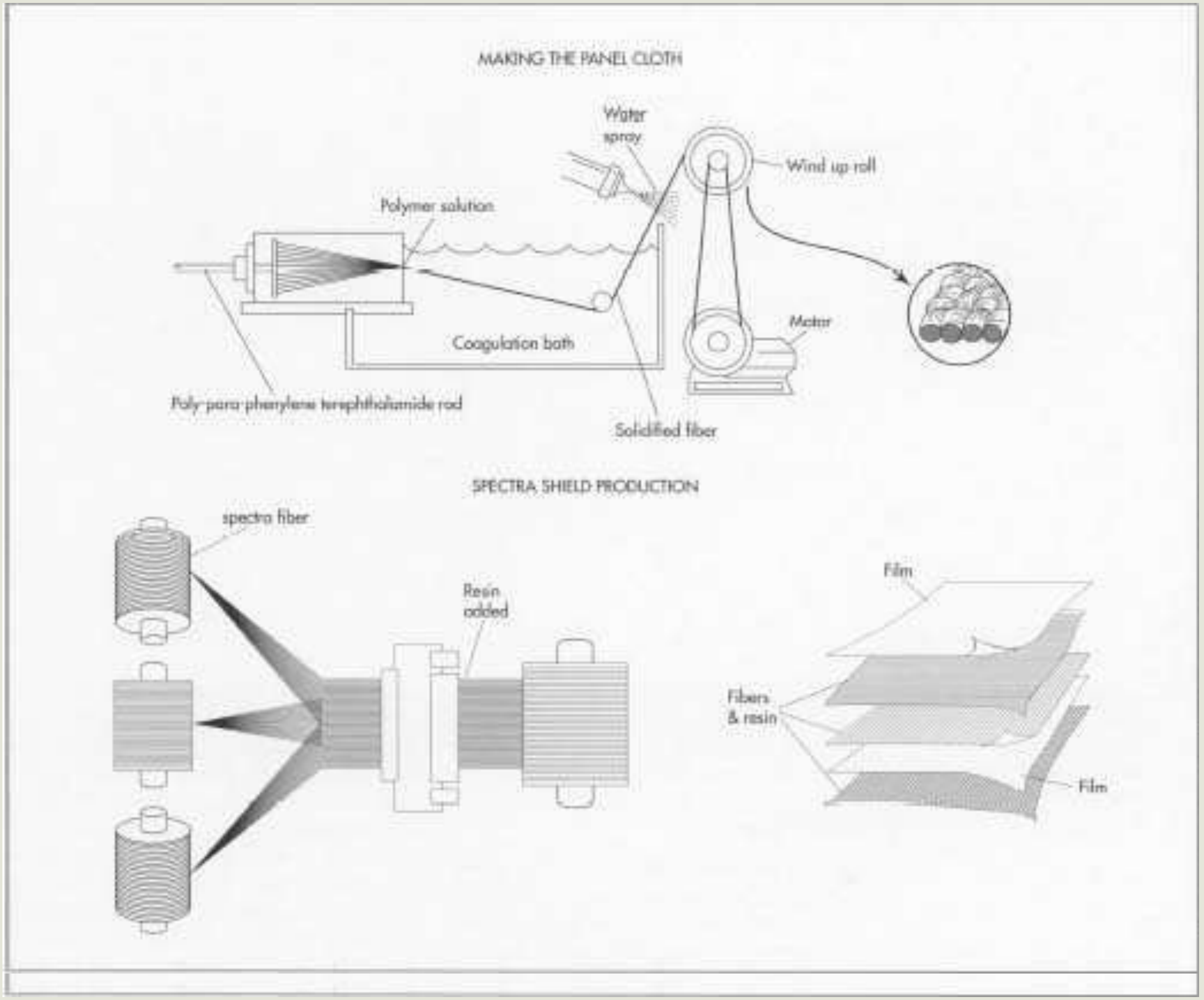
1. To make Kevlar, the polymer poly-para-phenylene terephthalamide must first be produced in the laboratory. This is done through a process known as *polymerization,*

2. The resultant crystalline liquid with polymers in the shape of rods is then extruded through a spinneret (a small metal plate full of tiny holes that looks like a shower head) to form Kevlar yarn.

3. The Kevlar fiber then passes through a cooling bath to help it harden. After being sprayed with water, the synthetic fiber is wound onto rolls.

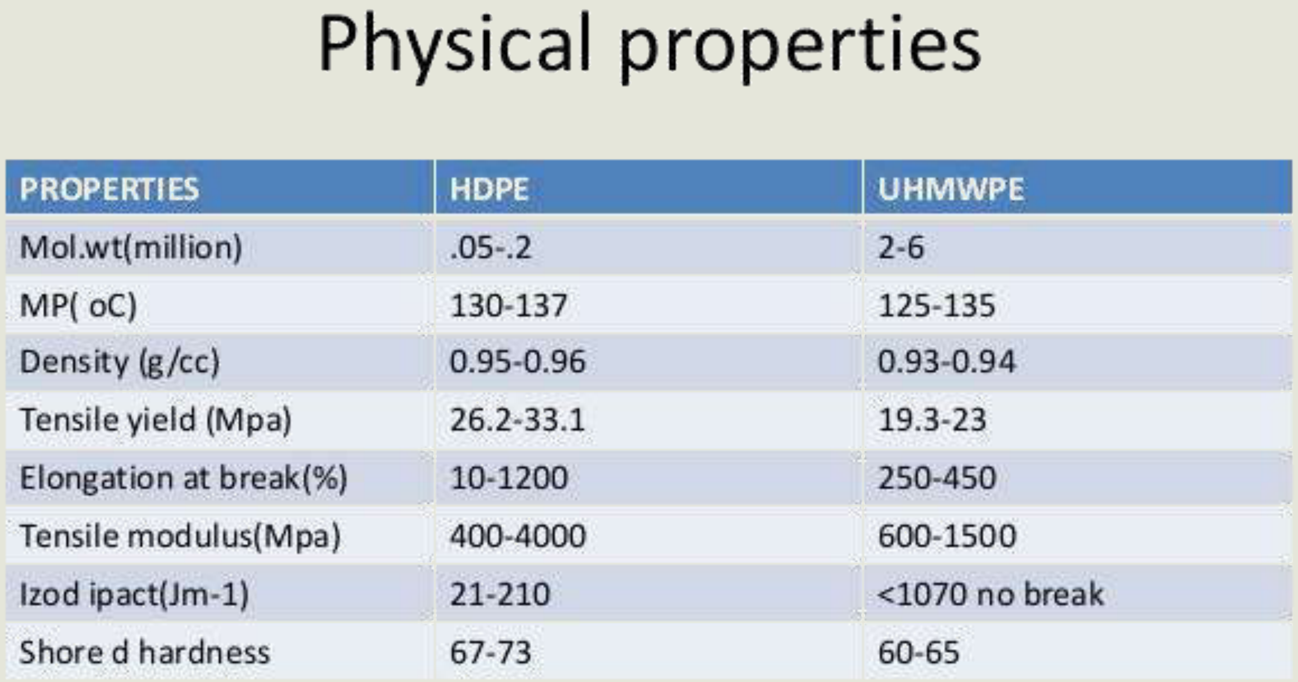
4. The Kevlar manufacturer then typically sends the fiber to throwsters, who twist the yarn to make it suitable for weaving.

5. To make Kevlar cloth, the yarns are woven in the simplest pattern, plain or tabby weave, which is merely the over and under pattern of threads that interlace alternatively.



Army Applications : Spectra Shield

Its made out of an ultra-high-molecular- weight polyethylene (UHMWPE) fiber



Physical properties

PROPERTIES	HDPE	UHMWPE
Mol.wt(million)	.05-.2	2-6
MP(oC)	130-137	125-135
Density (g/cc)	0.95-0.96	0.93-0.94
Tensile yield (Mpa)	26.2-33.1	19.3-23
Elongation at break(%)	10-1200	250-450
Tensile modulus(Mpa)	400-4000	600-1500
Izod ipact(Jm-1)	21-210	<1070 no break
Shore d hardness	67-73	60-65

Aerospace Applications : Satellites

Aerospace Applications : Satellites

The Properties Materials Need to Function in Space:

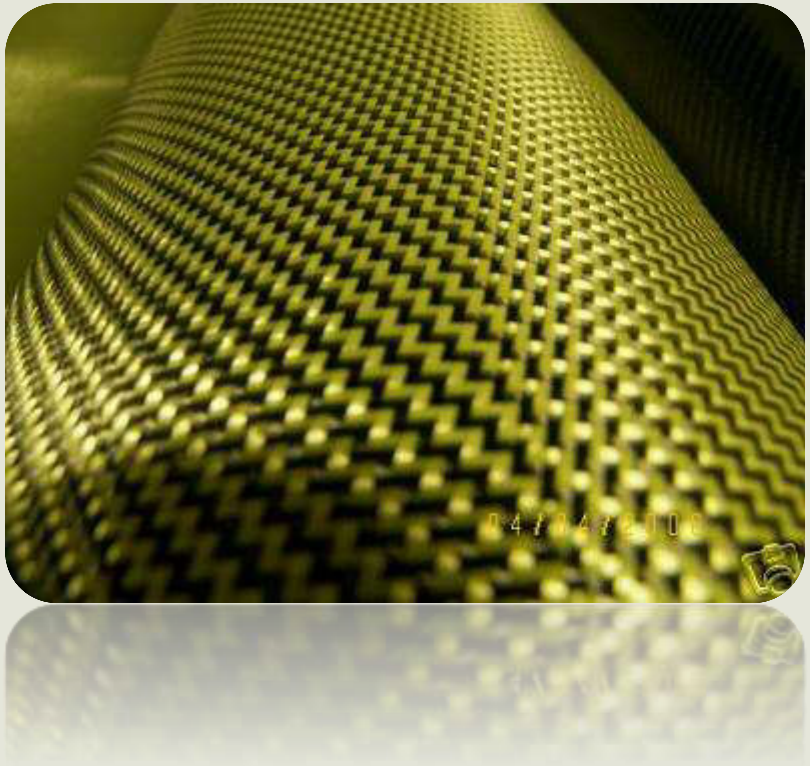
1. Dimensional Stability
2. Environment Stability
3. Strength and Stiffness
4. Versatile and unique in their integrity
5. Economically Viable (weight)

Aerospace Applications : Kevlar

Tensile Strength = 3,620 MPa

Chemical Composition :

- Kevlar is simply a **super-strong plastic** , It is made of ***paraphenylenediamine*** and ***terephthaloyl*** chloride.
- This combination creates aramid threads that are dissolved and then spun into regular fibers, which are woven into fabrics.
- The matrix for high performance composites is usually ***epoxy resin.***



Aerospace Applications : Kevlar

Advantages :

- maintains its strength and resilience down to cryogenic temperatures (−196 °C)
- High tensile strength-to-weight ratio (5 times stronger than steel)
- Can resist attacks from many different chemicals

Disadvantages :

- it has very poor *compressive* strength

Fiber Reinforced Concrete (FRC)

Reinforcement

- Glass fibers
- Steel fibers
- Polymeric fibers

Construction Applications : Chemical Composition of FRP

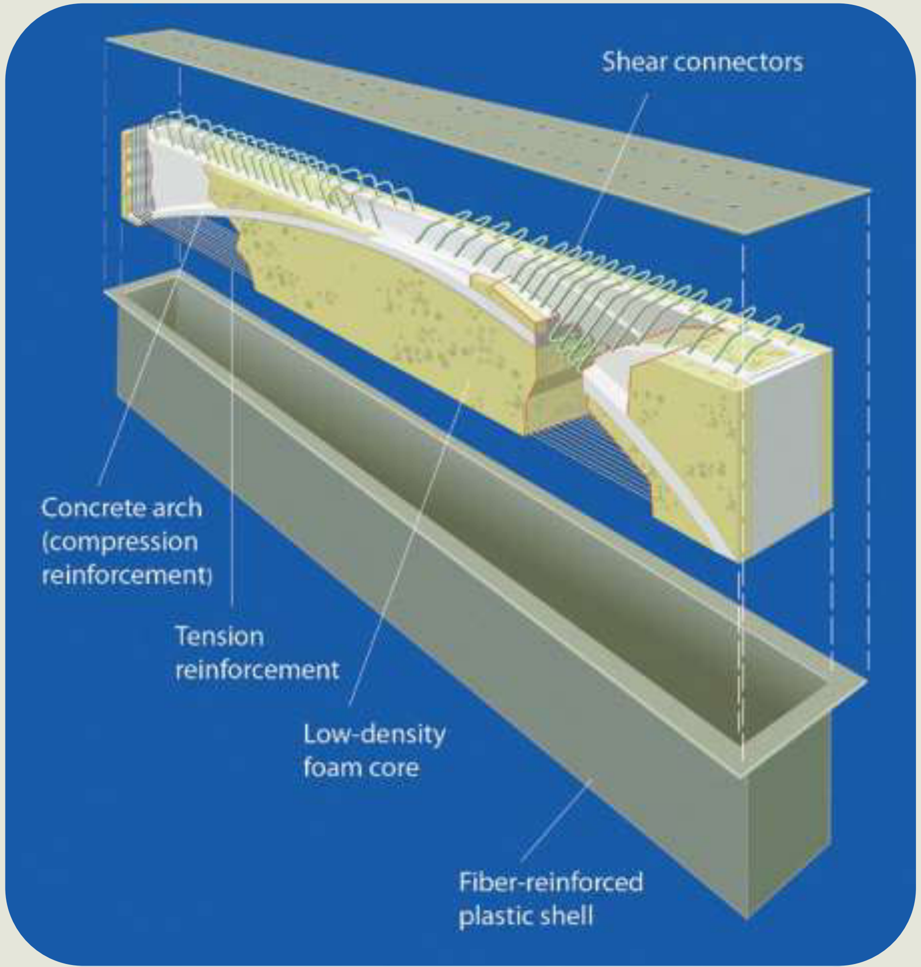
Fiber-reinforced plastic is a composite material made of a *polymer* matrix reinforced with *fibres*.

Reinforcement material :

- Glass fibers
- Natural fibers
- Carbon fibers

Particulate material :

- Sand, talc and other fillers
- Color chips
- Recycled glass



FRC : Applications - Façade Cladding Panels

FRC : Applications - Ornamental Concrete

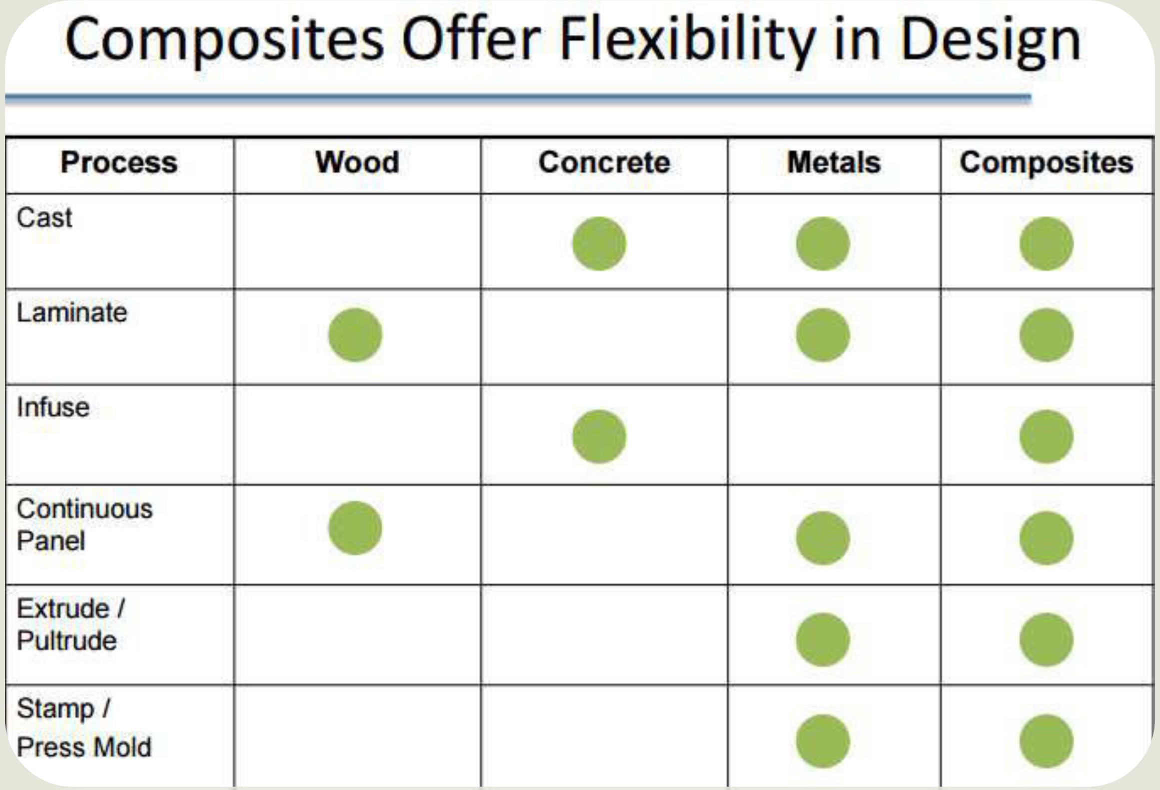
Construction Applications : Advantages of Composites

- Design Flexibility
- Corrosion Resistance
- High Strength to Weight
- Low Thermal & Electrical Conductivity
- Control of Water & Moisture
  - ❑ Holds water in or keeps water out
  - ❑ Does not rot, swell, rust, or spall
- High Durability
- Support sustainable building programs

U.S. GREEN BUILDING COUNCIL
MEMBER

The newly opened Sheraton Hotel in Milan features a dramatic design achieved through the use of exterior cladding made with pultruded FRP composites. The water-repellant skin has a quartz finish. The hotel and office complex is 450 m (1476 ft) wide and 14 m (45.9 ft) high.

Construction Applications : Advantages of Composites



Composites Offer Flexibility in Design

Process	Wood	Concrete	Metals	Composites
Cast		●	●	●
Laminate	●		●	●
Infuse		●		●
Continuous Panel	●		●	●
Extrude / Pultrude			●	●
Stamp / Press Mold			●	●