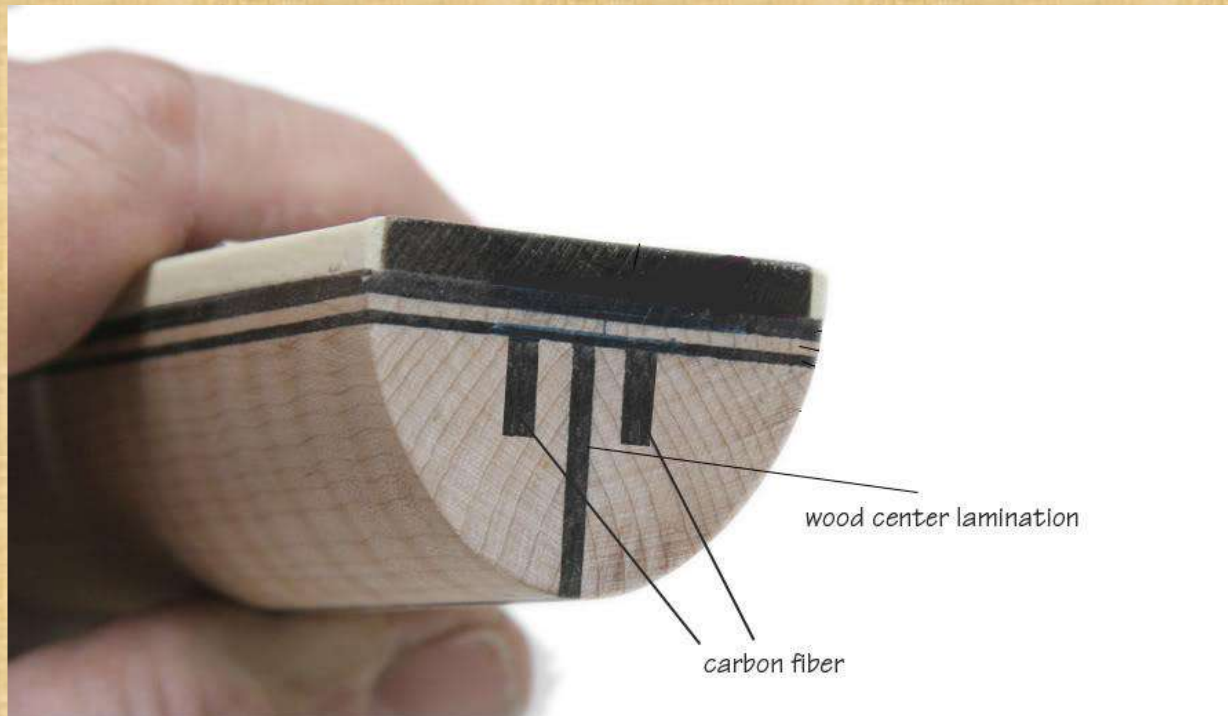
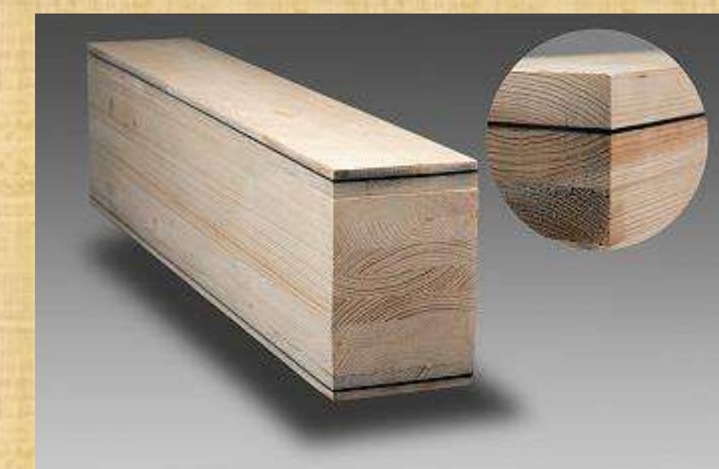
Μάθημα 3ο Carbon Fiber Reinforced Wood



Dr. George Ntalos



1.Composite Material Defined

- A materials system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents
- Examples:
  - Cemented carbides (WC with Co binder)
  - Plastic molding compounds containing fillers
  - Rubber mixed with carbon black
  - Wood (a natural composite as distinguished from a synthesized composite)

1. Why Composites are Important

- 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 (αντοχή και ακαμψία)
- Fatigue properties are generally better than for common engineering metals (αντοχή στη χρήση)
- Toughness is often greater too (σκληρότητα)
- Composites can be designed that do not corrode like steel (διάβρωση)
- Possible to achieve combinations of properties not attainable with metals, ceramics, or polymers alone (με ανώτερες ιδιότητες)

Nature of Composites:

- Advantages:
  - **High strength to weight ratio (low density high tensile strength) or high specific strength ratio!**
    - **1020 HRS spec strength = 1 (E6 in)**
    - **Graphite/Epoxy, spec strength = 5 (E6 in)**
  - **High creep resistance**
  - **High tensile strength at elevated temperatures**
  - **High toughness**
  - **Generally perform better than steel or aluminum in applications where cyclic loads are encountered leading to potential fatigue failure (i.e. helicopter blades).**
  - **Impact loads or vibration – composites can be specially formulated with high toughness and high damping to reduce these load inputs.**
  - **Some composites can have much higher wear resistance than metals.**
  - **Corrosion resistance**
  - **Dimensional changes due to temp changes can be much less.**
  - **Anisotropic – bi-directional properties can be design advantage (i.e. helicopter blades)**

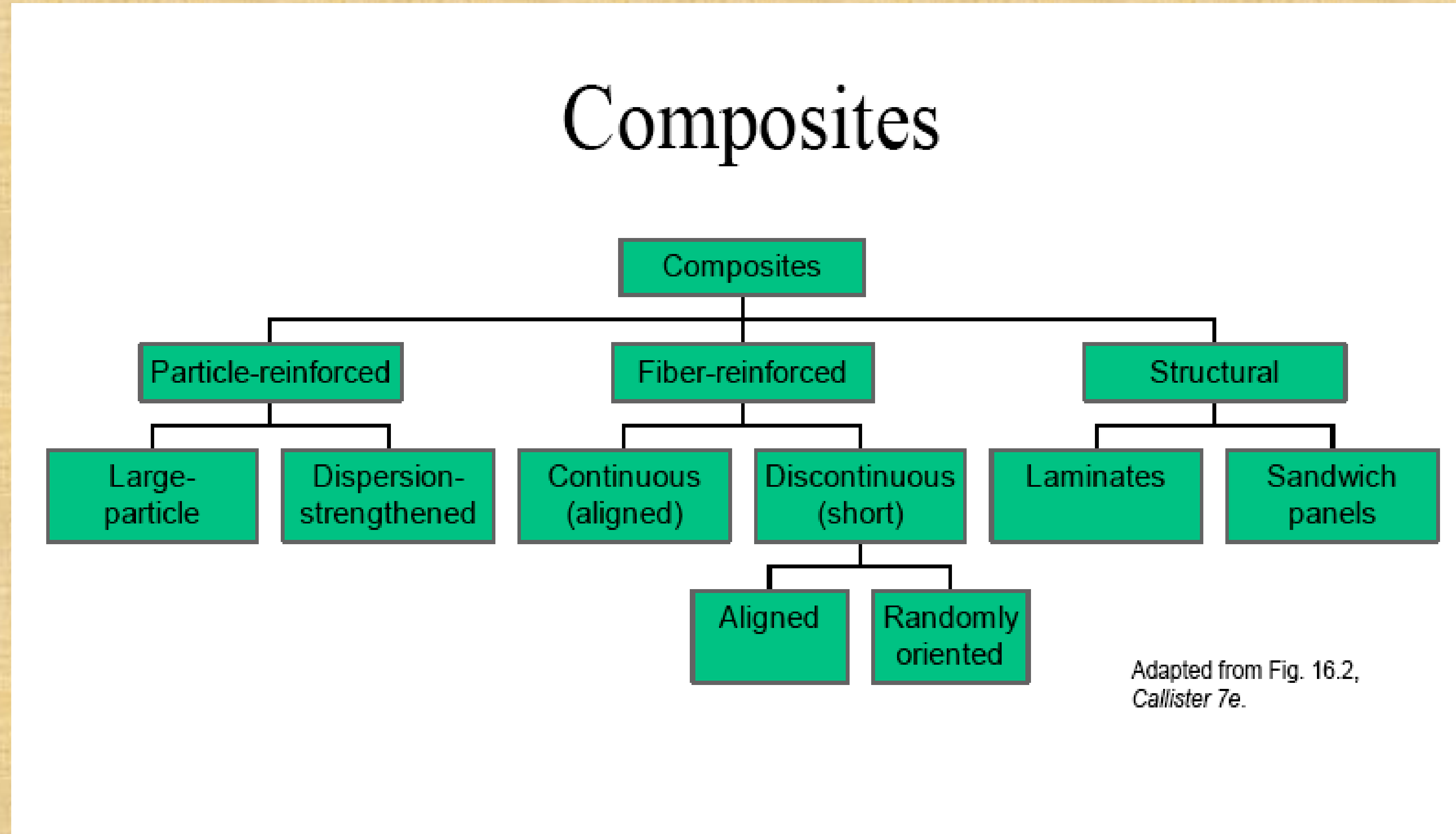
1. Disadvantages and Limitations of Composite Materials

- 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

1. One Possible Classification of Composite Materials

- **Traditional composites** – composite materials that occur in nature or have been produced by civilizations for many years
  - Examples: wood, concrete, asphalt
- **Synthetic composites** - modern material systems normally associated with the manufacturing industries, in which the components are first produced separately and then combined in a controlled way to achieve the desired structure, properties, and part geometry

1. Classification



1. Classification

Primary Phase, Matrix

Secondary Phase, Reinforcement

	Metal	Ceramic	Polymer
Metal	Infiltrated powder metallurgy parts	Cermets	Some molding compounds Brake linings
Ceramic	Cermets Cemented carbides Fiber-reinforced metals	SiC whisker-reinforced Al_2O_3	Plastic molding compounds Fiberglass-reinforced plastic
Polymer	NA	NA	Kevlar-reinforced epoxy
Elements (e.g., C, B)	Fiber-reinforced metals	NA	Rubber with carbon black B- or C-reinforced plastics

NA = not applicable currently.

- Dispersed phase:
  - -- Purpose: enhance matrix properties.
    - MMC: increase yield stress, tensile strength, creep resistance
    - CMC: increase fracture toughness
    - PMC: increase modulus, yield stress, tensile strength, creep resistance.
  - -- Classifications: Particle, fiber, structural

2. Functions of the Matrix Material (Primary Phase)

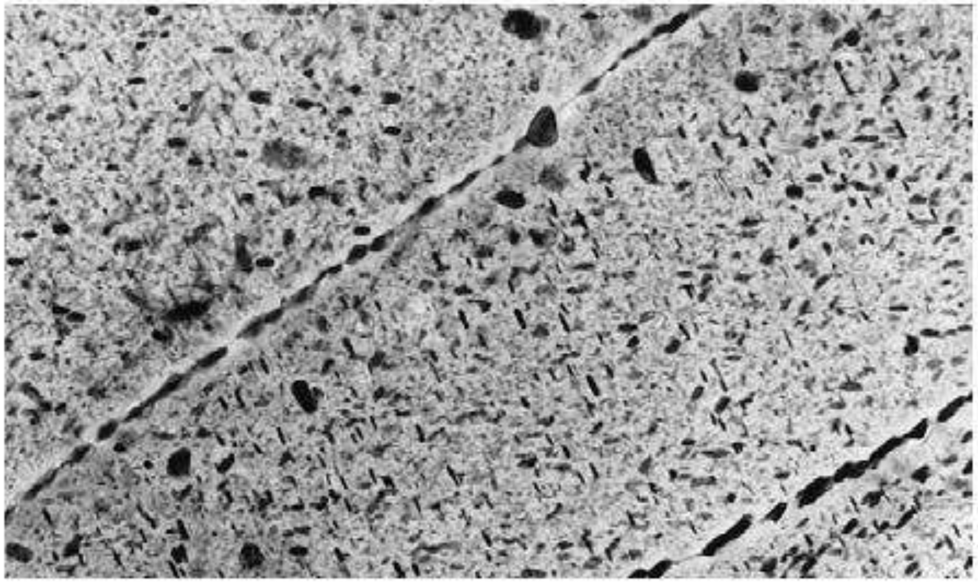
- Protect phases from environment
- Transfer Stresses to phases
- Holds the imbedded phase in place, usually enclosing and often concealing it
- When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent

2. Reinforcing Phase (Secondary)

Composites - Particles

Particle-reinforced | Fiber-reinforced | Structural

Precipitation hardening
fine enough dispersion
to block dislocation motion
between particles,
see Lecture 19



Composites - Particles

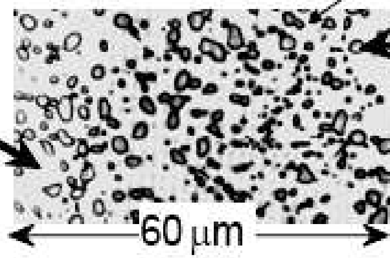
Particle-reinforced | Fiber-reinforced | Structural

Microscopic Dispersion

low volume fraction of dispersed phase

- Spheroidite steel

matrix: ferrite (α) (ductile)

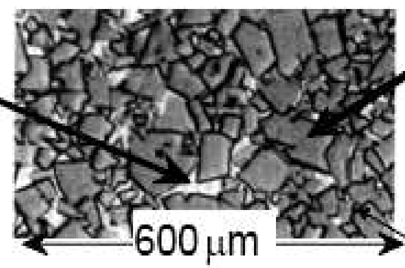


particles: cementite (Fe_3C) (brittle)

Adapted from Fig. 10.19, *Callister 7e*. (Fig. 10.19 is copyright United States Steel Corporation, 1971.)

- WC/Co cemented carbide

matrix: cobalt (ductile) V_m: 10-15 vol%!



particles: WC (brittle, hard)

Adapted from Fig. 16.4, *Callister 7e*. (Fig. 16.4 is courtesy Carboloy Systems, Department, General Electric Company.)

high volume fraction of dispersed phase

Composites - Particles

Particle-reinforced | Fiber-reinforced | Structural

Macroscopic Dispersion

Concrete – gravel + sand + cement

- Why sand *and* gravel? Both contribute to high compressive strength
  Sand packs into gravel voids – high volume fraction = strong + cheap

Composites - Fibers

Particle-reinforced | **Fiber-reinforced** | Structural

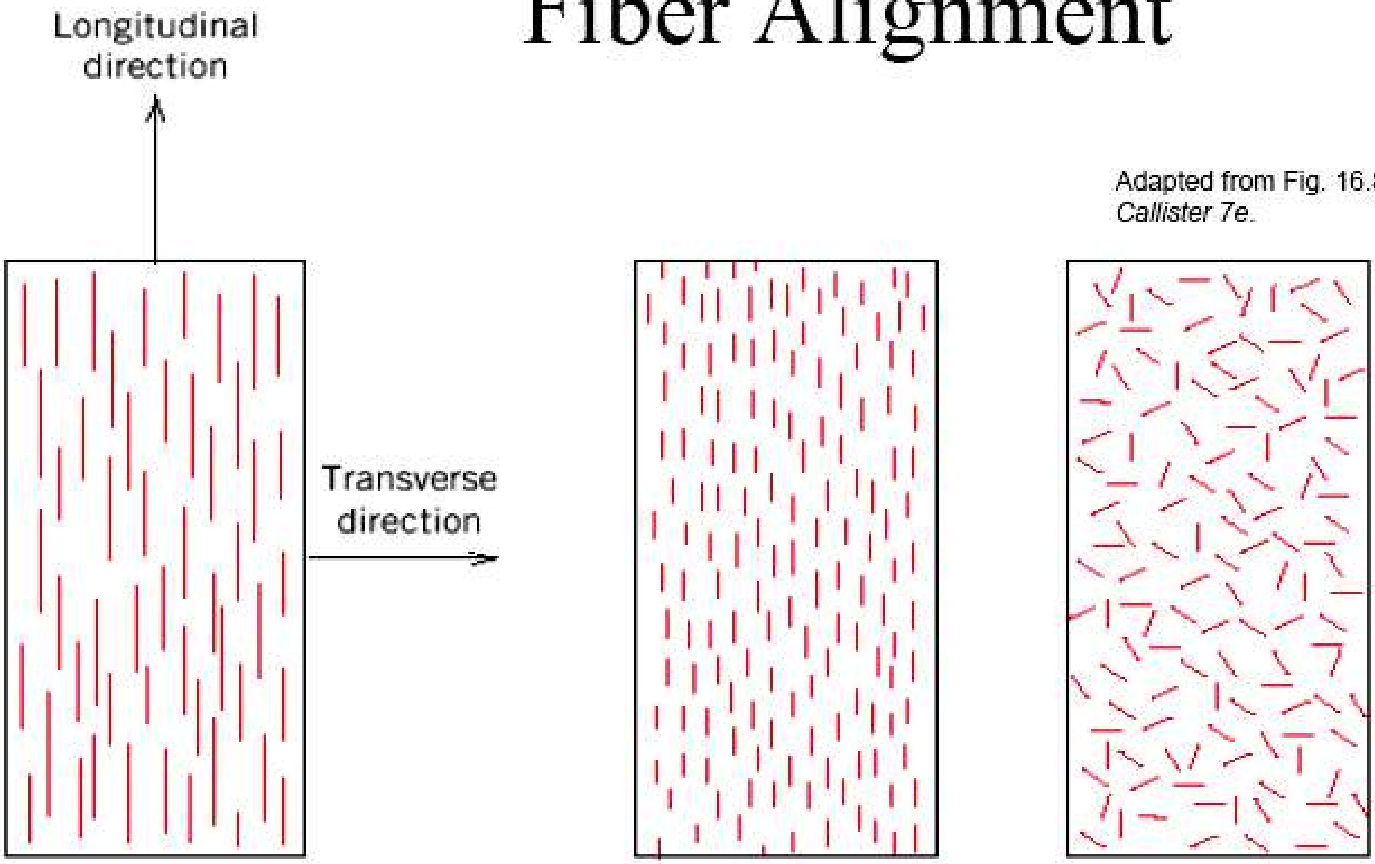
- **Fibers very strong**
  - **Provide significant strength improvement to material**
  - **Ex: fiber-glass**
    - **Continuous glass filaments in a polymer matrix**
    - **Strength due to fibers**
    - **Polymer simply holds them in place**

Composites - Fibers

Particle-reinforced | **Fiber-reinforced** | Structural

- Fiber Materials
  - Whiskers - Thin single crystals - large length to diameter ratio
    - graphite, SiN, SiC
    - high crystal perfection – extremely strong, strongest known
    - very expensive
  - Fibers
    - polycrystalline or amorphous
    - generally polymers or ceramics
    - Ex: Al_2O_3 , Aramid, E-glass, Boron, UHMWPE
  - Wires
    - Metal – steel, Mo, W

Fiber Alignment



Adapted from Fig. 16.8, *Callister 7e.*

aligned continuous

aligned discontinuous random

Strongest, but anisotropic

Weaker, but isotropic

Composites - Fibers

Particle-reinforced | **Fiber-reinforced** | Structural

- Critical fiber length for effective stiffening & strengthening:

fiber strength in tension (σ_f); fiber diameter (d); shear strength of fiber-matrix interface (τ_c)

$$\text{fiber length} > 15 \frac{\sigma_f d}{\tau_c}$$

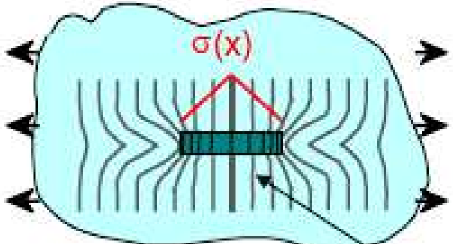
- Ex: For fiberglass, fiber length > 15 mm needed

Composites - Fibers

- **Why? Longer fibers carry stress more efficiently!**

Shorter, thicker fiber:

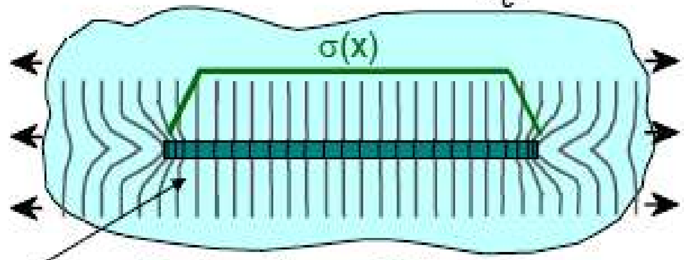
$$\text{fiber length} < 15\,\frac{\sigma_f d}{\tau_c}$$



Poorer fiber efficiency

Longer, thinner fiber:

$$\text{fiber length} > 15\,\frac{\sigma_f d}{\tau_c}$$



Better fiber efficiency

Adapted from Fig. 16.7, *Callister 7e*.

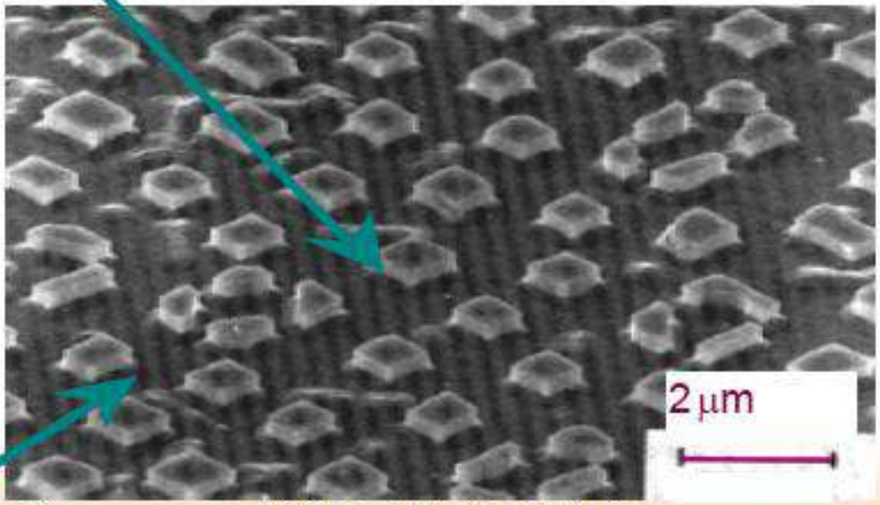
Tensile stress is transferred to the fiber from the matrix by a shear stress at the interface. If the fiber is too short, and near the ends, there is not enough surface area to transfer the full stress.

The fibers must be long enough that the "end-effect" is small.

Composites - Fibers

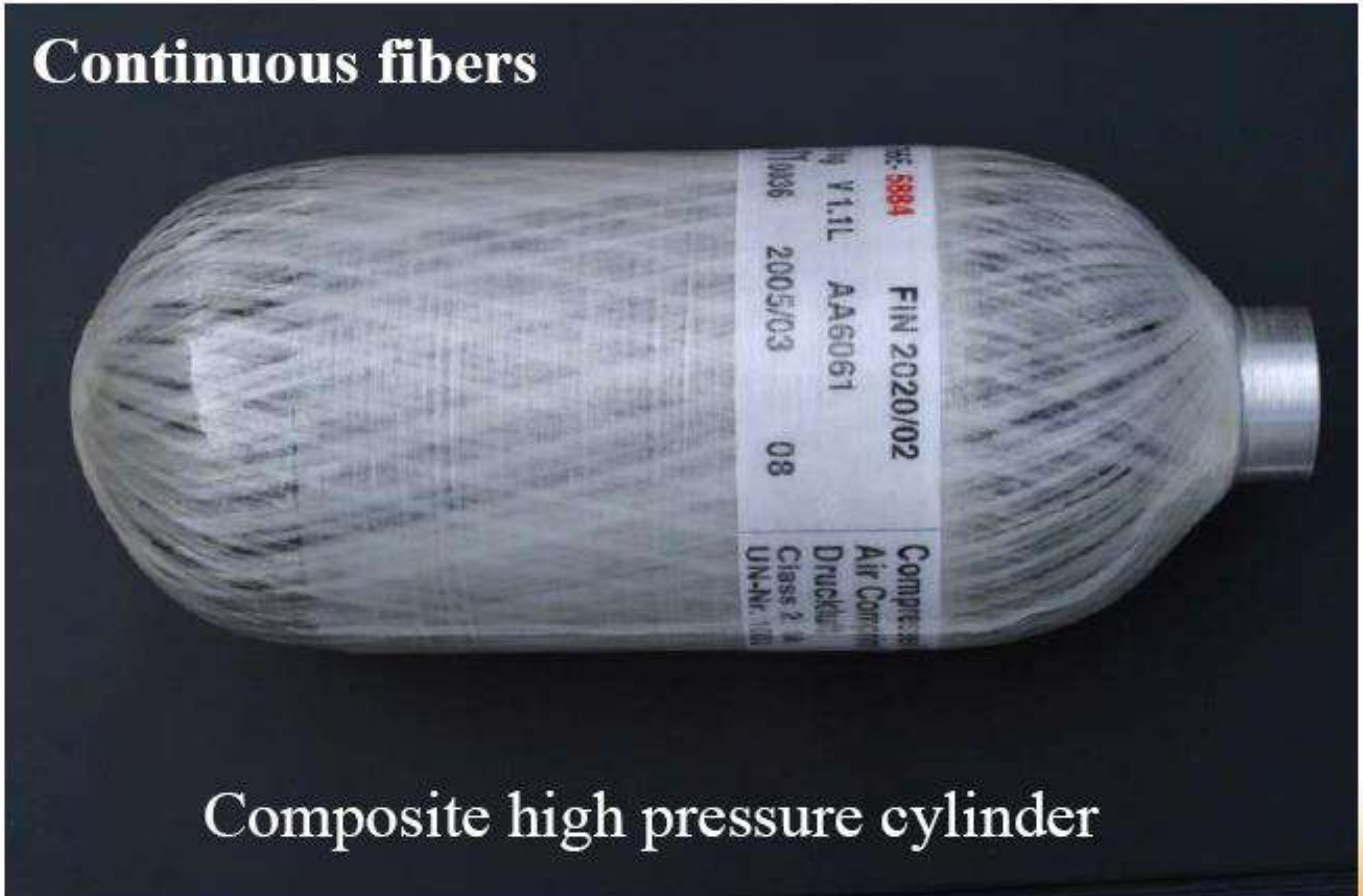
Particle-reinforced | **Fiber-reinforced** | Structural

- Aligned Continuous fibers
- Examples:
  - -- Metal: $\gamma'(Ni_3Al)-\alpha(Mo)$ by eutectic solidification.



From W. Funk and E. Blank, "Creep deformation of Ni3Al-Mo in-situ composites", *Metall. Trans. A* Vol. 19(4), pp. 987-998, 1988. Used with permission.

Composite Strength

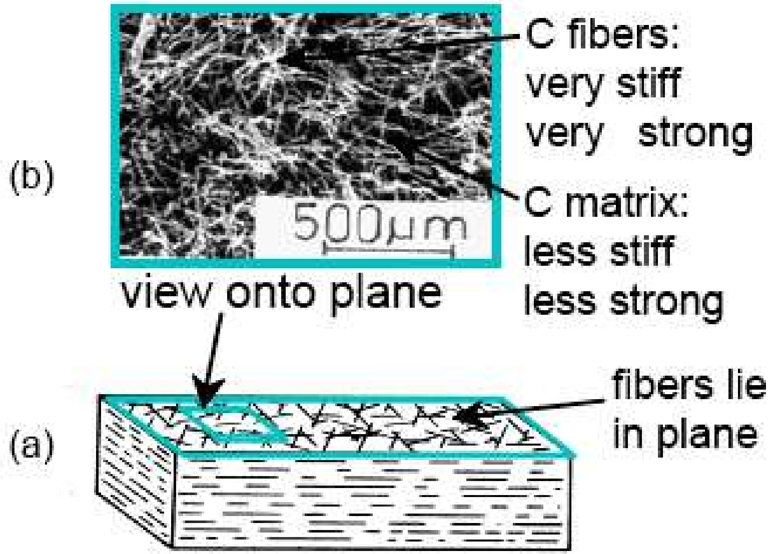


Composite high pressure cylinder

Composites - Fibers

Particle-reinforced | **Fiber-reinforced** | Structural

- Discontinuous, random 2D fibers
- Example: Carbon-Carbon
  - -- process: fiber/pitch, then burn out at up to 2500°C.
  - -- uses: disk brakes, gas turbine exhaust flaps, nose cones.



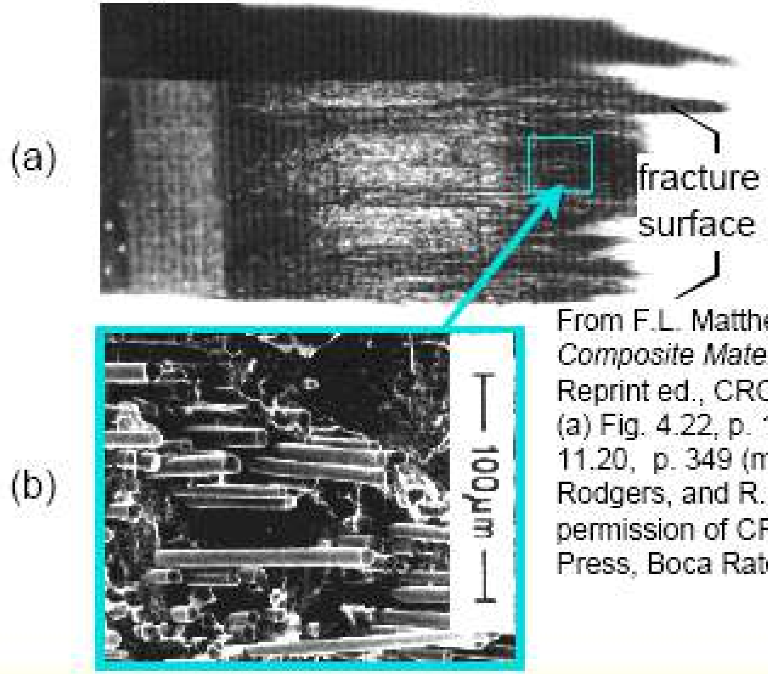
Adapted from F.L. Matthews and R.L. Rawlings, *Composite Materials; Engineering and Science*, Reprint ed., CRC Press, Boca Raton, FL, 2000. (a) Fig. 4.24(a), p. 151; (b) Fig. 4.24(b) p. 151. (Courtesy I.J. Davies) Reproduced with permission of CRC Press, Boca Raton, FL.

- Other variations:
  - -- Discontinuous, random 3D
  - -- Discontinuous, 1D

Fracture of Composites - Fibers

Ceramic: Glass w/SiC fibers formed by glass slurry

E_{glass} = 76 GPa; E_{SiC} = 400 GPa.

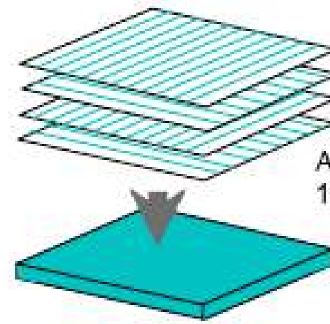


From F.L. Matthews and R.L. Rawlings, *Composite Materials; Engineering and Science*, Reprint ed., CRC Press, Boca Raton, FL, 2000. (a) Fig. 4.22, p. 145 (photo by J. Davies); (b) Fig. 11.20, p. 349 (micrograph by H.S. Kim, P.S. Rodgers, and R.D. Rawlings). Used with permission of CRC Press, Boca Raton, FL.

Composites - Laminates

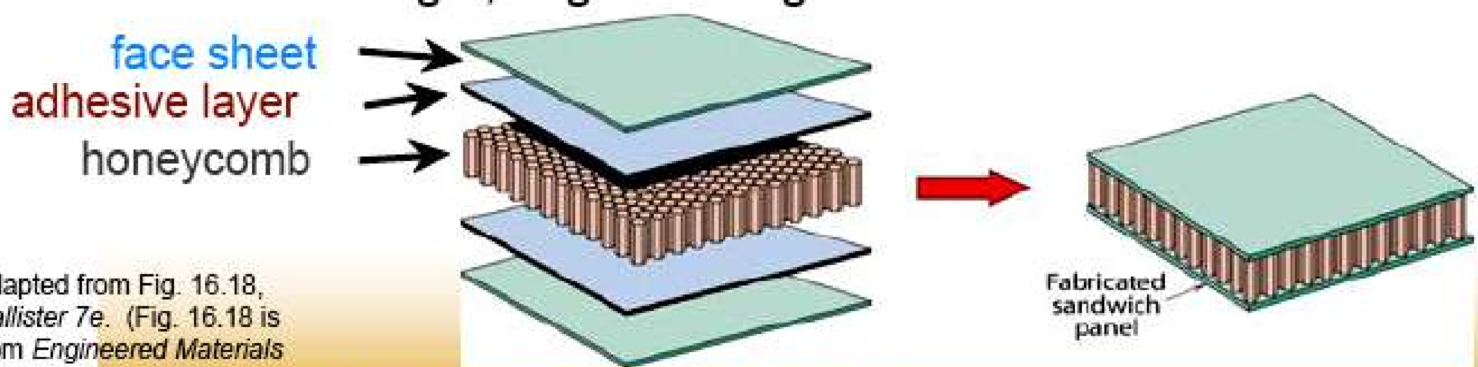
Particle-reinforced | Fiber-reinforced | **Structural**

- Stacked and bonded fiber-reinforced sheets
  - -- stacking sequence: e.g., 0º/90º
  - -- benefit: balanced, in-plane stiffness



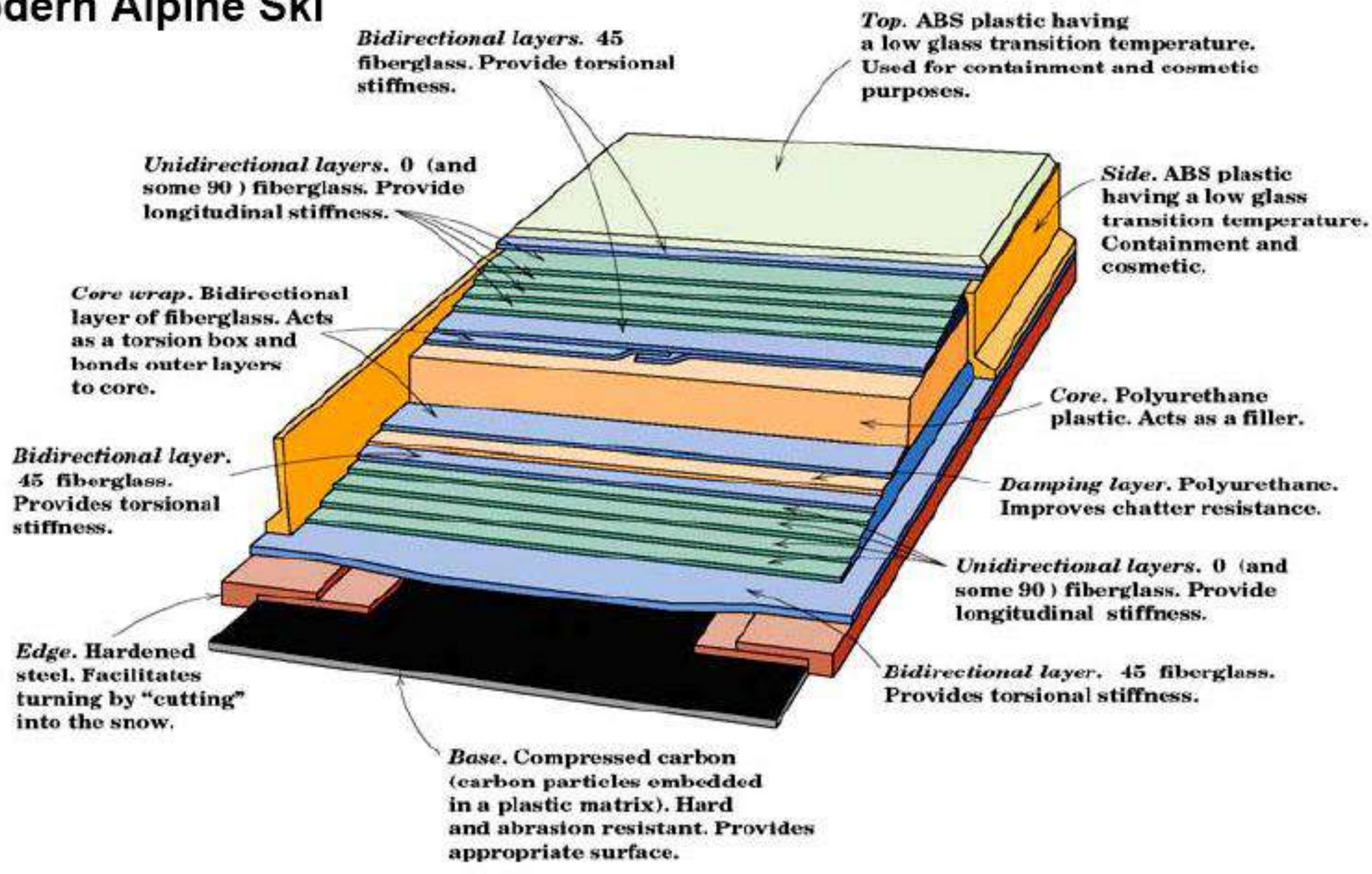
Adapted from Fig. 16.16, *Callister 7e*.

- Sandwich panels
  - -- low density, honeycomb core
  - -- benefit: small weight, large bending stiffness



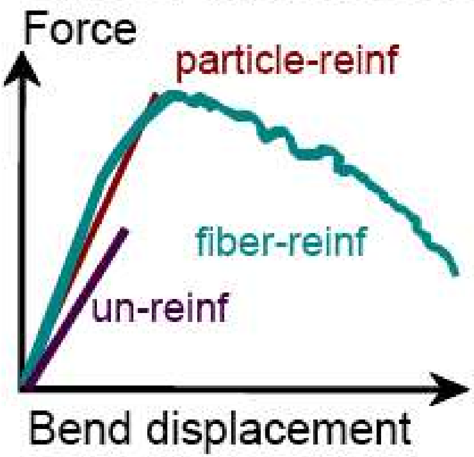
Adapted from Fig. 16.18, *Callister 7e*. (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

Modern Alpine Ski

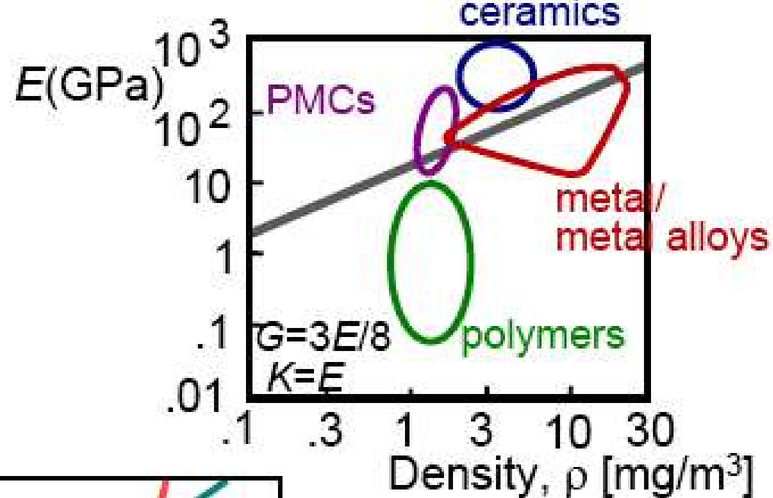


Composite Benefits

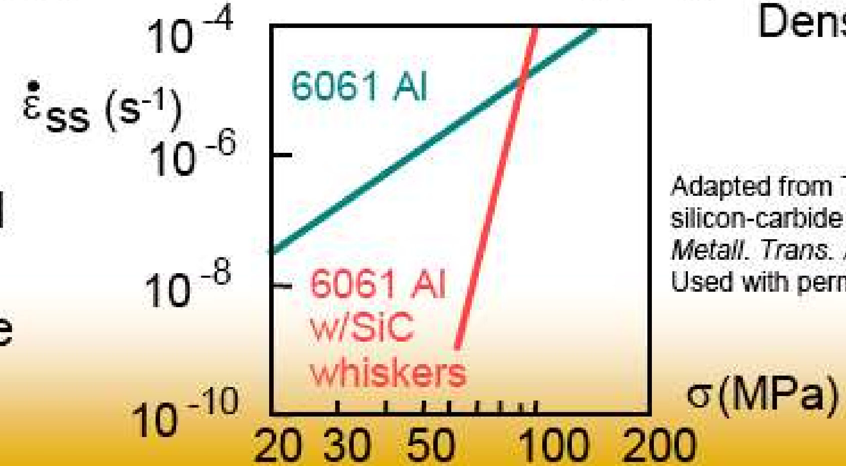
- CMCs: Increased toughness



- PMCs: Increased E/ρ



- MMCs:
  Increased creep resistance



Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans. A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

Metal & Ceramic Matrix Composites

- Cermets
  - Ceramic (up to 90%) contained in a metallic matrix
  - Cemented Carbides (tungsten, titanium, chromium)
  - Cutting Tools, Dies, Indenters
- Fibre Reinforced
  - Matrix is typically low density (e.g. al., mg., titanium)
  - Fibres are typically Al2O3, Boron, Carbon, SiC
- Ceramic Matrix Composites
  - Ceramic primary phase and fibres in secondary phase

Polymer Matrix Composites

- Fibre reinforced polymers (FRPs)
- Polymer matrix reinforced with fibres
- Matrix is typically TP (polyester or epoxy) and TS such as nylons, pvc, polycarbonates and polystyrene
- Fibres are typically glass, carbon and Kevlar 49 (up to 50%)

Components in a Composite Material

- Nearly all composite materials consist of two phases:
  - Primary phase - forms the matrix within which the secondary phase is imbedded
  - Secondary phase - imbedded phase sometimes referred to as a reinforcing agent, because it usually serves to strengthen the composite
    - The reinforcing phase may be in the form of fibers, particles, or various other geometries

Fibers

- Filaments of reinforcing material, usually circular in cross-section
- Diameters range from less than 0.0025 mm to about 0.13 mm, depending on material
- Filaments provide greatest opportunity for strength enhancement of composites
  - The filament form of most materials is significantly stronger than the bulk form
  - As diameter is reduced, the material becomes oriented in the fiber axis direction and probability of defects in the structure decreases significantly

Continuous vs. Discontinuous Fibers

- Continuous fibers - very long; in theory, they offer a continuous path by which a load can be carried by the composite part
- Discontinuous fibers (chopped sections of continuous fibers) - short lengths (L/D = roughly 100)
  - Important type of discontinuous fiber are whiskers - hair-like single crystals with diameters down to about 0.001 mm (0.00004 in.) with very high strength

Materials for Fibers

- Fiber materials in fiber-reinforced composites:
  - Glass – most widely used filament
  - Carbon – high elastic modulus
  - Boron – very high elastic modulus
  - Polymers - Kevlar
  - Ceramics – SiC and Al2O3
  - Metals - steel
- The most important commercial use of fibers is in polymer composites

Particles and Flakes

- A second common shape of imbedded phase is particulate, ranging in size from microscopic to macroscopic
- Flakes are basically two-dimensional particles - small flat platelets
- The distribution of particles in the composite matrix is random, and therefore strength and other properties of the composite material are usually isotropic
- Strengthening mechanism depends on particle size

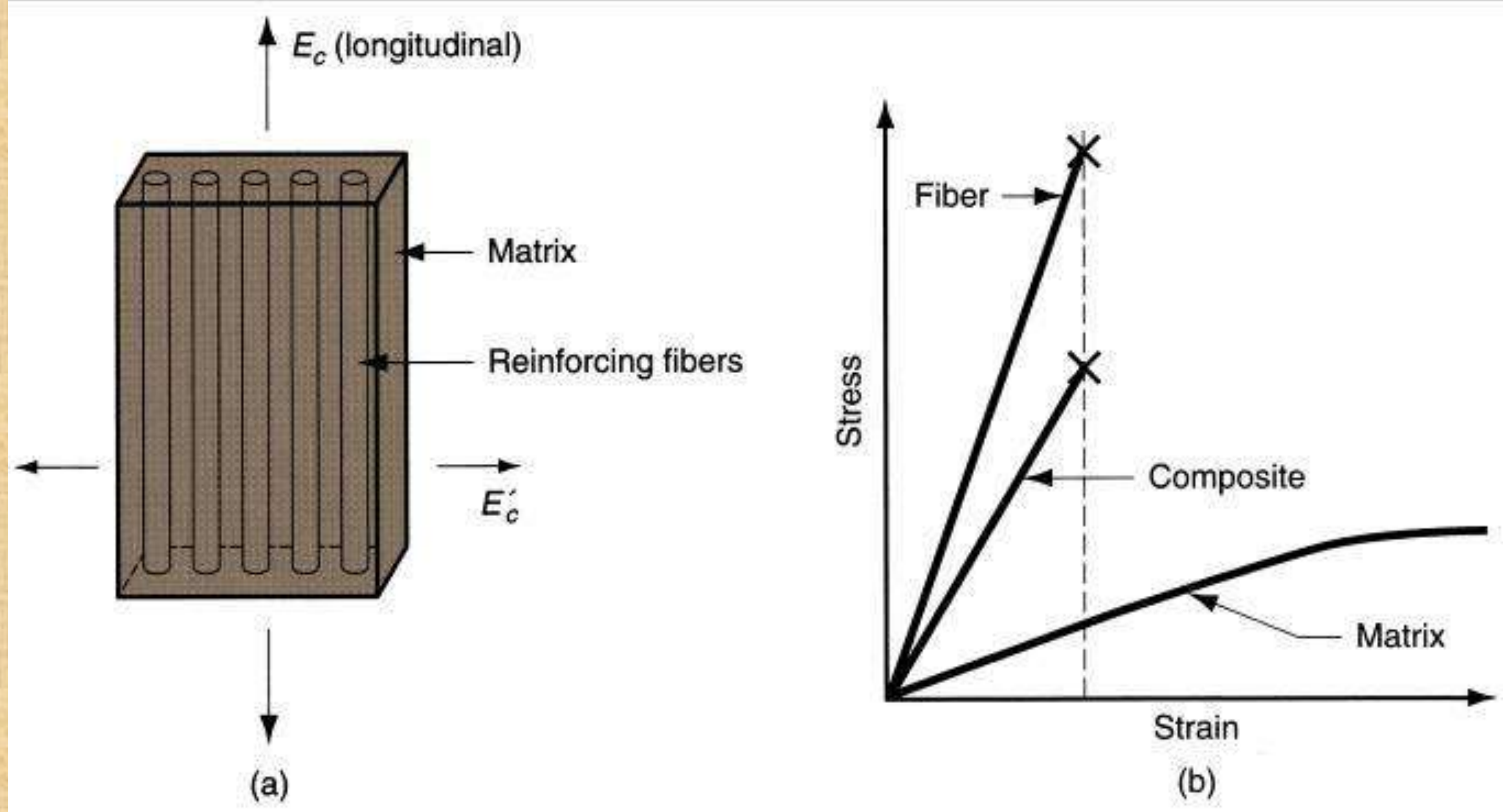
Properties of Composite Materials

- 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

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

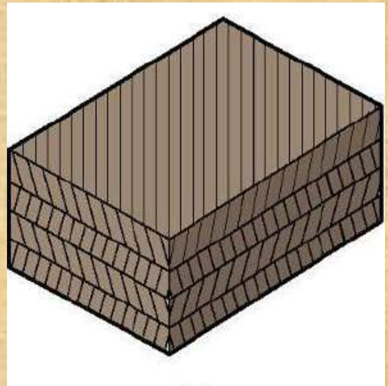


Fibers Illustrate Importance of Geometric Shape

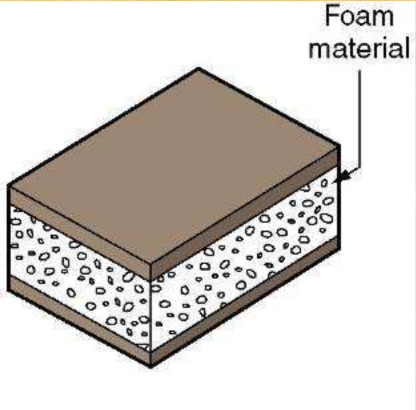
- Most materials have tensile strengths several times greater as fibers than in bulk
- By imbedding the fibers in a polymer matrix, a composite material is obtained that avoids the problems of fibers but utilizes their strengths
  - The matrix provides the bulk shape to protect the fiber surfaces and resist buckling
  - When a load is applied, the low-strength matrix deforms and distributes the stress to the high-strength fibers

Other Composite Structures

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



(a)



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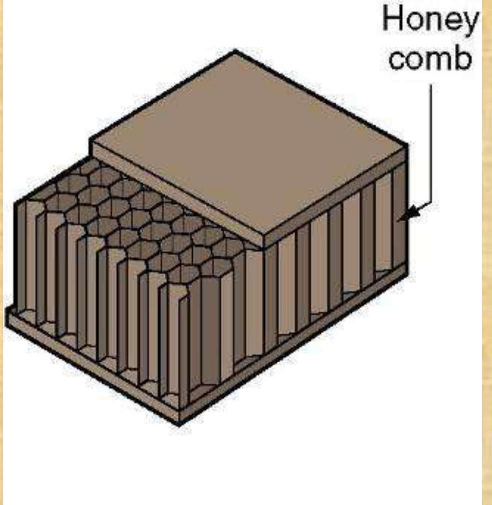


(c)

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

Metal Matrix Composites (MMCs)

- A metal matrix reinforced by a second phase
- Reinforcing phases:
  - Particles of ceramic (these MMCs are commonly called cermets)
  - Fibers of various materials: other metals, ceramics, carbon, and boron

Cermets

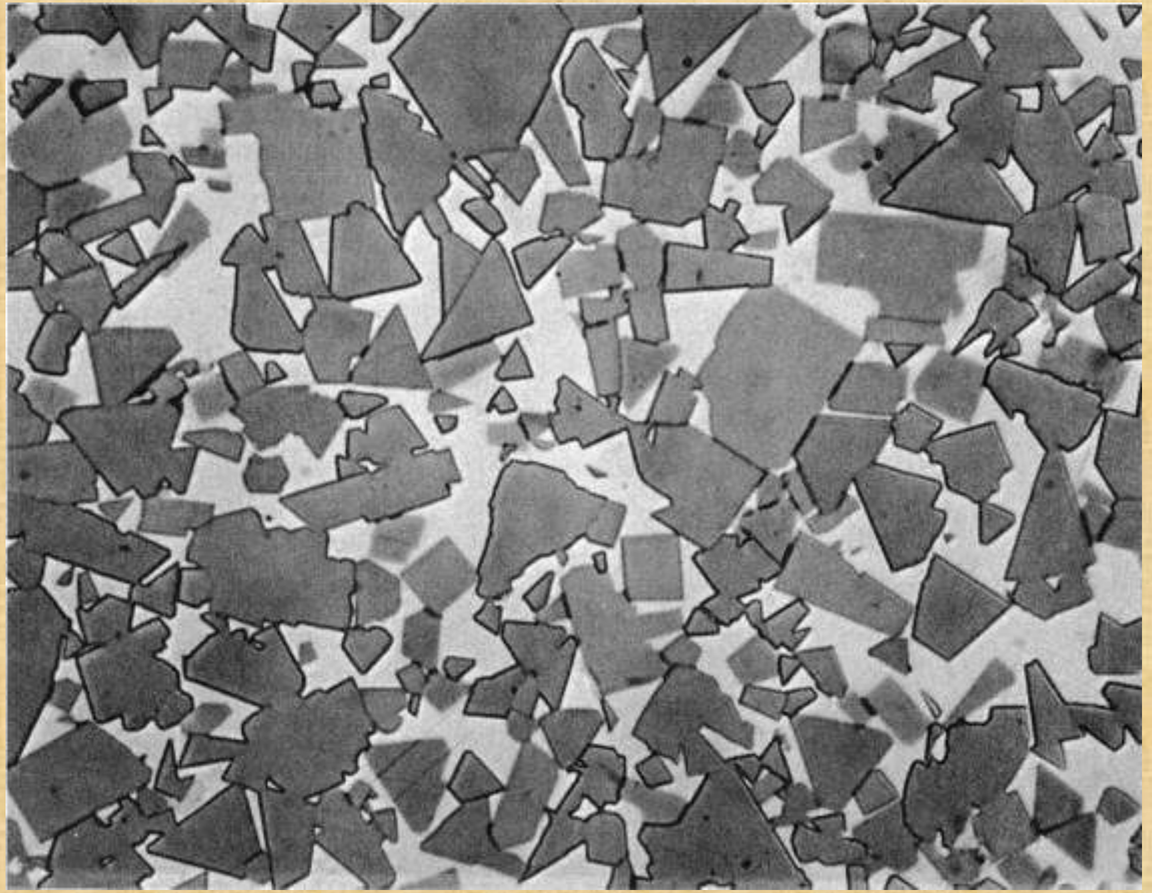
- MMC with ceramic contained in a metallic matrix
- The ceramic often dominates the mixture, sometimes up to 96% by volume
- Bonding can be enhanced by slight solubility between phases at elevated temperatures used in processing
- Cermets can be subdivided into
  - Cemented carbides – most common
  - Oxide-based cermets – less common

Cemented Carbides

- One or more carbide compounds bonded in a metallic matrix
- The term cermet is not used for all of these materials, even though it is technically correct
- Common cemented carbides are based on tungsten carbide (WC), titanium carbide (TiC), and chromium carbide (Cr_3C_2)
- Tantalum carbide (TaC) and others are less common
- Metallic binders: usually cobalt (Co) or nickel (Ni)

Cemented Carbide

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



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

Polymer Matrix Composites (PMCs)

- A polymer primary phase in which a secondary phase is imbedded as fibers, particles, or flakes
- Commercially, PMCs are more important than MMCs or CMCs
- Examples: most plastic molding compounds, rubber reinforced with carbon black, and fiber-reinforced polymers (FRPs)
- FRPs are most closely identified with the term composite

Fibers in PMCs

- Various forms: discontinuous (chopped), continuous, or woven as a fabric
- Principal fiber materials in FRPs are glass, carbon, and Kevlar 49
- Less common fibers include boron, SiC, and Al2O3, and steel
- Glass (in particular E-glass) is the most common fiber material in today's FRPs; its use to reinforce plastics dates from around 1920

Common FRP Structure

- 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

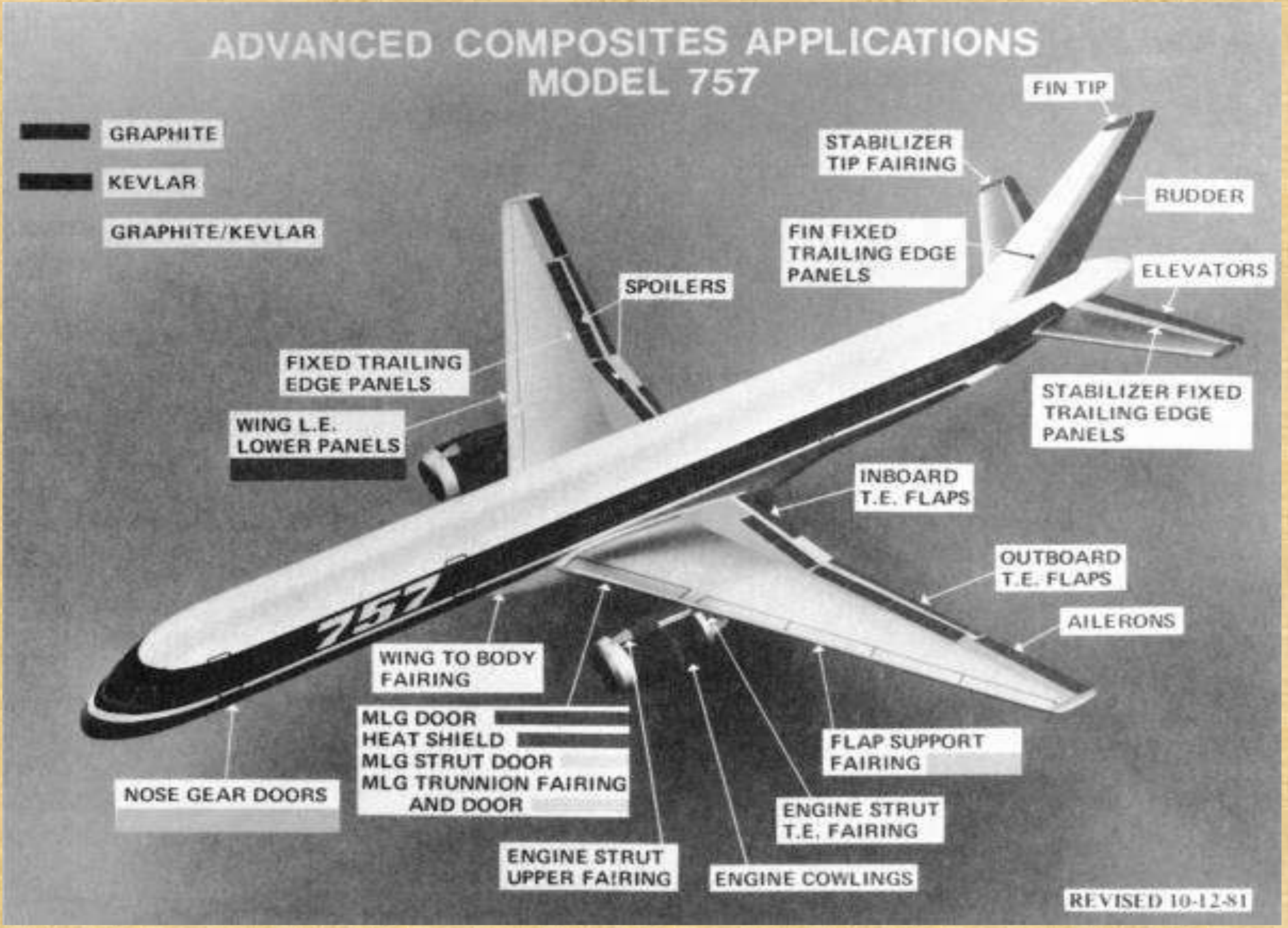
FRP Properties

- High strength-to-weight and modulus-to-weight ratios
- Low specific gravity - a typical FRP weighs only about 1/5 as much as steel; yet, strength and modulus are comparable in fiber direction
- Good fatigue strength
- Good corrosion resistance, although polymers are soluble in various chemicals
- Low thermal expansion - for many FRPs, leading to good dimensional stability
- Significant anisotropy in properties

FRP Applications

- Aerospace – much of the structural weight of todays airplanes and helicopters consist of advanced FRPs
- Automotive – somebody panels for cars and truck cabs
  - Continued use of low-carbon sheet steel in cars is evidence of its low cost and ease of processing
- Sports and recreation
  - Fiberglass reinforced plastic has been used for boat hulls since the 1940s
  - Fishing rods, tennis rackets, golf club shafts, helmets, skis, bows and arrows.

Aerospace Applications



Other Polymer Matrix Composites

- In addition to FRPs, other PMCs contain particles, flakes, and short fibers as the secondary phase
- Called fillers when used in molding compounds
- Two categories:
  - Reinforcing fillers – used to strengthen or otherwise improve mechanical properties
    - Examples: wood flour in phenolic and amino resins; and carbon black in rubber
  - Extenders – used to increase bulk and reduce cost per unit weight, but little or no effect on mechanical properties

Guide to Processing Composite Materials

- The two phases are typically produced separately before being combined into the composite part
- Processing techniques to fabricate MMC and CMC components are similar to those used for powdered metals and ceramics
- Molding processes are commonly used for PMCs with particles and chopped fibers
- Specialized processes have been developed for FRPs

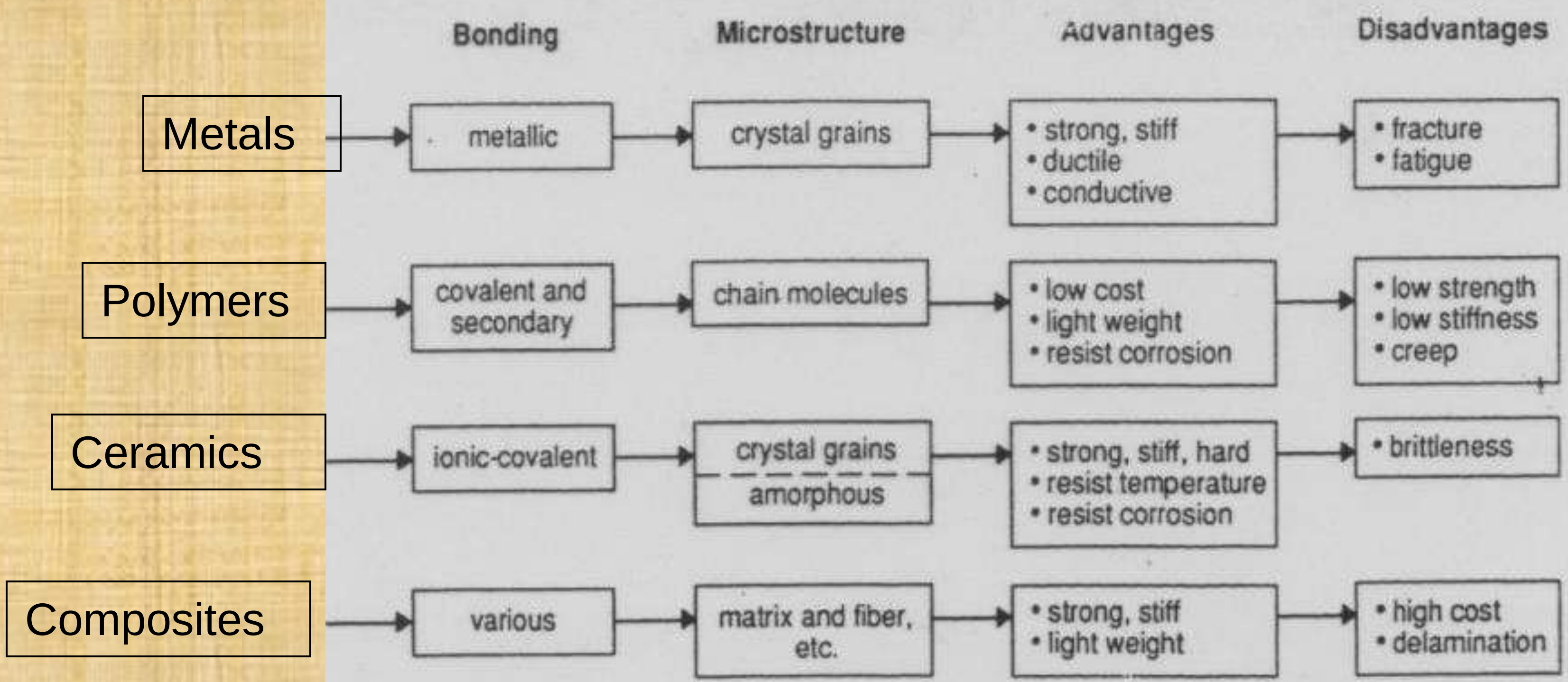


Figure 2.1 General characteristics of the major classes of engineering materials.

Composites consist of:

1. Combination of two or more materials Composite = matrix + fiber (filler):
   - Matrix:
     - material component that surrounds the fiber.
     - Usually **a ductile, or tough, material w/ low density**
     - **Strength usually = 1/10 (or less) than that of fiber**
     - Examples include: thermoplastic or thermoset
       - Thermoset most common (epoxy, pheneolic)
     - Serves to hold the fiber (filler) in a favorable orientation.
   - Fiber aka reinforcing material aka Filler:
     - **Materials that are strong with low densities**
     - Examples include glass, carbon or particles.
2. Designed to display a combination of the best characteristics of each material i.e. **fiberglass** acquires **strength from glass** and **flexibility from the polymer**.
3. Matrix and filler bonded together (adhesive) or mechanically locked together!

Where are composites used??????

CFRP – carbon fiber reinforced composite.

GFRP – glass fiber reinforced composite

Composites in industry

- Engineering applications
  - Aerospace
  - Automobile
  - Pressure vessel and pipes
- Any place where high performance materials are desired

Turret Shield

Industrial Spring

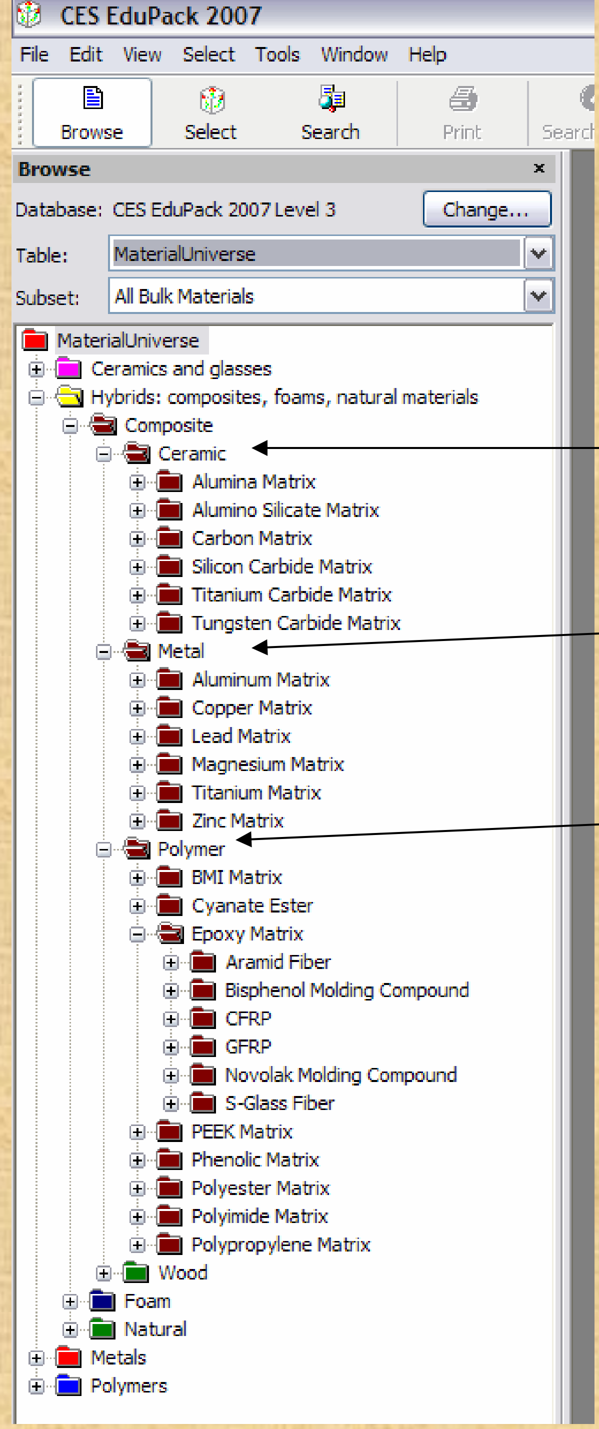
Medical Table

Bullet proof shields

www.composiflex.com

Nature of Composites:

- Disadvantages (or limitations):
  - **Material costs**
  - **Fabrication/ manufacturing difficulties**
  - **Repair can be difficult**
  - **Wider range of variability (statistical spread)**
  - **Operating temperature can be an issue for polymeric matrix (i.e. 500 F). Less an issue for metal matrix (2,700 F).**
  - **Properties non-isotropic makes design difficult!**
    - **Example – video test in line w/ fibers 10X stronger vs fibers oriented at an angle.**
  - **Inspection and testing typically more complex.**



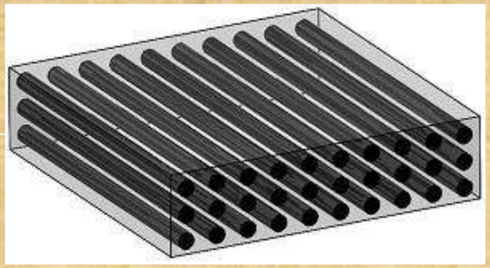
Classification of Composite Materials by Matrix:

1. Metal matrix
2. Ceramic matrix
3. Polymer (Resin) matrix

Ceramic (Cermets)

Metal

Polymer (resin)



Most common – also called fiber reinforced polymer

Classification of Composite Materials by Matrix:

- **Polymer matrix composites or Fiber Reinforced Polymer (FRP)**
  - Fibers generally glass, carbon or kevlar
  - Matric can be:
    - Thermoplastics: PE, Nylon, PS, PP, PC, PVC
    - Thermosets: Epoxy, polyester, phenolics
  - Have high strength and stiffness to weight ratio
  - Aerospace, sporting goods marine
  - Examples: GFRP aka fiberglass (polyester or epoxy and glass), CFRP (polyester or epoxy and carbon), KFRP (polyester or epoxy and Keflar)

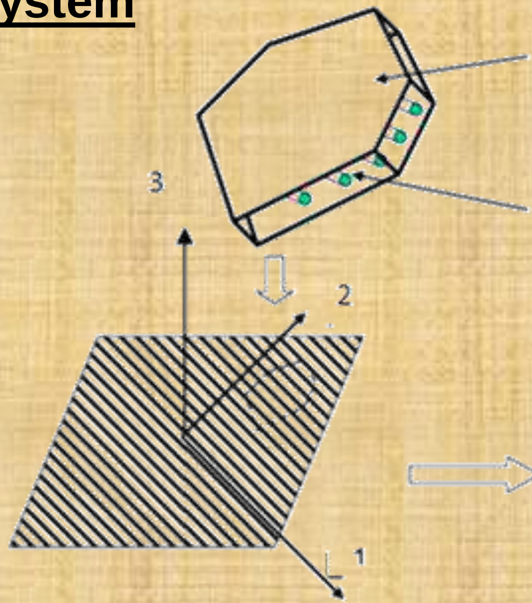
Filler = ? Matrix = ?

Layered Composites

Coordinate System

Lamina – 1,2,3

Laminate – x,y,z



Matrix- A homogenous base material that forms the bulk of a composite material layer.

Fibers- Bonded or embedded reinforcing fibers that are usually responsible for the anisotropy of the composite.

Lamina- A composite material in sheet form usually referred to as a **layer** or **ply**. The material properties of a layer is usually determined through an equivalent homogenization (smearing) process.

Laminate- A stack of lamina joined together in arbitrary directions, referred to as a composite **lay-up**.

Ranking of Most Common Fibers for FRP

Property	**Glass**	**Carbon**	**Kevlar**
Strength	Worst	In - between	Best
Stiffness	Worst	Best	In – between
Cost	Best	Worst	In – between
Weight	Worst	Best	In-between

Manufacturing FRP (see video)

- Hand lay-up (http://www.youtube.com/watch?v=_GDqxnahwbk&list=PL9FC6FF2112573125&index=2
- Filament winding or Pultrusion (http://www.youtube.com/watch?v=4MoHNZB5b_Y
- Resin Transfer (or) Injection Molding (RTM)

http://www.scaled.com/index.html

http://www.ckcomposites.com/

Classification of Composite Materials by Matrix:

- **Metal matrix composites (MMC):**
  - Metal matrix: Al, Ti, Mg, Fe, Cu, Ni
  - Example: Al-SiC (silicon carbide)
  - Example: Al-Al_2O_3 (aluminum oxide)
  - High strength, high stiffness, abrasion resistance, dimensional stability, high temperature and toughness.

= matrix

Classification of Composite Materials by Matrix:

- **Ceramic matrix composites (CMC):**
  - Silicon carbide-silicon carbide (SiC-SiC)
  - Same material both matrix and filler BUT filler different form such as whickers, chopped fibers or strands to achieve preferred properties.

= matrix

Nature of Composites:

- **The strength of the composite depends primarily on the amount, arrangement and type of fiber (or particle) reinforcement in the resin.**
- **Typically, the higher the reinforcement content, the greater the strength. In some cases, glass fibers are combined with other fibers, such as carbon or aramid (Kevlar29 and Kevlar49), to create a "hybrid" composite that combines the properties of more than one reinforcing material.**

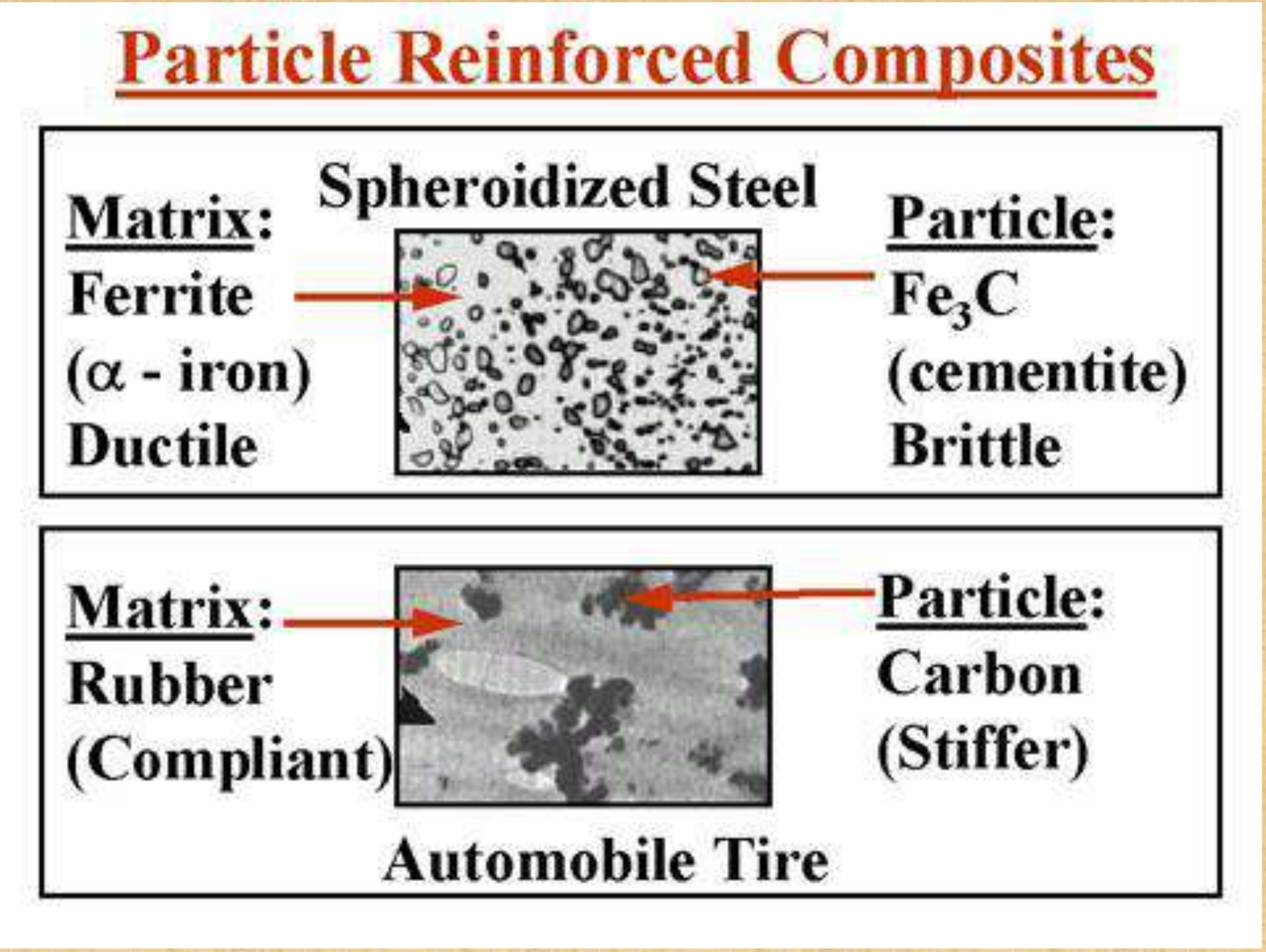
Classification of Composite by Filler Type:

- Particle-reinforced composites
- Fiber-reinforced composites
- Structural composites

Particle Reinforced Composites:

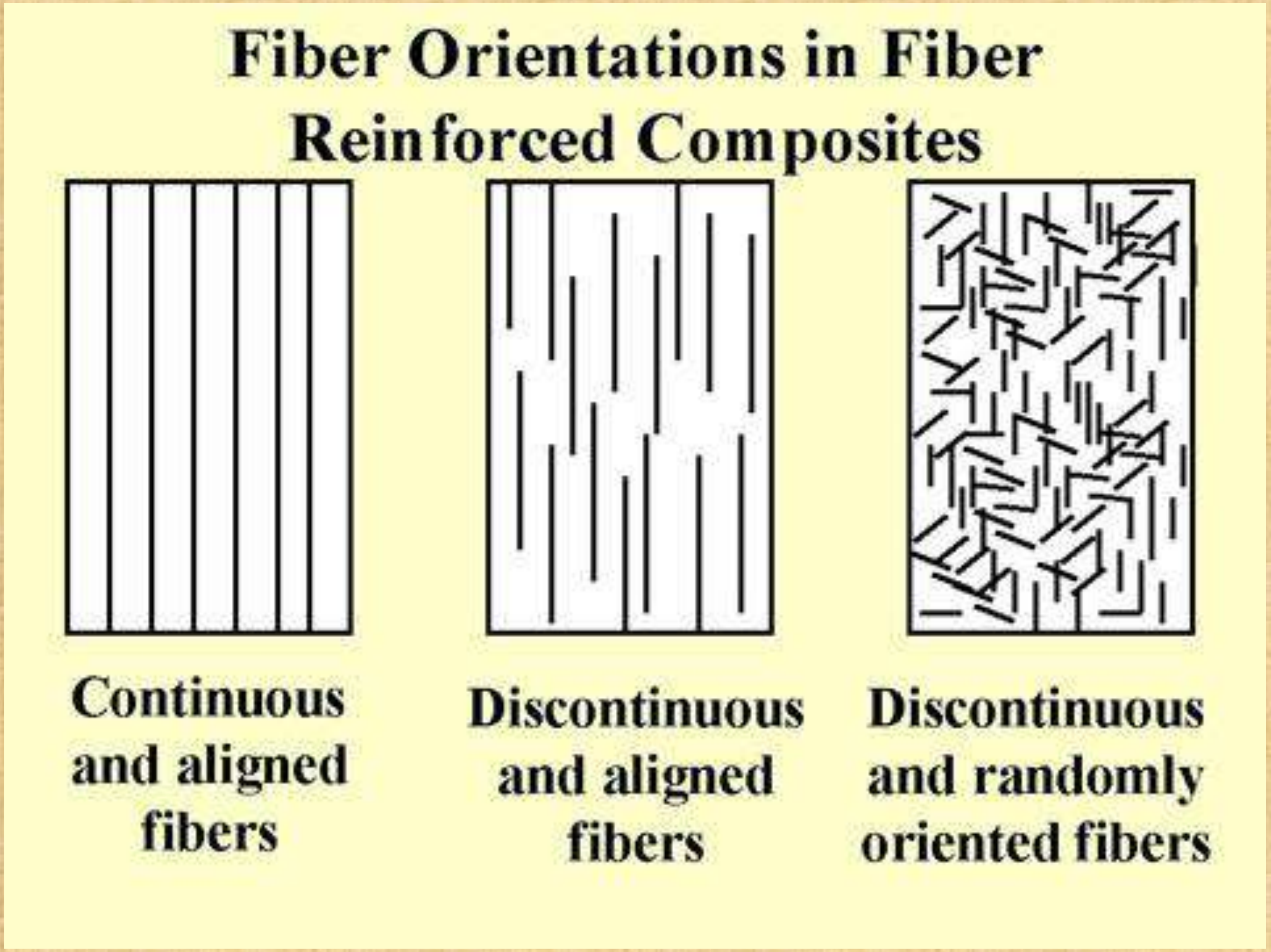
- Particles used for reinforcing include:
  - ceramics and glasses such as small mineral particles,
  - metal particles such as aluminum,
  - and amorphous materials, including polymers and carbon black.
- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix.
- Particle reinforced composites support higher tensile, compressive and shear stresses
- Particles are also used to produce inexpensive composites.
- Examples:
  - automobile tire which has carbon black particles in a matrix of elastomeric polymer.
  - spheroidized steel where cementite is transformed into a spherical shape which improves the machinability of the material.
  - concrete where the aggregtes (sand and gravel) are the particles and cement is the matrix.

Figure 1. Examples for particle-reinforced composites. (Spheroidized steel and automobile tire)



Fiber-reinforced Composites:

- Reinforcing fibers can be made of metals, ceramics, glasses, or polymers that have been turned into graphite and known as carbon fibers. Fibers increase the modulus of the matrix material. The strong covalent bonds along the fiber's length gives them a very high modulus in this direction because to break or extend the fiber the bonds must also be broken or moved. Fibers are difficult to process into composites which makes fiber-reinforced composites relatively expensive. Fiber-reinforced composites are used in some of the most advanced, and therefore most expensive, sports equipment, such as a time-trial racing bicycle frame which consists of carbon fibers in a thermoset polymer matrix. Body parts of race cars and some automobiles are composites made of glass fibers (or fiberglass) in a thermoset matrix.
- The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites. Applications involving totally multidirectional applied stresses normally use discontinuous fibers, which are randomly oriented in the matrix material. Consideration of orientation and fiber length for a particular composites depends on the level and nature of the applied stress as well as fabrication cost. Production rates for short-fiber composites (both aligned and randomly oriented) are rapid, and intricate shapes can be formed which are not possible with continuous fiber reinforcement.

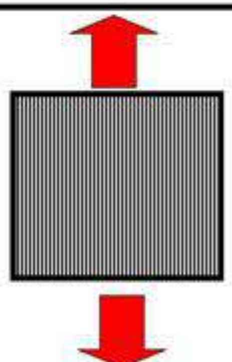


Note: Fiber composite manufacturers often rotate layers of fibers to avoid directional variations in the modulus.

The modulus of the entire composite, matrix plus reinforcer,is governed by the rule of mixtures:

LONGITUDINAL LOADING

ISOSTRAIN CONDITION: Deformation of matrix and fibers is the same.



Force parallel to fiber direction

$$S_c = S_m * V_m + S_f * V_f$$

$$E_c = E_m * V_m + E_f * V_f$$

S = Tensile Strength
E = Modulus of Elasticity
V = Volume Fraction
m = Matrix
f = Fiber
c = Composite

TRANSVERSE LOADING

ISOSTRESS CONDITION: Matrix and fibers are under the same stress.($S_c=S_m=S_f$)

Force perpendicular to fiber direction

$$E_c = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

S = Tensile Strength
E = Modulus of Elasticity
V = Volume Fraction
m = Matrix
f = Fiber
c = Composite

Stiff and Strong!!

See case study at end!!

Soft and Weak!

Structural Composites:

- **The properties of structural composites depend on:**
  - **Constituents**
  - **Geometrical design**

Structural Composites:

- Common structural composite types are:
  - **Laminar:** Is composed of two-dimensional sheets or panels that have a preferred high strength direction such as is found in wood and continuous and aligned fiber-reinforced plastics. The layers are stacked and cemented together such that the orientation of the high-strength direction varies with each successive layer. One example of a relatively complex structure is modern ski and another example is plywood.

Structural Composites:

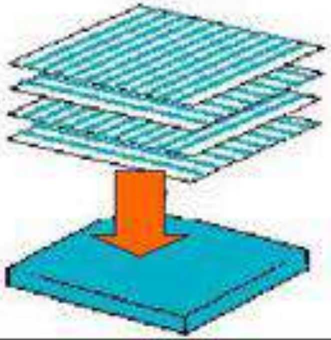
- **Common structural composite types are:**
  - **Sandwich Panels: Consist of two strong outer sheets which are called face sheets and may be made of aluminum alloys, fiber reinforced plastics, titanium alloys, steel. Face sheets carry most of the loading and stresses. Core may be a honeycomb structure which has less density than the face sheets and resists perpendicular stresses and provides shear rigidity. Sandwich panels can be used in variety of applications which include roofs, floors, walls of buildings and in aircraft, for wings, fuselage and tailplane skins.**

Show example (ref: bh user's conference)

Structural Composites

Stacked and bonded fiber-reinforced sheets

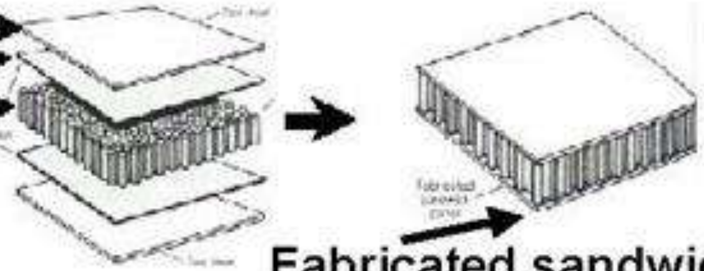
- stacking sequence: e.g., 0/90
- benefit: balanced, in-plane stiffness



Sandwich panels

- low density honeycomb core
- benefit: small weight, large bend stiffness

face sheet
adhesive layer
honeycomb



Fabricated sandwich panel

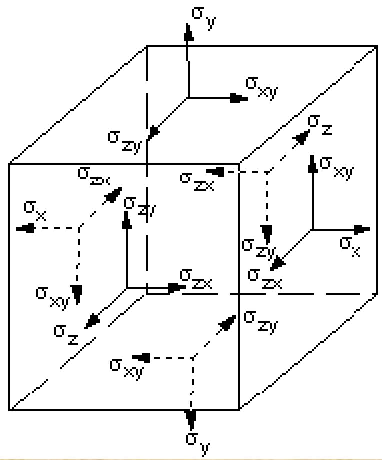
Neat Links!!!

- http://www.scaled.com/index.html
- http://composite.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Fpoisson.me.dal.ca%2FDesign_projs%2F96_97%2Fcomposite%2F
- http://en.wikipedia.org/wiki/Composite_material
- http://www.youtube.com/watch?v=_GDqxnahwbk&list=PL9FC6FF2112573125&index=2

Good manufacturing videos

Case Study: Generating Properties for FE Analysis of Composites

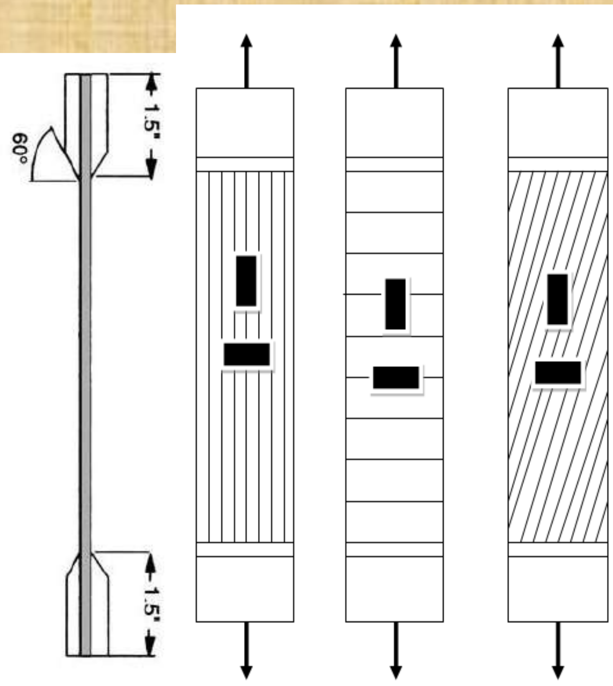
- **Orthotropic material data requires nine values to be fully described**
  - Three Young's moduli (E_x,E_y,E_z)
  - Three Poissons ratio(v_{xy}, v_{yz},v_{xz})



$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \varepsilon_{xy} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \end{Bmatrix} = \begin{bmatrix} 1/E_x & & & & & \\ -v_{yx}/E_y & 1/E_y & & & \text{symm} & \\ -v_{zx}/E_z & -v_{zy}/E_z & 1/E_z & & & \\ 0 & 0 & 0 & 1/G_{xy} & & \\ 0 & 0 & 0 & 0 & 1/G_{yz} & \\ 0 & 0 & 0 & 0 & 0 & 1/G_{xz} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{Bmatrix}$$

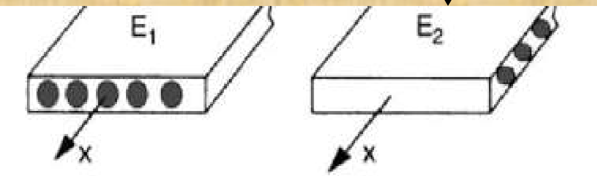
Project work completed

- Tested 75 specimens
  - 3 different volume fractions.
    - Tensile test at 0^o,90^o,10^o off axis
    - 3 point bend test at 0^o and 90^o
  - Applied over 150 strain gages
  - Applied 120 tabs for tensile specimens

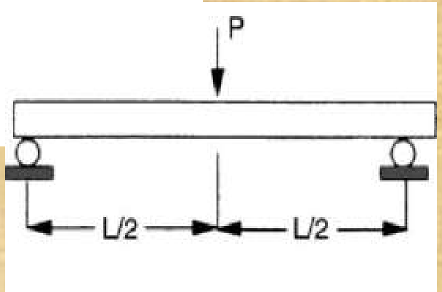


10 degrees off y axis

15 of each

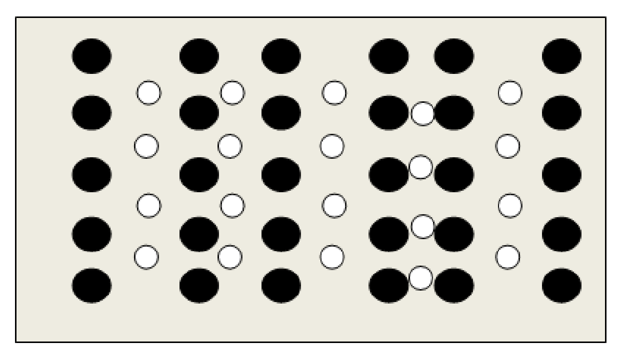


15 of each



Project work completed

- Researched Mechanics of Composites
  - To obtain theoretical data we used the Rule of Mixtures
    - Why the rule of mixtures?



Beige = Resin
Black = Fibers
White = Voids

Typical Material Properties

- **Grafil 34-700 carbon fiber tows**
  - Tensile tow strength $\sigma = 700$ ksi
  - Tensile Modulus E = 34,000 ksi
  - Density $\rho = .065$ lbm/in^3

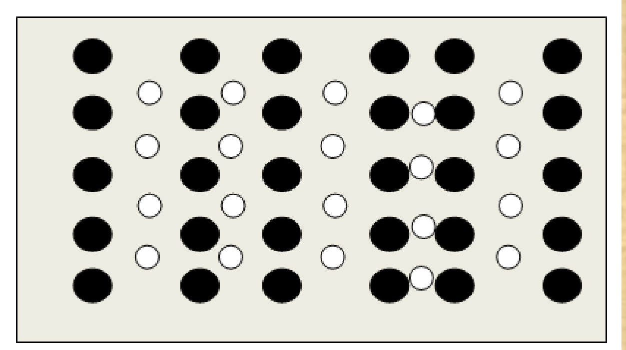
- **Newport 301 Epoxy Resin**
  - Tensile strength $\sigma = 8300$ psi
  - Tensile Modulus E = 460 ksi
  - Shear Modulus G = 500 ksi
  - Density $\rho = .0441$ lbm/in^3

NEWPORT ADHESIVES AND COMPOSITES, INC.

A subsidiary of MITSUBISHI RAYON CO., LTD.

Rule of Mixtures (cont.)

- F = Fibers
- R = Resin
- C = Composites
- V_F = Fiber volume fraction
    - Density
    - Longitudinal Modulus
    - Transverse Modulus



Beige = Resin
Black = Fibers
White = Voids

$$V_F = \frac{v_F}{v_C}$$

$$\rho_C = \rho_F \cdot V_F + \rho_R \cdot (1 - V_F)$$

$$E_1 = E_F \cdot V_F + E_R \cdot (1 + V_F)$$

$$E_2 = \frac{E_F \cdot E_R}{E_R \cdot V_F + E_F \cdot (1 - V_F)}$$

Finding Volume Fraction

Composite Specimen in Nitric Acid

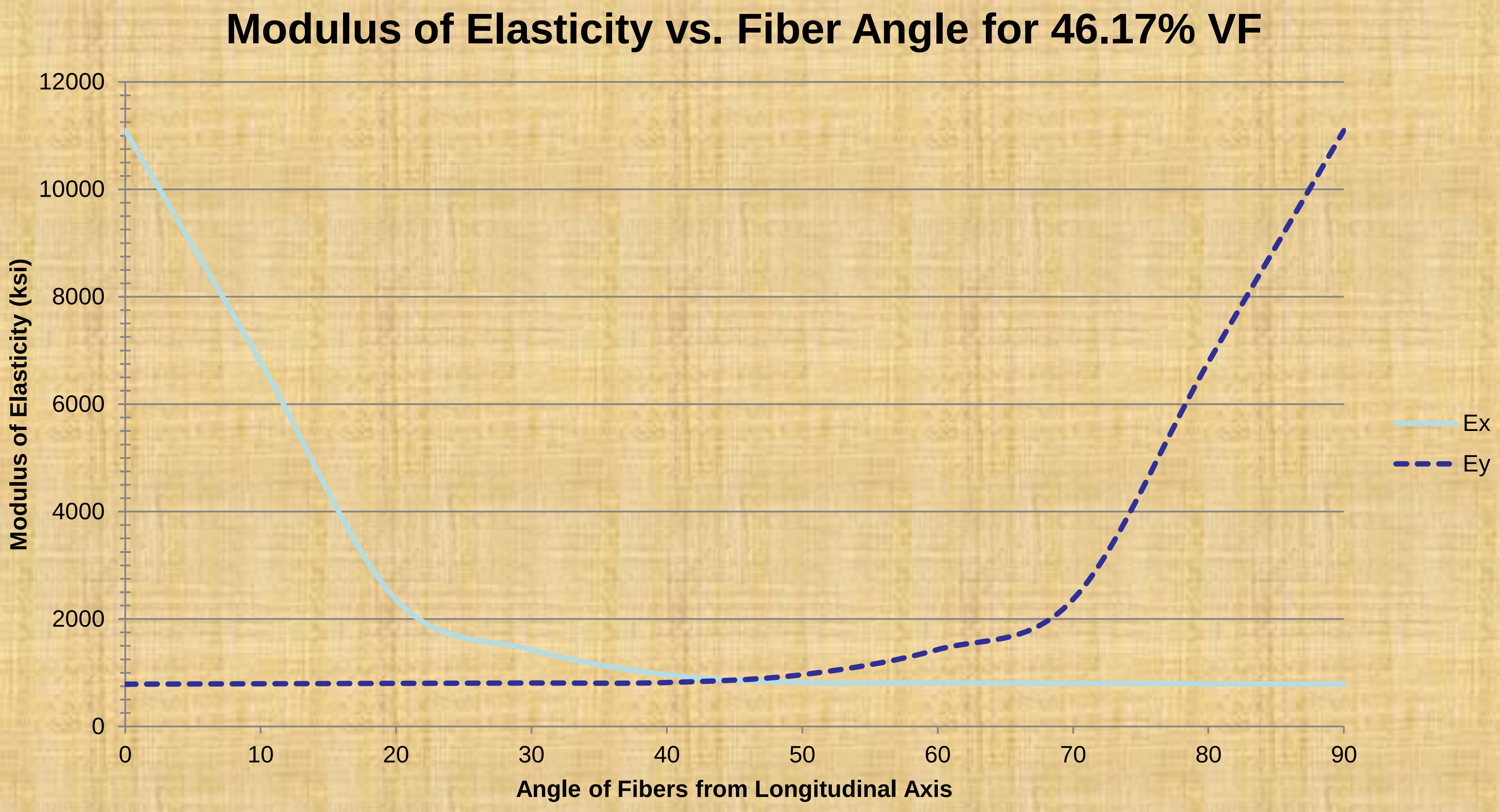
$$v_f = \frac{W_f/\rho_f}{W_c/\rho_c}$$

Determining mass of fibers after acid bath

$$v_v = 1 - \rho\left[\frac{m_f}{\rho_f} + \frac{m_m}{\rho_m}\right]$$

Fibers in bookner

Modulus Based on Fiber Angle

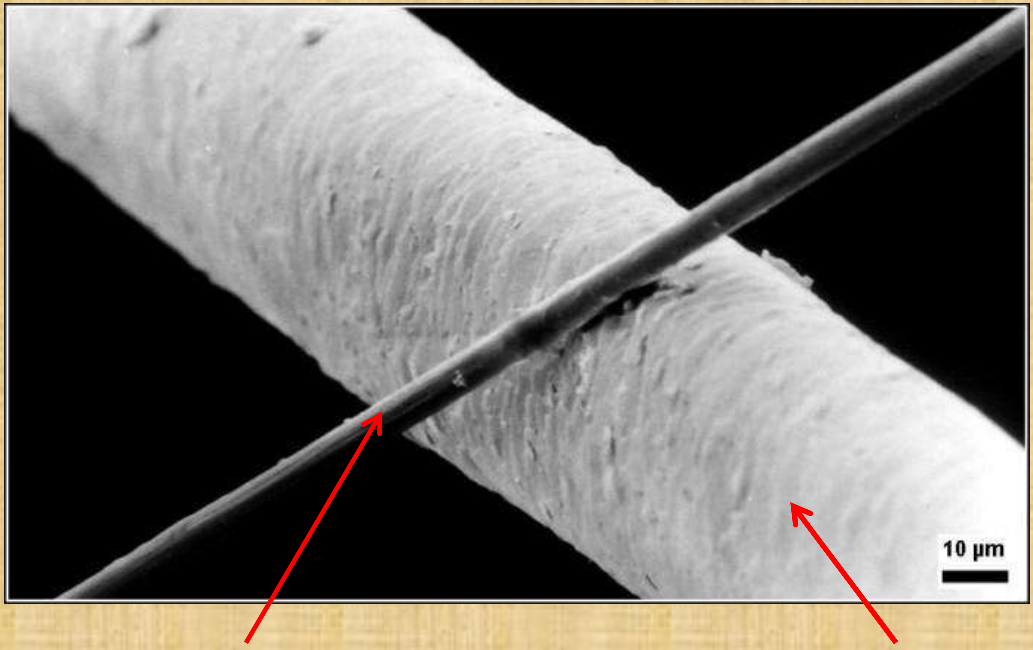


See material summary sheet!!

Carbon Fiber Reinforced Polymer

Τι ακριβώς είναι…???

Ένα υλικό που ψηφίστηκε από την National Academy of Engineering ως ένα από τα σημαντικότερα επιτεύγματα του 20ου αιώνα αλλά και ένα υλικό που μόλις τα τελευταία χρόνια άρχισε να χρησιμοποιείται ευρέως από την βιομηχανία αυτοκινήτου.



Μία ίνα άνθρακα σε σύγκριση με μία ανθρώπινη τρίχα

Τι είναι οι ίνες άνθρακα;

Είναι ένα συνθετικό υλικό. Με πολύ απλά λόγια, αυτό σημαίνει ότι είναι ένα υλικό που αποτελείται από δύο ή περισσότερα διακριτά μέρη, ούτως ώστε να έχει σημαντικά καλύτερα ποιοτικά χαρακτηριστικά από τα επιμέρους συστατικά του!

Οι ίνες άνθρακα ειδικότερα, κατασκευάζονται από πολυμερικές ίνες πολυακρυλονιτριλίου (PAN), ίνες τεχνητής μέταξας (rayon) ή πίσσα. Οι ίνες PAN, που σημειωτέον ότι είναι η πιο δημοφιλής πρώτη ύλη για ίνες άνθρακα αυτή τη στιγμή, κατασκευάζονται σε τρία στάδια, με διαδοχικές φάσης θερμικής και χημικής επεξεργασίας που ξεκινά από την οξείδωση τους σε χαμηλή θερμοκρασία (100-200^o C) και καταλήγει στην γραφιτίαση που συμβαίνει σε θερμοκρασίες που μπορεί να φτάσουν τους 2500-3000^o C.

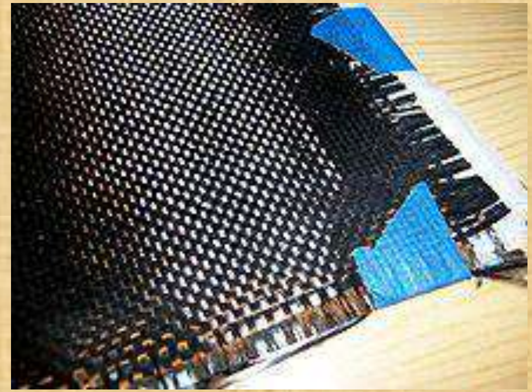
Αυτές συνδυάζονται στη συνέχεια με την εποξική ρητίνη για να δημιουργηθούν αυτό που ονομάζουμε απλοϊκά “ανθρακονήματα” – το συνθετικό υλικό.

Η ιστορία των ινών άνθρακα, ξεκινά από τα τέλη του 19ου αιώνα!Ο Thomas Edison ήταν αυτός που χρησιμοποίησε ίνες άνθρακα στους πρώτους λαμπτήρες πυράκτωσης όμως αυτές που χρησιμοποίησε ο Edison δεν έχουν καμία σχέση με τα ανθρακονήματα όπως τα γνωρίζουμε σήμερα.
Για να μπούμε στην σύγχρονη εποχή των ανθρακονημάτων, πρέπει να κάνουμε fast forward αρκετά χρόνια – συγκεκριμένα, μέχρι το 1958, όταν ο Roger Bacon παρουσίασε στον κόσμο τις πρώτες ίνες άνθρακα “υψηλών επιδόσεων”.
Αν θέλουμε να εστιάσουμε στα αυτοκίνητα, το “Gulf” Ford GT40 του 1968 που χρησιμοποίησε ίνες άνθρακα για να ενισχύσει ορισμένα μέρη του αμαξώματος.
Από εκεί και πέρα, η McLaren MP4/1 θεωρείται το πρώτο μονοθέσιο F1 με ανθρακονημάτινο monocoque ενώ η McLaren F1 ήταν το πρώτο αυτοκίνητο παραγωγής με ανθρακονημάτινο monocoque.


TopSpeed
Gulf
40
Gulf

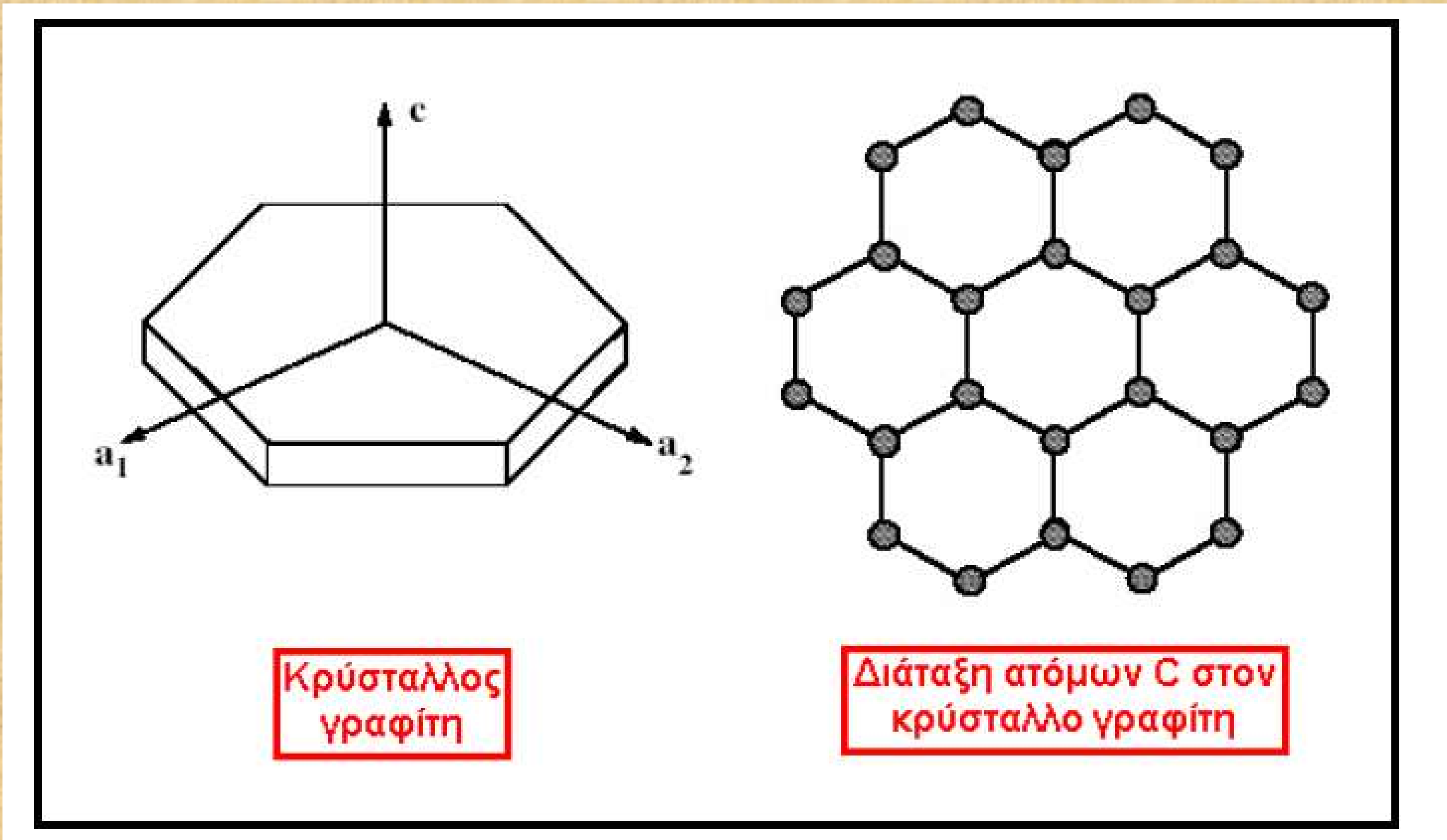
Οι ίνες γραφίτη είναι η επικρατέστερη ενίσχυση υψηλής αντοχής και υψηλού μέτρου ελαστικότητας, η οποία χρησιμοποιείται για την παρασκευή υψηλών επιδόσεων σύνθετων υλικών ρητινικής μήτρας. Γενικά, όταν απαιτείται ο βέλτιστος συνδυασμός μηχανικής συμπεριφοράς και ελάττωσης του βάρους, οι χρησιμοποιούμενες ίνες είναι, συνήθως, ίνες άνθρακα. Επίσης, οι ίνες άνθρακα προτιμούνται όταν η θερμική διαστολή ενός υλικού πρέπει να συγκρατηθεί σε χαμηλό επίπεδο ή όταν απαιτείται συμβατότητα των χαρακτηριστικών διαστολής δύο συνενωμένων διαφορετικών υλικών. Η υπεροχή αυτή των ανθρακονημάτων οφείλεται στη φύση του άνθρακα (ως στοιχείου) και τους ενδοατομικούς δεσμούς που σχηματίζει με άλλα άτομα άνθρακα. Ο γραφίτης αποτελείται από ανισότροπους πολυκρυσταλλίτες, των οποίων η ανισοτροπία εξαρτάται από τις συνθήκες παρασκευής τους.

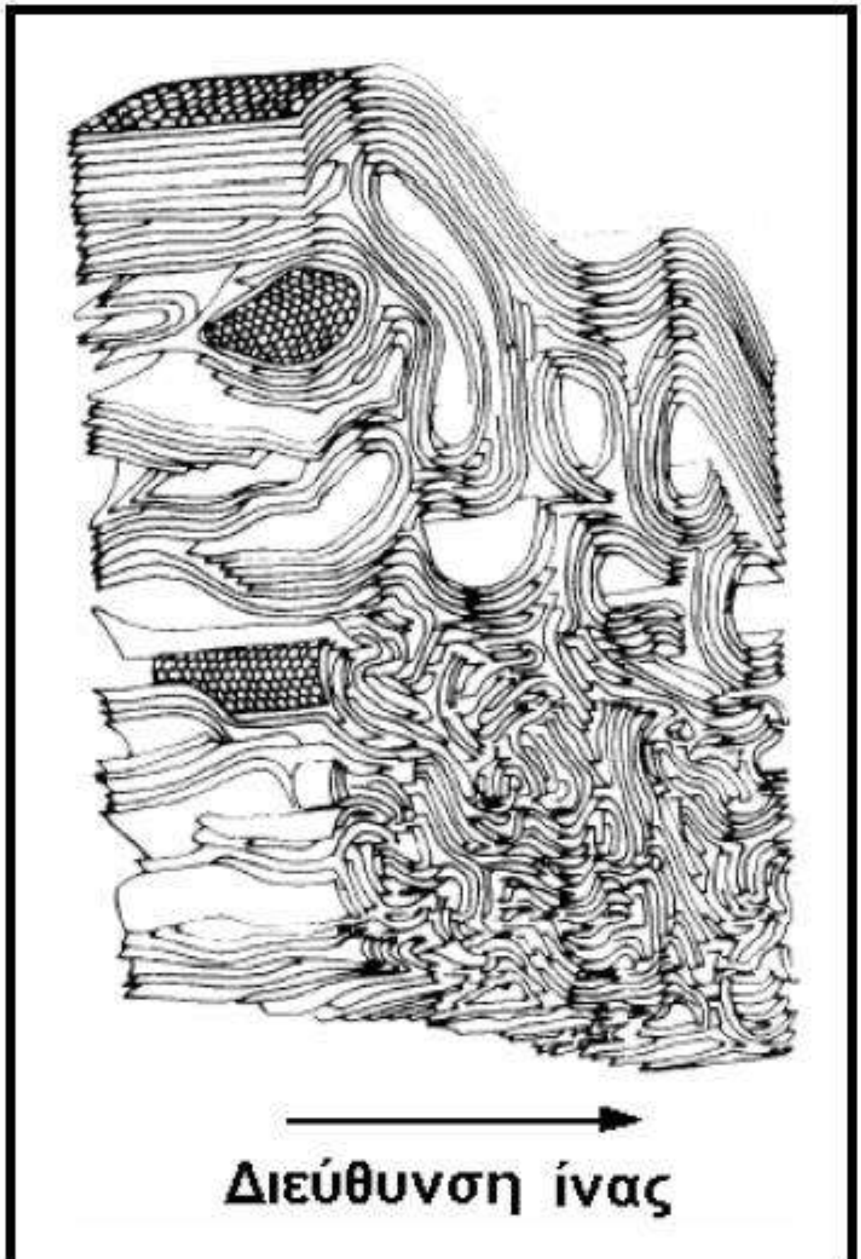
Αποτέλεσμα του ισχυρού προσανατολισμού των κρυσταλλιτών παράλληλα στο διαμήκη άξονα των ανθρακονημάτων είναι η υψηλή στιβαρότητα και αντοχή σε θραύση και ο χαμηλός συντελεστής θερμικής διαστολής κατά τη διεύθυνση αυτή. Στη γραφιτική δομή τα άτομα C διατάσσονται πολύ πυκνά με τη μορφή εξαγωνικών επιπέδων,

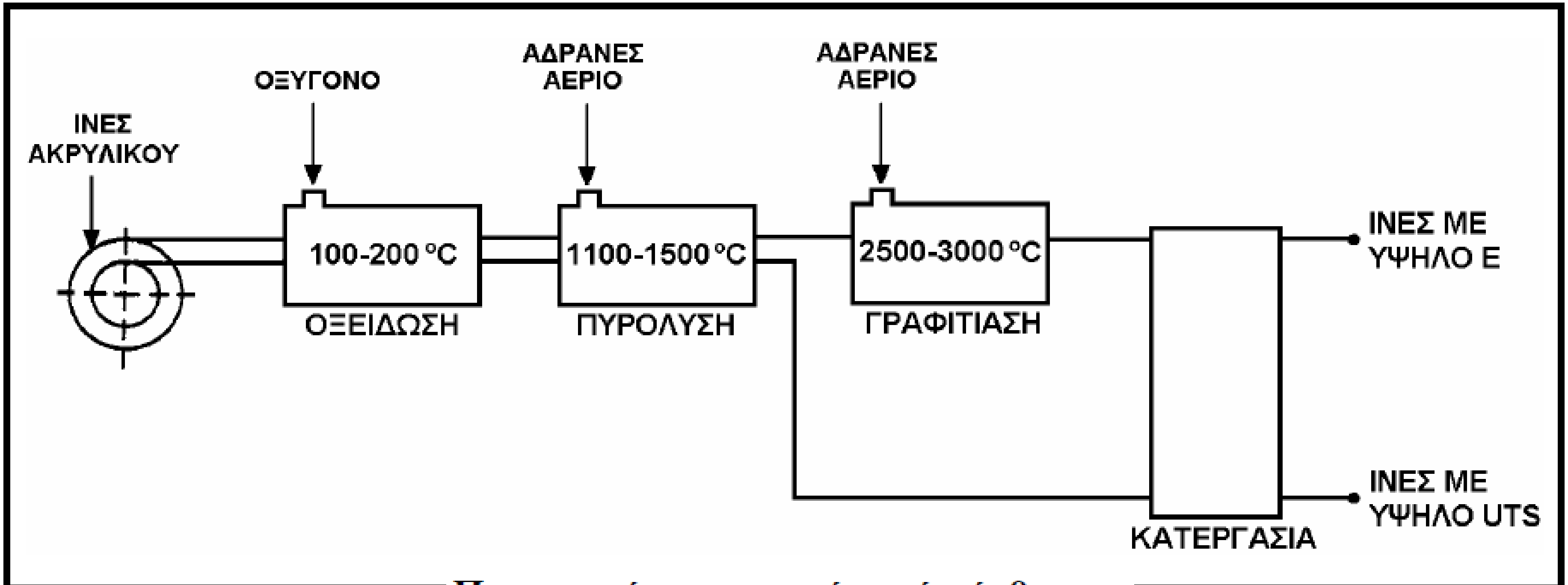


Ο ισχυρός δεσμός μεταξύ των ατόμων C στις επίπεδες αυτές εξαγωνικές στρώσεις οδηγεί σε εξαιρετικά υψηλό μέτρο ελαστικότητας. Αντίθετα, ο ασθενής τύπου Van der Waals δεσμός που υφίσταται μεταξύ γειτονικών στρώσεων, έχει ως αποτέλεσμα ένα χαμηλότερης τιμής μέτρο ελαστικότητας σε αυτή τη διεύθυνση.

Τυπική δομή ανθρακονήματος, όπως έχει ληφθεί από ηλεκτρονικό μικροσκόπιο




Διεύθυνση ίνας



Παραγωγή ενισχυτικών ινών άνθρακα

Οξείδωση των ινών PAN στον αέρα και σε χαμηλή θερμοκρασία (100-200 °C), με ταυτόχρονη εφαρμογή τάσης, η οποία είναι απαραίτητη για την ευθυγράμμιση των αλυσίδων του πολυμερούς.

Πυρόλυση, υπό τάση, σε ουδέτερη ή αναγωγική ατμόσφαιρα και σε θερμοκρασία 1100- 1500°C. Οι παραγόμενες ίνες στο στάδιο χαρακτηρίζονται ως *ίνες άνθρακα υψηλής αντοχής* (high strength carbon fibers) και η αντοχή τους φτάνει τα 3000 MPa.

Η θέρμανση σε ουδέτερη ή αναγωγική ατμόσφαιρα συνεχίζεται σε υψηλές θερμοκρασίες (2500-3000°C), οπότε πραγματοποιείται *γραφιτίαση*, με ταυτόχρονη ανακρυστάλλωση, που οδηγεί σε ισχυρό προσανατολισμό των κρυσταλλιτών. Οι παραγόμενες ίνες σε αυτό το στάδιο χαρακτηρίζονται ως *ίνες άνθρακα υψηλού μέτρου ελαστικότητας* (high module carbon fibers) και έχουν μέτρο ελαστικότητας περίπου 400 GPa, η δε διάμετρός τους είναι περίπου 10 μm.

ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ	ΙΝΕΣ ΥΨΗΛΗΣ ΑΝΤΟΧΗΣ	ΙΝΕΣ ΥΨΗΛΟΥ ΜΕΤΡΟΥ ΕΛΑΣΤΙΚΟΤΗΤΑΣ
Μέτρο Ελαστικότητας (GPa)	180-230	350-420
Αντοχή σε εφελκυσμό (MPa)	2500-3400	1900-2300
% περιεκτικότητα άνθρακα	95-98	99
Πυκνότητα (g/cm^3)	1,8	1,9
Μέγιστη θερμοκρασία χρήσης (^{o}C)	2000	2500

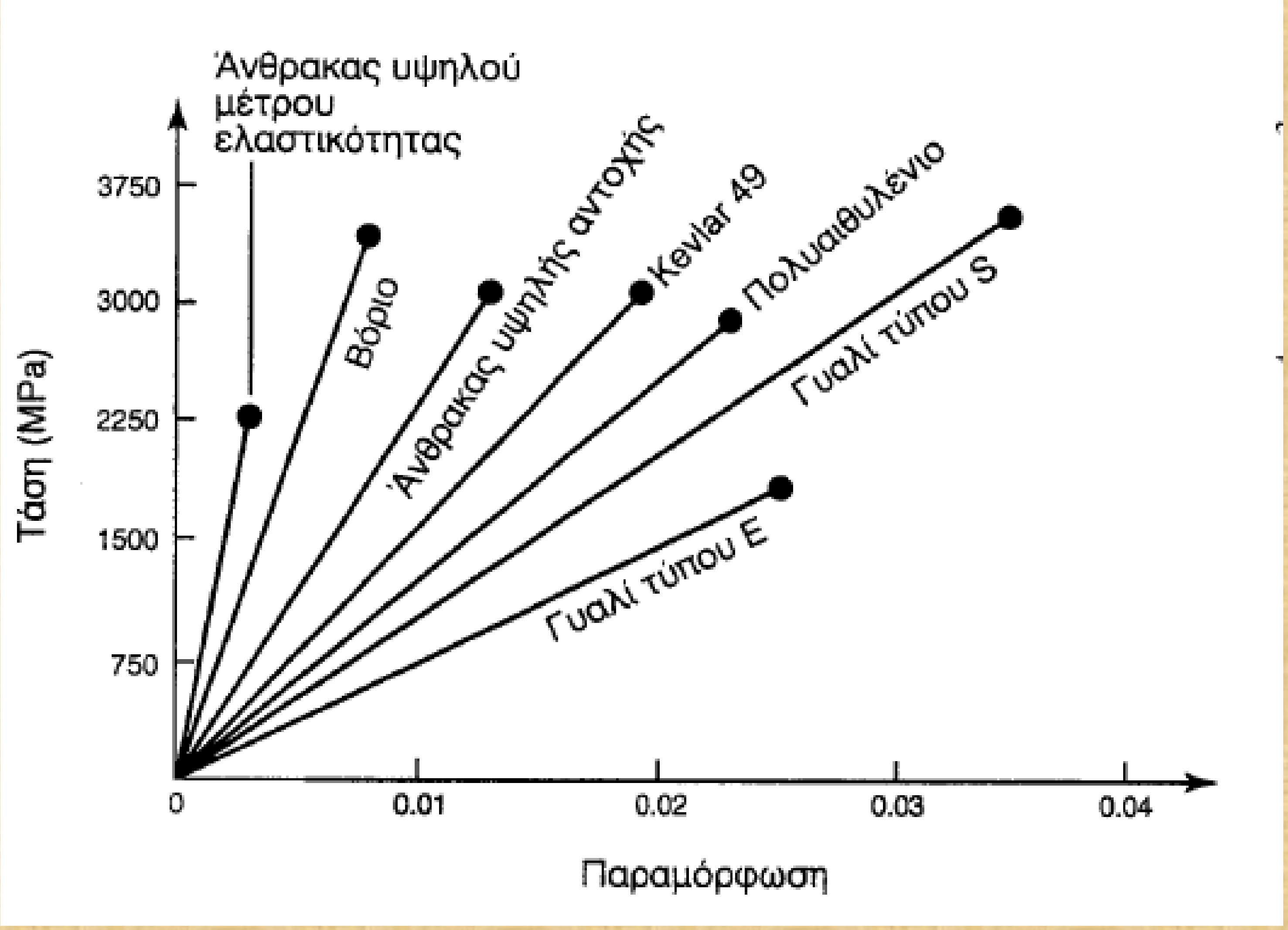
Χαρακτηριστικές ιδιότητες ινών άνθρακα.

Σε οξειδωτική ατμόσφαιρα, η μέγιστη θερμοκρασία χρήσης των ανθρακονημάτων περιορίζεται στους 500 °C και για τους δύο τύπους ινών. Κατά το σχεδιασμό του συνθέτου πρέπει οπωσδήποτε να λαμβάνεται υπόψη και η μέγιστη θερμοκρασία χρήσης της μήτρας.

Οι ιδιότητες των χρησιμοποιούμενων ανθρακονημάτων εξαρτώνται σημαντικά από την αρχιτεκτονική των ινών του PAN (μονοδιευθυντικές ίνες, δισδιάστατο πλέγμα, τρισδιάστατο πλέγμα). Ο τρόπος διευθέτησης των ινών αυτών καθορίζει και το βαθμό ανισοτροπίας των ανθρακονημάτων που προκύπτουν και μπορεί να ποικίλλει από την πλήρη ισοτροπία ως την πλήρη ανισοτροπία.

Η δυνατότητα επιλογής, από ένα μεγάλο εύρος τιμών της θερμοκρασίας κάθε σταδίου παραγωγής ανθρακονημάτων, δίνει την ευχέρεια παραγωγής ανθρακονημάτων διαφορετικού βαθμού γραφιτίασης και διαφορετικών ιδιοτήτων (οι μηχανικές και οι φυσικές ιδιότητες, όπως η θερμική και η ηλεκτρική αγωγιμότητα, εξαρτώνται από το βαθμό γραφιτίασης και το βαθμό ανισοτροπίας). Γενικά, όσο καλύτερα προσανατολισμένες είναι οι ίνες και όσο υψηλότερη περιεκτικότητα σε γραφίτη διαθέτουν τόσο καλύτερες μηχανικές ιδιότητες επιδεικνύουν.

Τέλος, το κόστος παραγωγής των ινών γραφίτη είναι δέκα φορές τουλάχιστον υψηλότερο από το κόστος παραγωγής των ινών γυαλιού.


Άνθρακας υψηλού μέτρου ελαστικότητας
Βόριο
Άνθρακας υψηλής αντοχής
Kevlar 49
Πολυαιθυλένιο
Γυαλί τύπου S
Γυαλί τύπου Ε
Τάση (MPa)
3750
3000
2250
1500
750
0
0.01
0.02
0.03
0.04
Παραμόρφωση

Ίνα	T_{max} (^oC)
Spectra	150
Kevlar	250
Glass	800
SiC	1000
Alumina	1370
Carbon	2000*

* Παρουσία οξυγόνου: T_{max}=500 ^oC

Σύγκριση θερμικής ευστάθειας ινών

Ίνα	Παραμόρφωση θραύσης (%)
Kevlar	3-4
Glass	2
Carbon	1
Ceramic	<1

Σύγκριση παραμόρφωσης θραύσης ινών

Η λέξη ανθρακόνημα θα μπορούσε να συγκριθεί με την λέξη κράμα όσον αφορά στην ασάφεια. Ναι, σου δίνει μία γενική ιδέα για το υλικό, αλλά δεν παρέχει επιπλέον πληροφορίες. Δεν σου λέει για παράδειγμα αν οι ίνες άνθρακα είναι 1Κ, 2Κ, 6Κ, 24Κ κ.ο.κ. (εννοώντας x χιλιάδες ίνες άνθρακα σε κάθε δεσμίδα).

Δύο σημαντικοί παράγοντες για παράδειγμα, είναι το μέτρο ελαστικότητας και η αντοχή εφελκυσμού. Η λέξη “ανθρακονήματα” δεν σου λέει αν το τελικό προϊόν σχηματίστηκε από ίνες Ultra-High Modulus (UHM) ή High Modulus ή αν θέλουμε να περιπλέξουμε τα πράγματα, HT (Low Modulus and High Tensile). Και ακόμα, είμαστε επί της ουσίας στην πρώτη ύλη…

Από εκεί και πέρα, αυτή ακριβώς η πρώτη ύλη θα “πλεχθεί” σε ύφασμα και η λέξη ανθρακονήματα δεν σου περιγράφει την πλέξη. Άλλες οι ιδιότητες της unidirectional πλέξης και άλλες της biredictional. Στην unidirectional, οι ίνες πλέκονται η μία παράλληλα με την άλλη με ορισμένες κάθετες στην πλέξη ίνες αποκλειστικά και μόνο για να ευθυγραμμίζονται οι κύριες ίνες. Αυτού του είδους η πλέξη προσφέρει κορυφαία αντοχή σε εφελκυσμό αλλά μόνο στην κατεύθυνση των ινών.

Από την άλλη, η bidirectional πλέξη, έχει τις ίνες κάθετες η μία στην άλλη ώστε η αντοχή σε εφελκυσμό να είναι *–περίπου–* η ίδια σε δύο άξονες. Ακόμα και αυτή όμως, έχει υποκατηγορίες. Μπορεί η πλέξη να είναι 2/2 Twill ή απλή… ανάλογα με την χρήση του εξαρτήματος που θα κατασκευαστεί από ανθρακονήματα, χρησιμοποιείται “διαφορετικό” υλικό. Πολλές φορές όμως, τοποθετούνται πολλαπλά στρώματα unidirectional ή/και birectional υφασμάτων σε ενδιάμεσες γωνίες για να πετύχουμε την καλύτερη δυνατή κάλυψη.

Και ακόμα δεν έχουμε πιάσει το έτερον ήμισυ των CFRP… την ρητίνη! Γιατί αν το τελικό προϊόν που ονομάζουμε ανθρακονήματα είναι το μπετόν αρμέ, τότε οι ίνες άνθρακα είναι ο οπλισμός και η ρητίνη το σκυρόδεμα! Είναι αυτή που θα “δέσει” το ύφασμα στο επιθυμητό σχήμα και θα δώσει το τελικό αποτέλεσμα. Δύο είναι οι ρητίνες που χρησιμοποιούνται ευρέως στην κατασκευή ανθρακονημάτων και όπως φαντάζεσαι, κάθε μία επηρεάζει σημαντικά την ποιότητα του CFRP.

Ceramic Structural Composites
The Most Advanced Structural Material

Carbon/Carbon Composites

- ***In widespread structural use***
- ***Manufacturing and design methods understood***
- ***Expensive…***

Η πρώτη κατηγορία, είναι αυτή των πολυεστερικών ρητίνων. Φθηνότερες και πιο εύχρηστες και γι’ αυτό κάποιοι τις προτιμούν. **Όμως** οι πολυεστερικές ρητίνες είναι λιγότερο εύκαμπτες όταν στερεοποιηθούν. Απαιτείται μεγαλύτερη ποσότητα ρητίνης, κάτι που οδηγεί σε βαρύτερο τελικό προϊόν. Σε βάθος χρόνου, η ρητίνη θα συρρικνωθεί – *έστω και ελάχιστα*– και θα αλλάξει το σχήμα του προϊόντος και τέλος, δεν η συγκεκριμένη κατηγορία δεν παρέχει κανενός είδους προστασία από τις υπεριώδεις ακτινοβολίες

Από την άλλη, υπάρχουν οι εποξικές ρητίνες… ή όπως ισχυρίζονται πολλοί, η μοναδική **σωστή** κατηγορία. Οι εποξικές ρητίνες είναι πολύ πιο εύκαμπτες, δεν συρρικνώνονται, προσφέρουν τελικό προϊόν με σαφώς καλύτερη εμφάνιση και προστατεύουν το τελικό προϊόν από τις υπεριώδεις ακτινοβολίες. Σε γενικές γραμμές και χωρίς να μπαίνουμε σε λεπτομέρειες, οι εποξικές ρητίνες είναι αντικειμενικά και τεκμηριωμένα καλύτερες από τις πολυεστερικές με τις τελευταίες να χρησιμοποιούνται κατά κανόνα σε υποδεέστερα ή/και φθηνότερα προϊόντα.

ΜΗΤΡΑ	ΙΝΕΣ	ΕΦΑΡΜΟΓΕΣ
Εποξειδική	Kevlar	Αεροναυπηγική και ναυπηγική βιομηχανία. Βιομηχανία αθλητικών ειδών (ρακέτες τέννις, μπαστούνια golf, είδη τοξοβολίας, καλάμια ψαρέματος)
Πολυεστερική	Γραφίτη	Αεροναυπηγική και αυτοκινητο - βιομηχανία. Μέρη αεροσκαφών, πλοιαρίων και αυτοκινήτων, μικρού βάρους και υψηλής αντοχής σε διάβρωση.
Πολυμερική	Γυαλιού	Αθλητικός εξοπλισμός

Χαρακτηριστικά παραδείγματα συνθέτων υλικών οργανικής μήτρας

ΜΗΤΡΑ	ΙΝΕΣ	ΕΦΑΡΜΟΓΕΣ
Al	Borsic	Πτερύγια στροβιλοκινητήρων αεροσκαφών.
	Al_2O_3	Έμβολα μηχανών Diesel.
	SiC	Πτερύγια εκτόξευσης βλημάτων.
	Γραφίτη	Ιστοί κεραίων τηλεσκοπίου Hubble.
Κραμάτων Cu	SiC	Υψηλής αντοχής προπέλες σκαφών.
Κράματα Ti και W	SiC & B_4N	Πτερύγια και δίσκοι στροβίλων.

Χαρακτηριστικά παραδείγματα συνθέτων υλικών μεταλλικής μήτρας

ΜΗΤΡΑ	ΙΝΕΣ	ΕΦΑΡΜΟΓΕΣ
Άνθρακα	Άνθρακα	Μέρη αεροσκαφών και διαστημοπλοίων υψηλών προδιαγραφών (επιτρεπτή η λειτουργία ως τους 3000 °C). Δισκόφρενα σε αγωνιστικά αυτοκίνητα
Al_2O_3, SiC, ZrO_2, Si_3N_4 και κεραμικά γυαλιά	Al_2O_3 & SiC	Αγωγοί εναλλακτών θερμότητας, συστήματα θερμομόνωσης.

Χαρακτηριστικά παραδείγματα συνθέτων υλικών κεραμικής μήτρας

Carbon Fiber Reinforced Composites

TREK Madone 5.9

Carbon Fiber Composite

Glass Fiber Reinforced Composites

Ferrari 308 GT4

Glass Fiber Composite

Ανθρακονήματα Carbon Modern Marvels

https://www.youtube.com/watch?v=4xcWI7UabVc&index=1&list=PLC46D9799690F98BA

FIRP™ System

Damaged spire of the Merseburg cathedral (D) due to high wind loads and weathering. Cantilever joint afte strengthening with CRPF's

Strengthening of Glulam Beams with Carbon FRP in Coolidge High School Gymnasium

https://www.youtube.com/watch?v=gnaw-PqOoxw

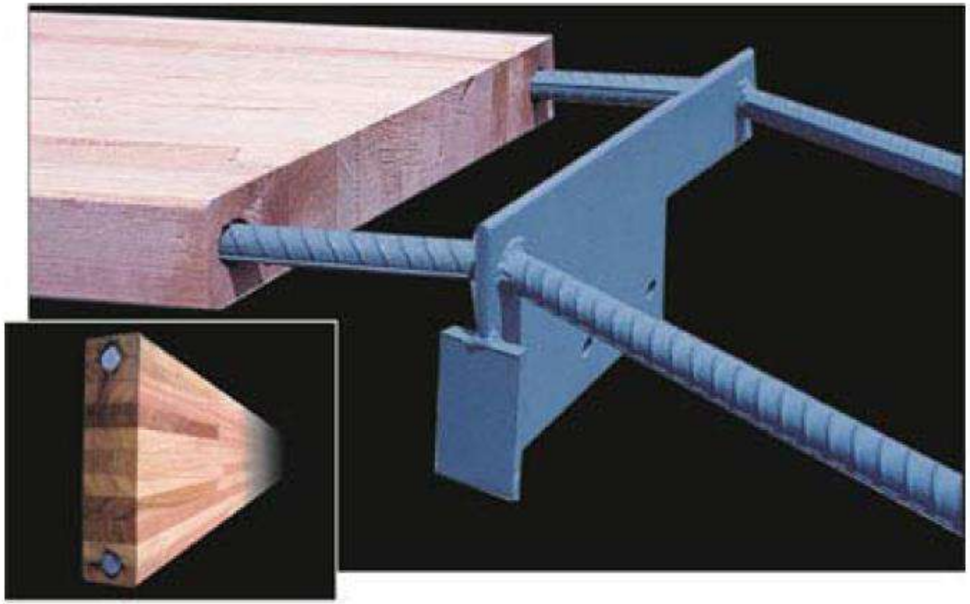
Reinforcement with CFRP of floor beams on the tensile side.

Economic considerations

1. Does the effectiveness of the strengthened system compensate for the increase in costs resulting from the additional workmanship, use of complex adhesives and the still quite high (though decreasing) cost of the aforementioned reinforcement materials?
2. Whilst the use of reinforcement may dramatically improve the performance of a concrete structure, much more moderate results are to be expected with timber, because this material can withstand both tensile and compressive stresses quite well. If, for instance, a perfectly composite behaviour of a CFRP-reinforced timber beam is assumed and the cross-section is homogenized, one may easily conclude that a 1 mm-thick CFRP-laminate is roughly equivalent to an extra 20mm timber lamella. Does it make economic sense to use reinforcement?
3. In most practical cases, the control of the serviceability limit state, in particular with regard to deflections and vibrations, is the most important factor governing the required size of the timber beam. An analysis suggests that the use of reinforcement may not always be very helpful in this case. While the ratio between the design strengths of many engineered reinforcement materials, particularly CFRP and timber may be as high as 100, the ratio of their modulus of elasticity is only of about 20.

4. Ultimate limit state calculations of reinforced elements show that the stress in the reinforcement material is well below the strength. Timber tensile failure occurs at strains of about 0.2 – 0.3%, which is well below the yield strain of many steel types or the service strain of most plastic fibres (> 0.5%), which means that we cannot make full use of the potentially high strength of the reinforcement materials.

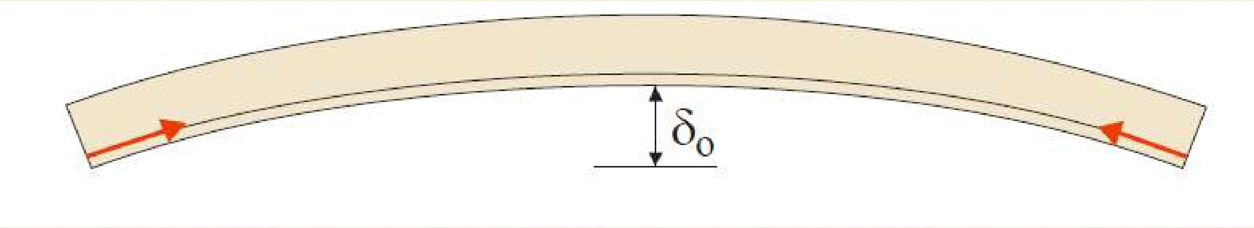
5. Given the high cost of the new plastic reinforcement materials, the economy of such strengthening of timber does not seem to justify the use in new structures. Many European authors such as Schober and Rautenstrauch suggest that the only really feasible market for strengthening and upgrading existing structures.



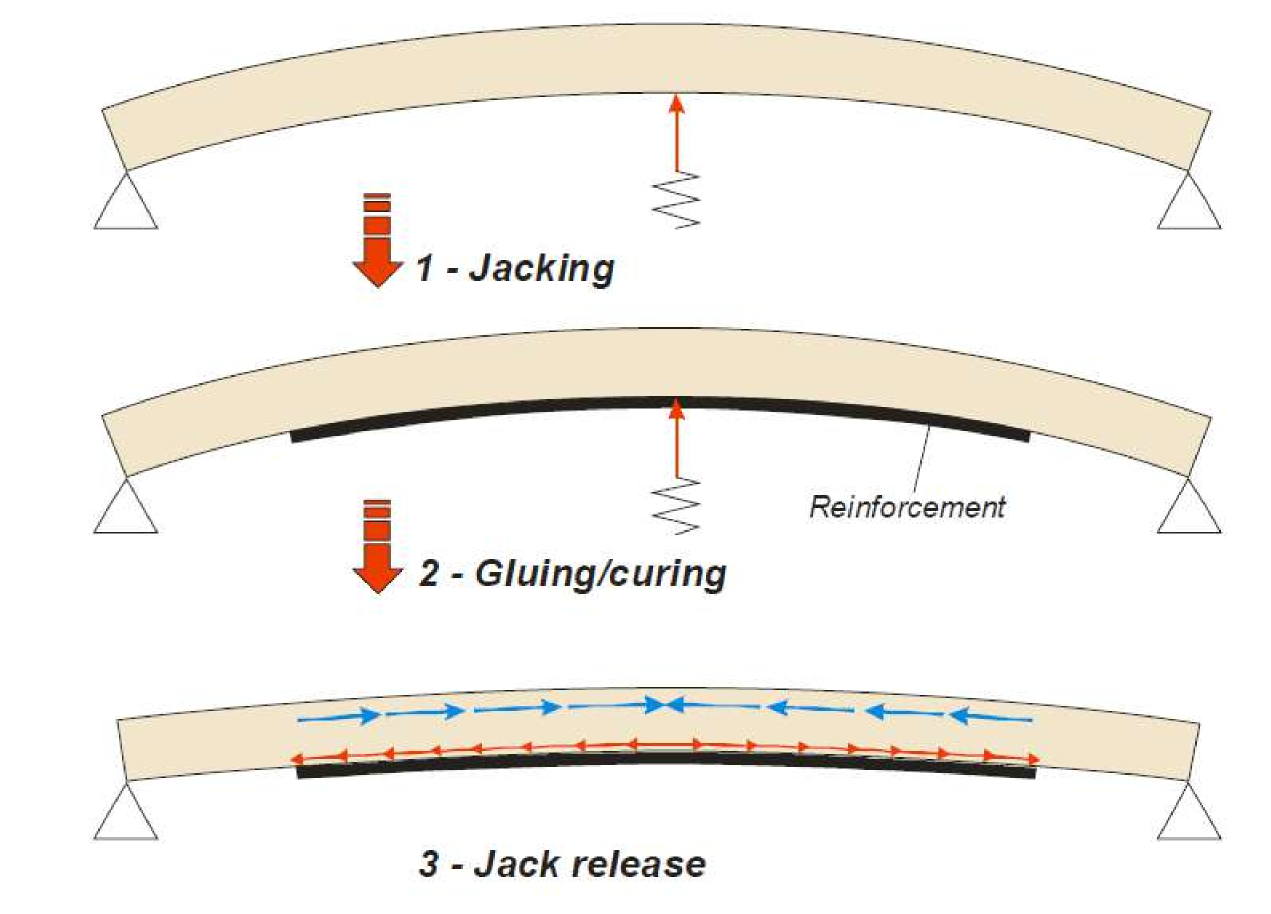
Steel reinforcement systems (left systems Tasbeam™, right: Aralam™)

Shear reinforcement in cracked, old growth timber beams with ASSY VG full thread wood screws

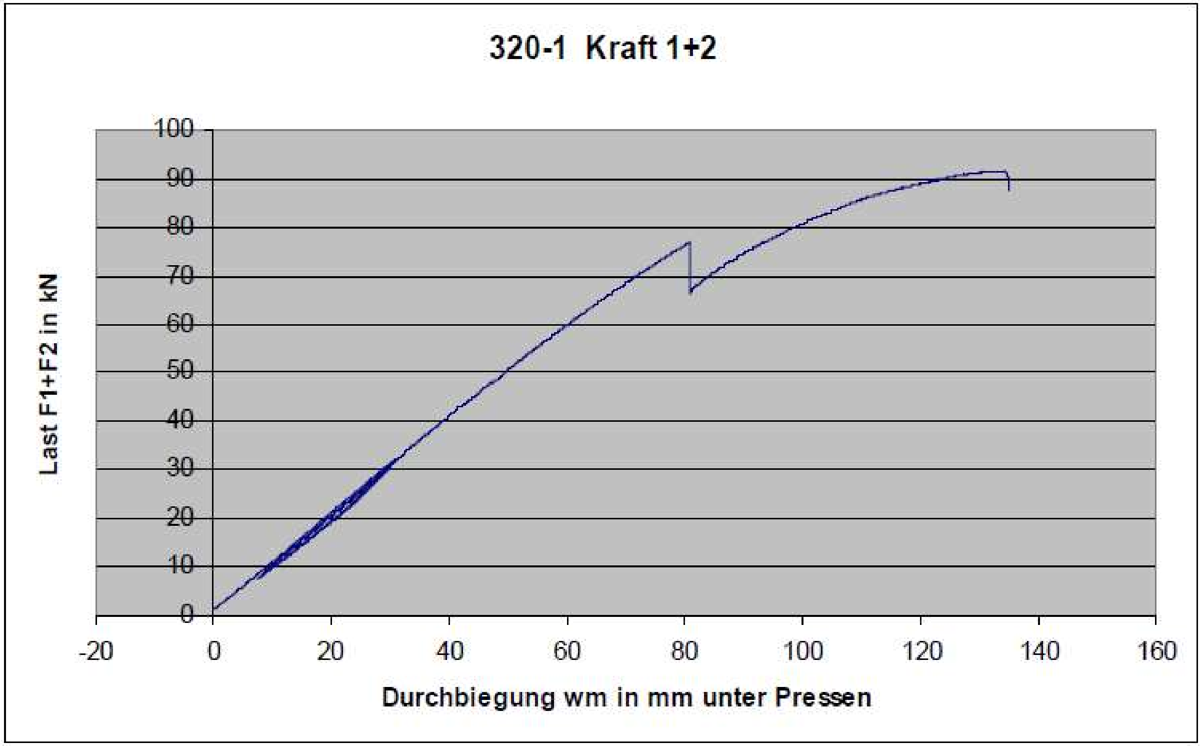
https://www.youtube.com/watch?v=AdTYA9FiXQU



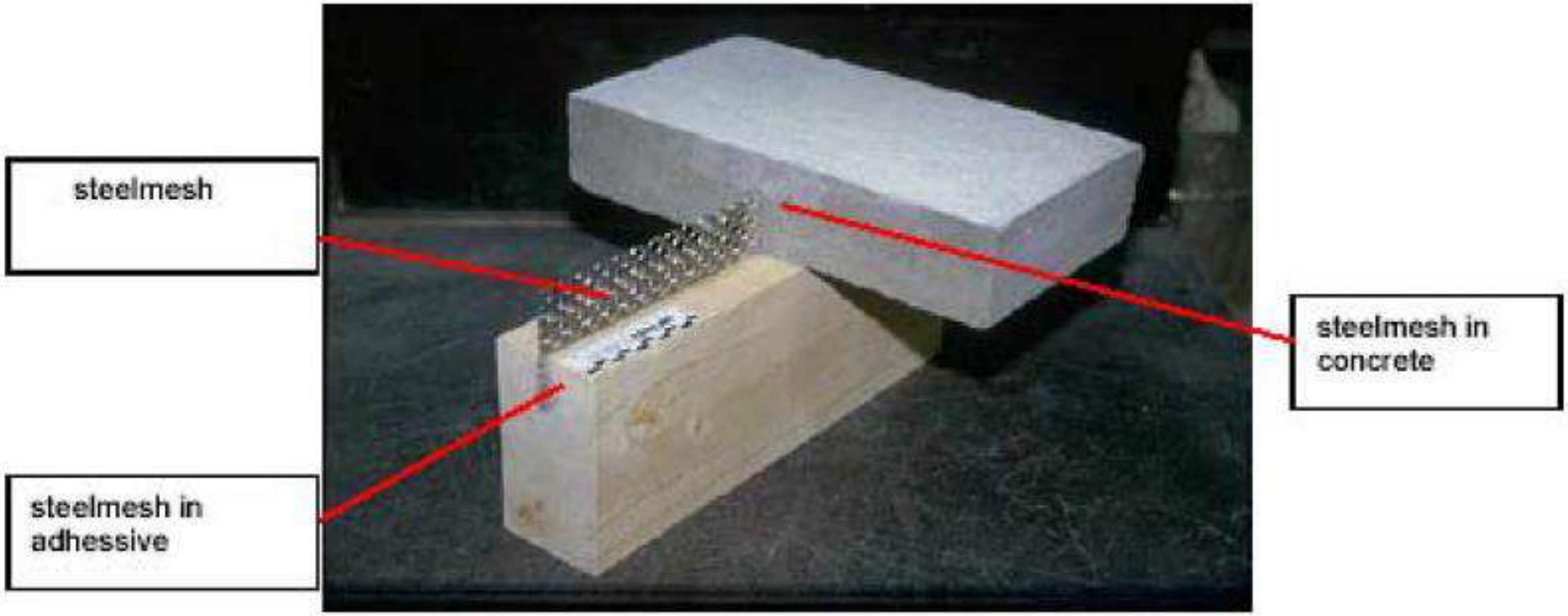
Pre-stressing-induced camber



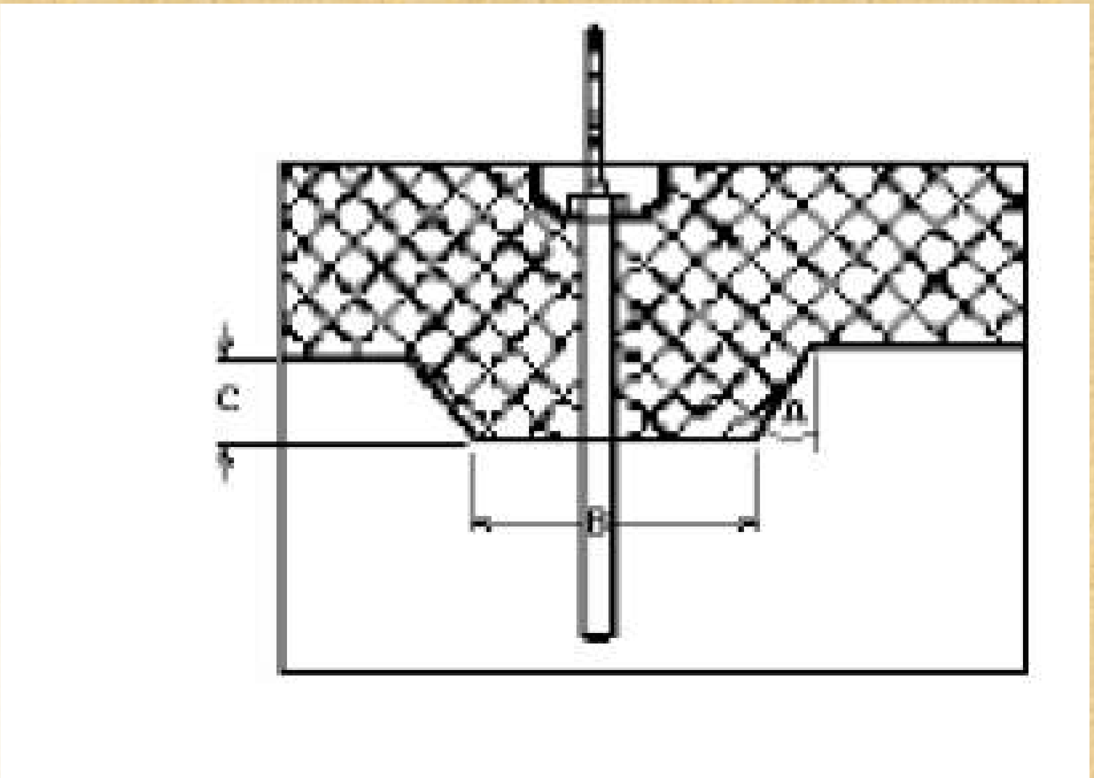
Pre-stressing by cambering



Typical load-deflection behaviour of the glulam beams pre-stressed with multi-CFRP [7]

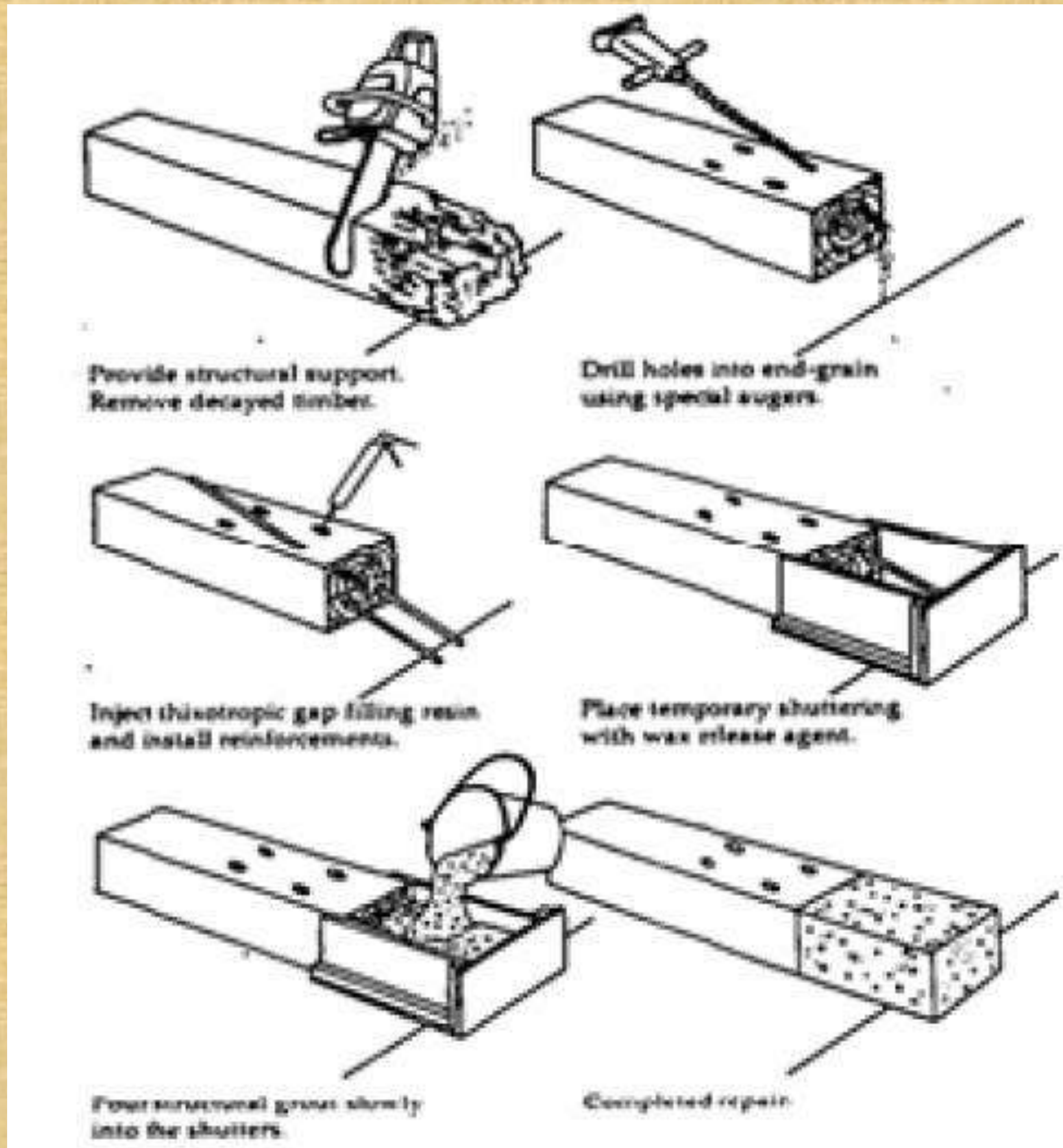


Continuous mesh shear-connector

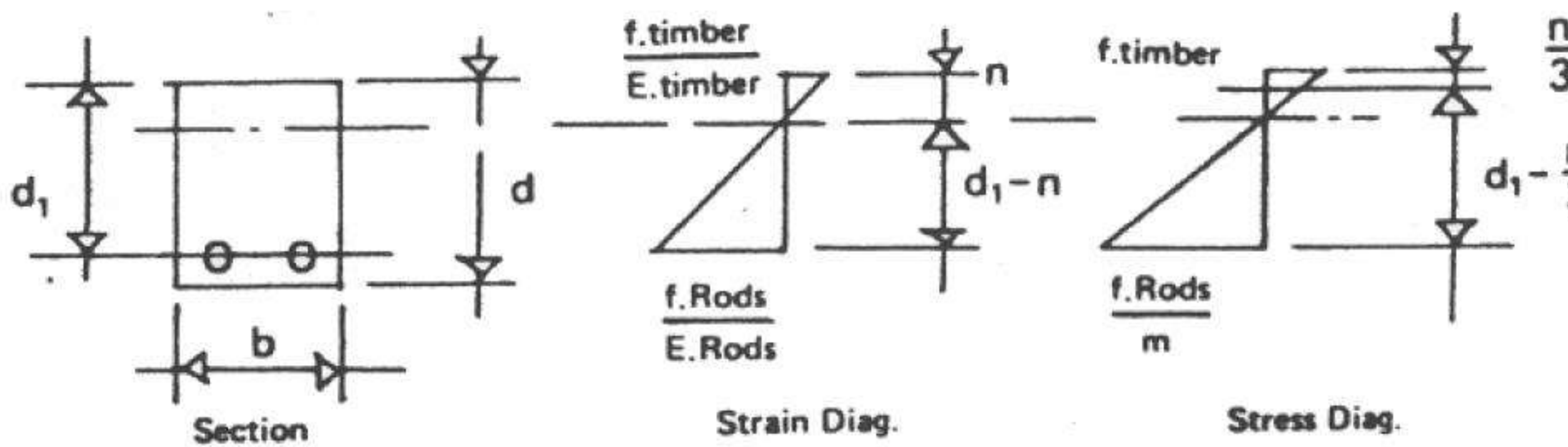


Notch and shear key connection

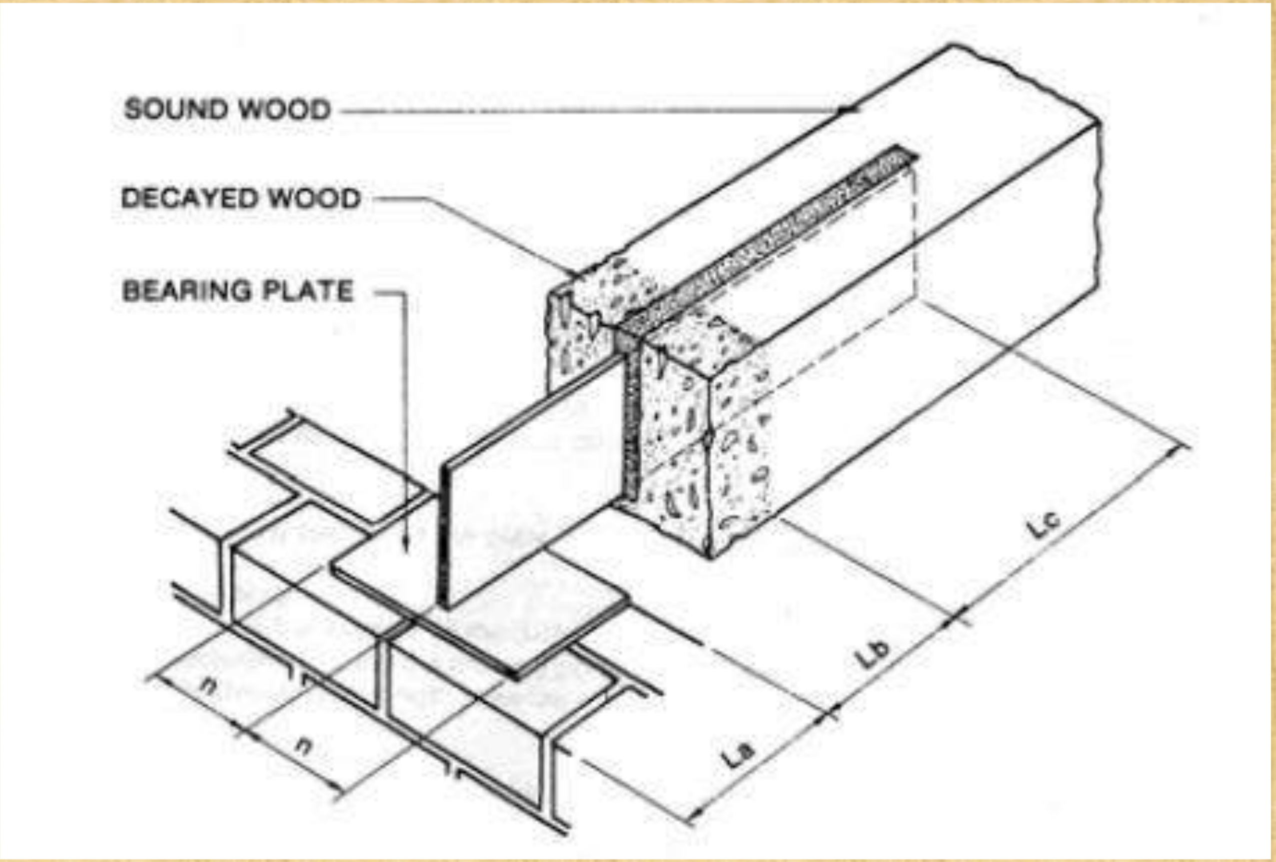
Shear connector

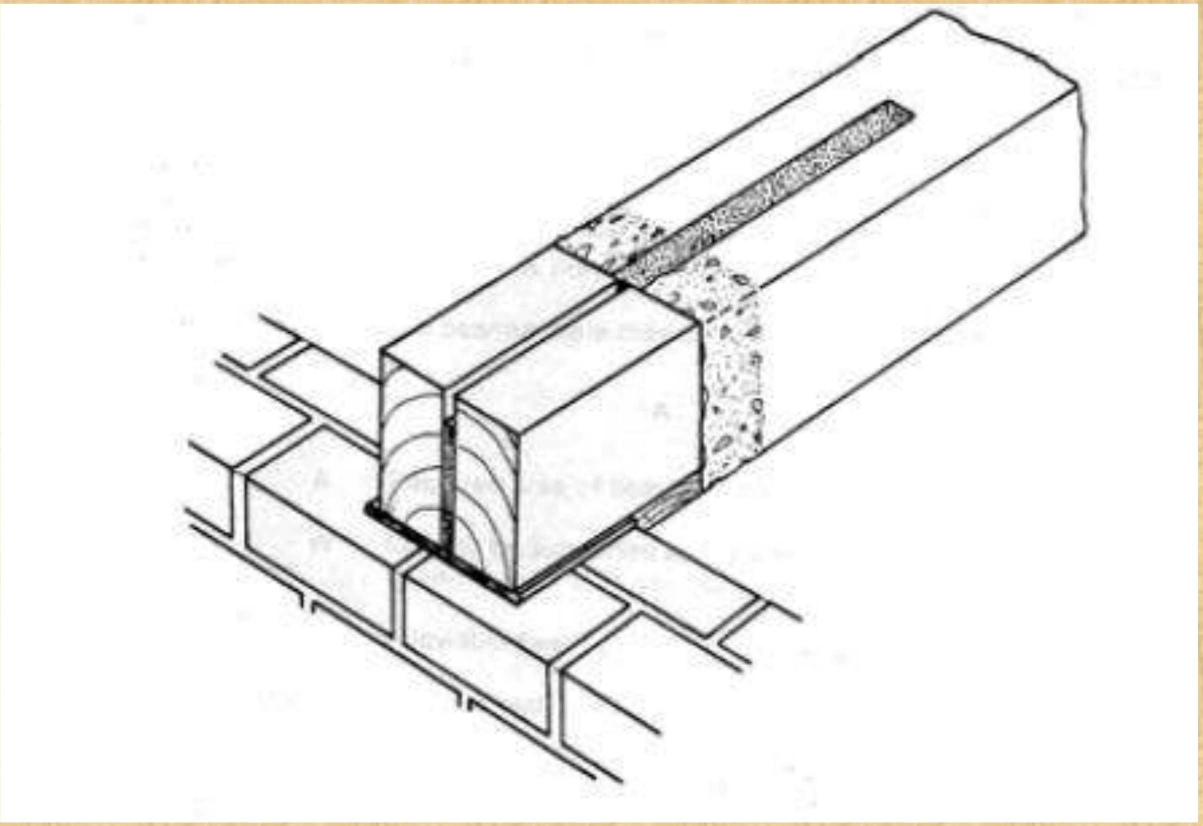


Schematic steps of Beta-System technique



Design method used for the Beta-System


SOUND WOOD
DECAYED WOOD
BEARING PLATE
n
n
La
Lb
Lc



Decayed end reinforcement (W.E.R.-System)

Inclined cut of decayed end

Shaping of integration element

Linking grooves between integration and original timber

Partially filling of the grooves with adhesive

Insertion of a final wood wedge

Repaired beam

Shear reinforcement with GFRP