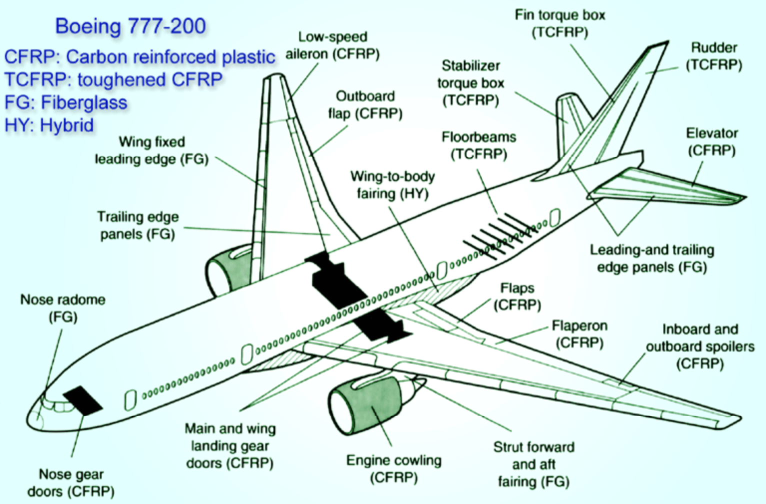
Chapter 17

Composite Materials

How to fabricate optimum/complex materials from single materials

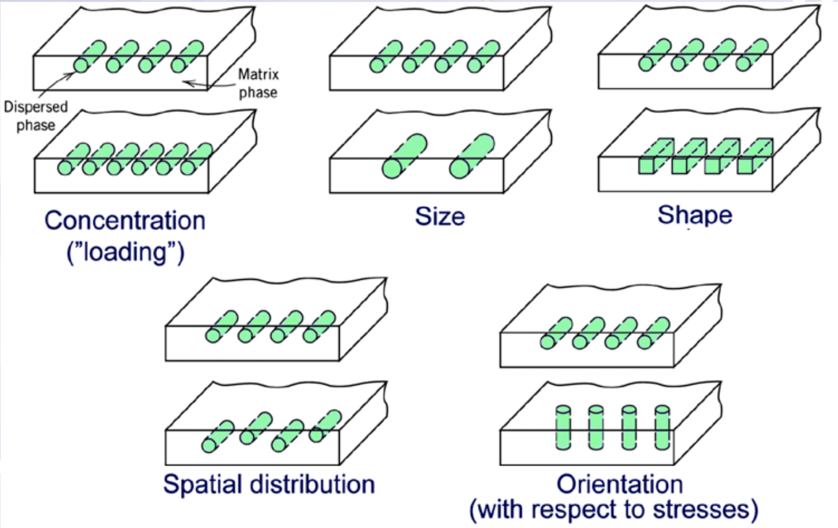


Components of a Composite Material

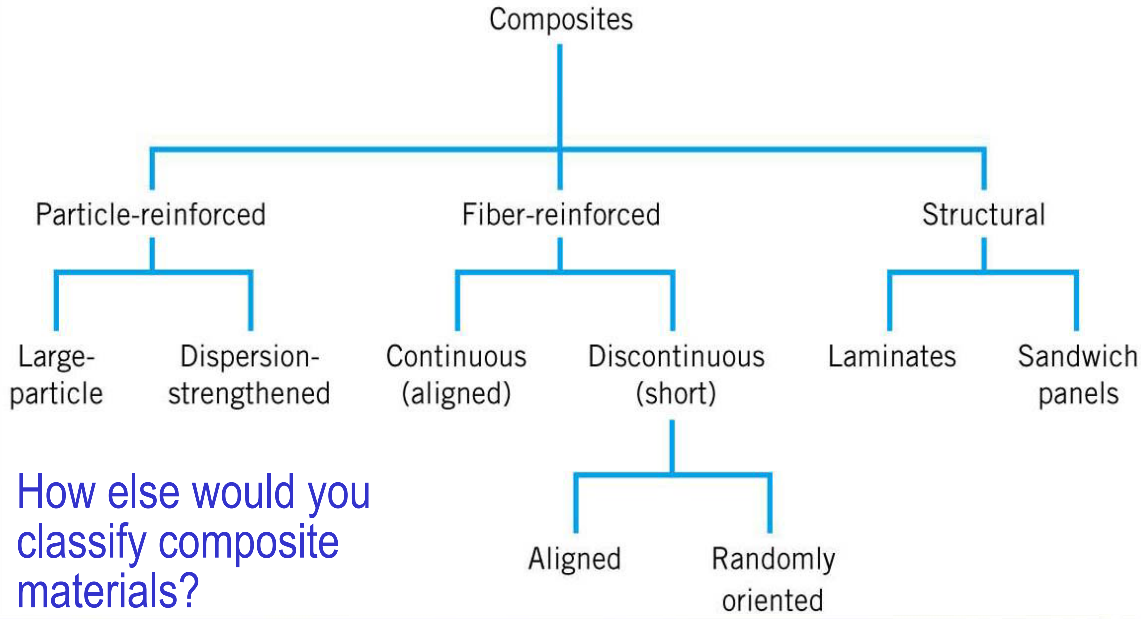
- Matrix: this is what holds the reinforcements together.
- Reinforcements or dispersed phase.

From the interaction between both matrix and reinforcements we get the final properties of the composite. So the designer has a not-so-trivial job!

Reinforcers geometry regulates the behavior of the composite



This is brief (and incomplete) classification of composite materials based upon the reinforcements.



How else would you classify composite materials?

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1. Particle-reinforced composites

- Large particle composites
- Dispersion-strengthened composites

Examples of large particle composites:
-Polymers with *fillers*
-Concrete (cement + sand/gravel)

To achieve optimum isotropic behavior:
-uniform distribution of reinforcers
-equiaxed distribution of reinforcers

The effect of the particle volume fraction on some mechanical properties can be derived.

For instance, the resulting E of the composite can be roughly calculated by the rule of mixtures:

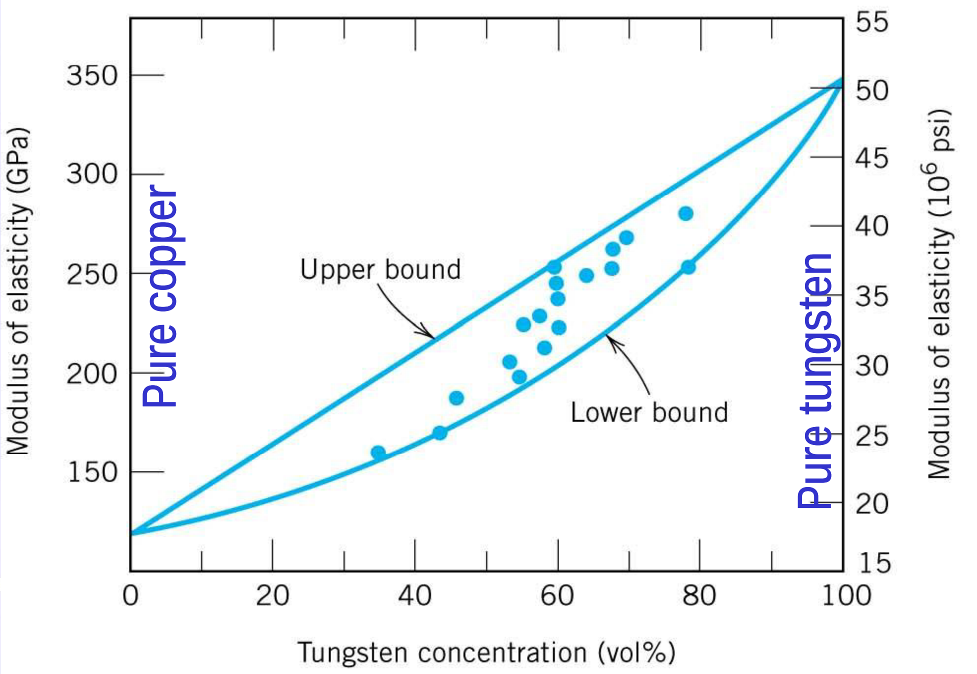
$$E_{\mathrm{composite}} = E_{\mathrm{matrix}} V_{\mathrm{matrix}} + E_{\mathrm{reinforcer}} V_{\mathrm{reinforcer}}$$

Upper limit

$$E_{\mathrm{composite}} = \frac{E_{\mathrm{matrix}} \cdot E_{\mathrm{reinforcer}}}{E_{\mathrm{matrix}} \cdot V_{\mathrm{matrix}} + E_{\mathrm{reinforcer}} \cdot V_{\mathrm{reinforcer}}}$$

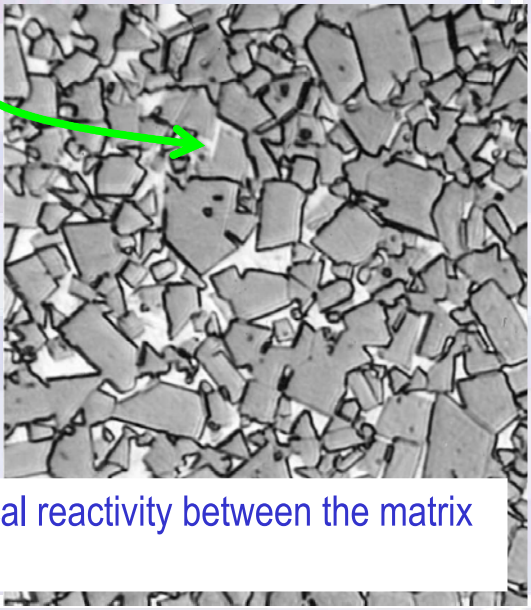
Lower limit

The rule of mixture is not perfect to describe a composite mechanical behavior of these particulate-reinforced composites. Why?



This photomicrograph of a cobalt/tungsten carbide composite is an example of a particle-reinforced composite

WC is a cubic carbide extremely hard commonly used for machine tools due to its high abrasion resistance.



Cobalt (the matrix) has a high corrosion resistance.

So what would you expect from this composite?

Any thoughts about any potential chemical reactivity between the matrix and the reinforcers?

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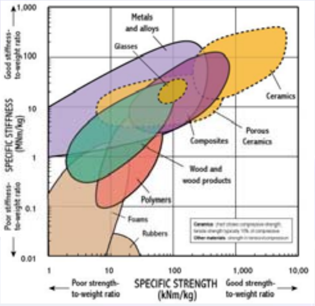
2. Fiber-Reinforced Composites

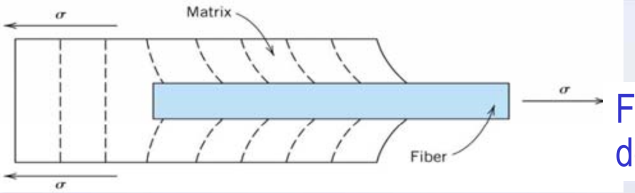
In general, they are more effective than particle-reinforced composites in the load-transfer and load-alignment characteristics.

New mechanical properties:

$$\text{Specific strength} = \frac{\text{UTS}}{\gamma}$$

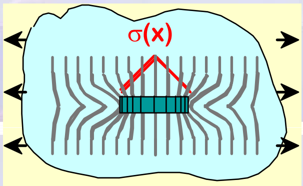
$$\text{Specific modulus} = \frac{E}{\gamma}$$

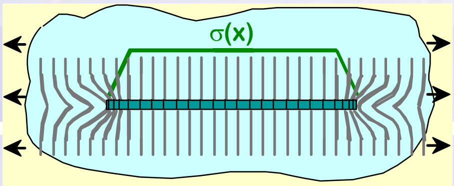




Fiber pull-out and matrix deformation pattern

Short fibers are not efficient to transfer (distribute stresses):





Fiber-reinforced composites (cont.)

There is a *critical length* at which the load is triangular:

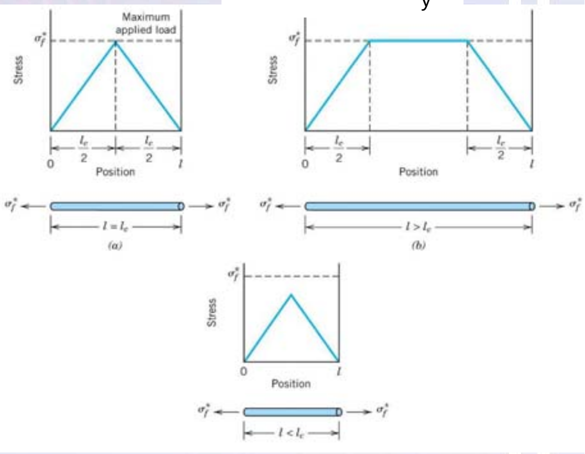
$$\ell_{\text{critical}} = \frac{\text{UTS} \cdot d}{2 \cdot \tau_y}$$

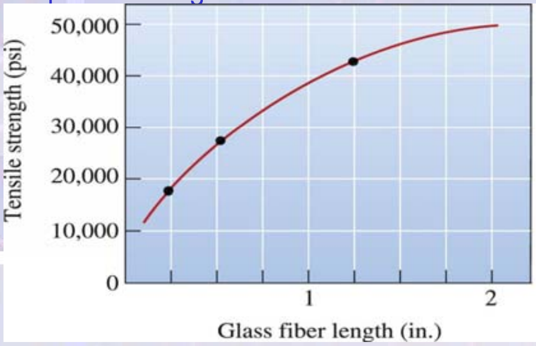
The critical length depends on the shear strength of the bond (or of the fiber): the stronger the better.

When $\ell_{critical} << \ell$ we have a short-fiber or discontinuous fiber-reinforced composite.

Practically optimal fiber lengths are usually about 30 times $\ell_{critical}$.

So the longer the fiber, the higher the composite strength

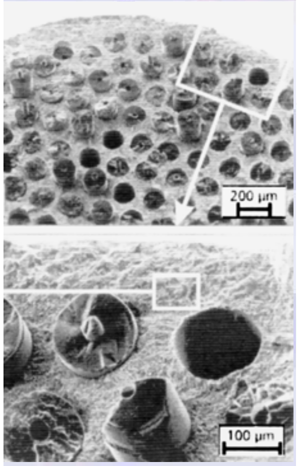




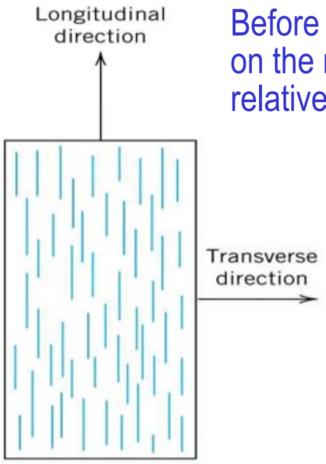
Epoxy + 50% glass fiber

Fiber orientation and concentration influence the composite general strength and anisotropic behavior.

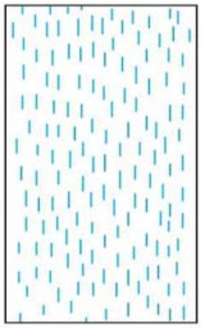
Before analyzing the effect of the reinforcements on the mechanical behavior we must know the relative properties between matrix and fiber



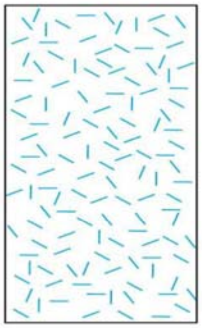
Fractured SiC fiber-reinforced titanium alloy



Aligned and continuous

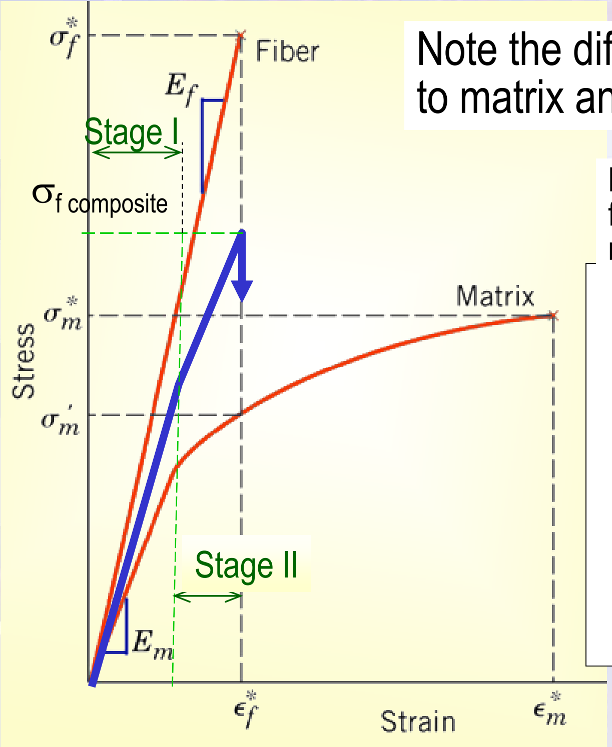


Aligned and discontinuous



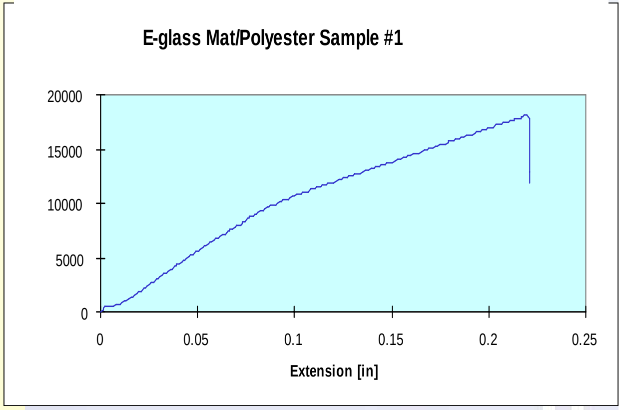
Random discontinuous

Remember the tensile behavior of ceramics, metals and polymers.



Note the different stages and how they relate to matrix and fiber behavior

Real load vs. displacement data for a glass-fiber-reinforced composite with polymeric matrix



FRC Elastic Longitudinal Behavior

- Compatibility condition: $\varepsilon_{matrix} = \varepsilon_{fiber} = \varepsilon_{composite}$
- In the longitudinal direction the elastic modulus is:

$$E_{composite\ long} = E_{matrix} \cdot (1 - V_{fiber}) + E_{fiber} \cdot V_{fiber}$$

$$\frac{F_{fiber}}{F_{matrix}} = \frac{E_{fiber} \cdot V_{fiber}}{E_{matrix} \cdot V_{matrix}}$$

The load transfer between fibers and matrix can also be modeled

Please solve Example Problem 17.5

FRC Elastic Transversal Behavior

- Compatibility condition: $\sigma_{matrix} = \sigma_{fiber} = \sigma_{composite}$ also

$\varepsilon_{composite} = \varepsilon_{matrix} V_{matrix} + \varepsilon_{fiber} V_{fiber}$

- In the transverse direction the elastic modulus is:

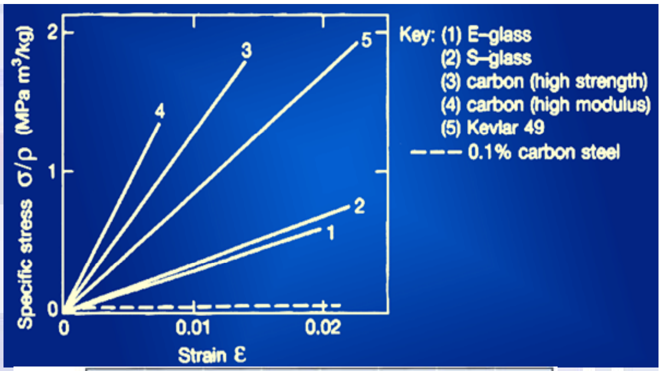
$$\frac{1}{E_{comp\ trans}} = \frac{V_{matrix}}{E_{matrix}} + \frac{V_{fiber}}{E_{fiber}}$$

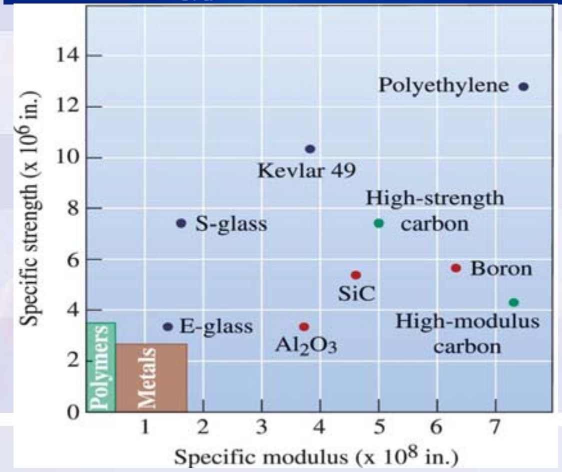
$$E_{comp\ trans} = \frac{E_{fiber} \cdot E_{matrix}}{(1 - V_{fiber}) \cdot E_{fiber} + V_{fiber} \cdot E_{matrix}}$$

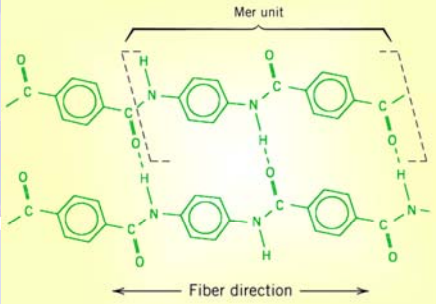
Please solve Example Problem 17.6

FRC Components

- Matrix (metal, polymer, ceramic)
  - binds fibers together
  - transfers load to fibers
  - protect fibers from environment
  - prevents crack propagation
  - $E_{matrix} < E_{fiber}$
- Fibers:
  - for polymer PMC: glass (E-glass), carbon, aramid
  - for metal MMC: carbon, alumina, boron, SiC
  - for ceramic: other ceramics





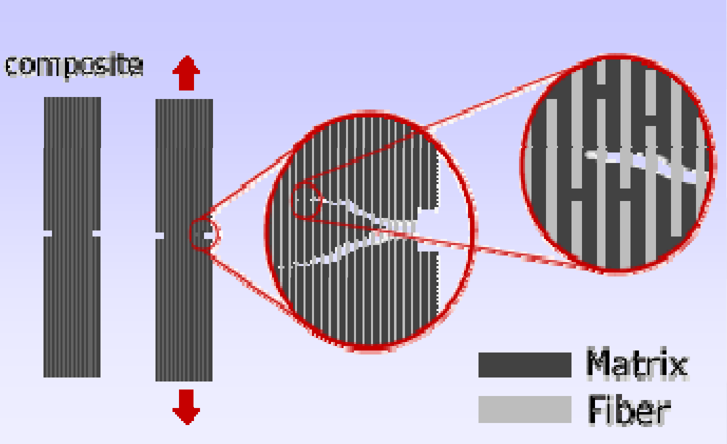


How a smartly designed composite can lower a crack propagation rate

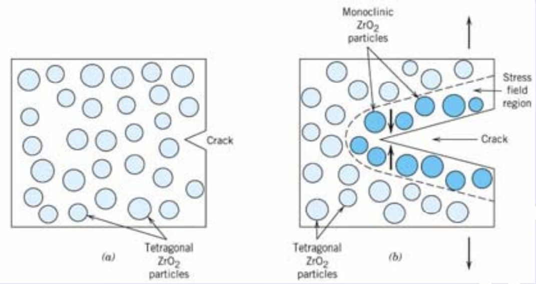
When applying force to a composite material, the brittle matrix cracks at low stress levels but the fibers take over

Cracks reveal the reinforcing fibers that bridge the matrix

The fibers are then called bridging fibers and the stresses they carry are, accordingly, called bridging stresses



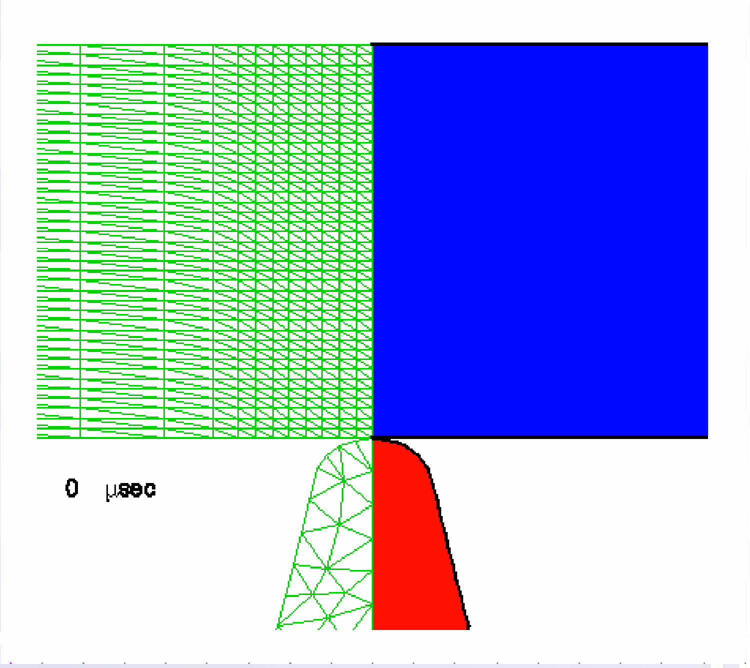
One application of CMC: Remember that partially stabilized zirconia has a high K_{IC} ?



This is a simulation of ballistic impact on a composite

The composite contains glass fibers and is laminated in layers of a polymer (the matrix).

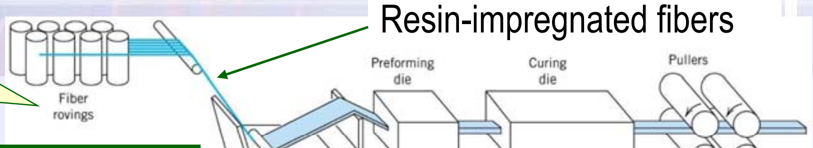
Notice where the failure occurs during the impact

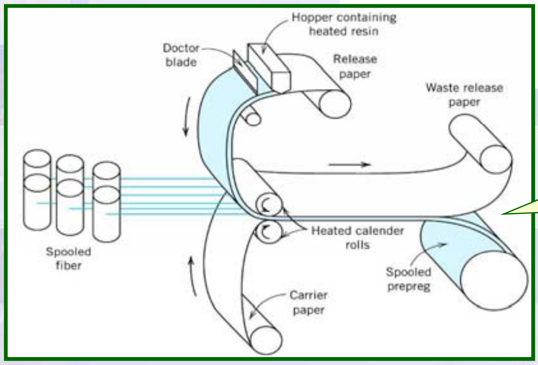


There are numerous composite fabrication processes

Pultrusion for PMC for rods, beams etc.

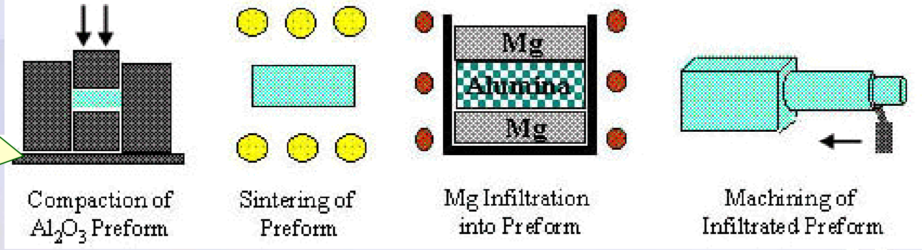
Resin-impregnated fibers



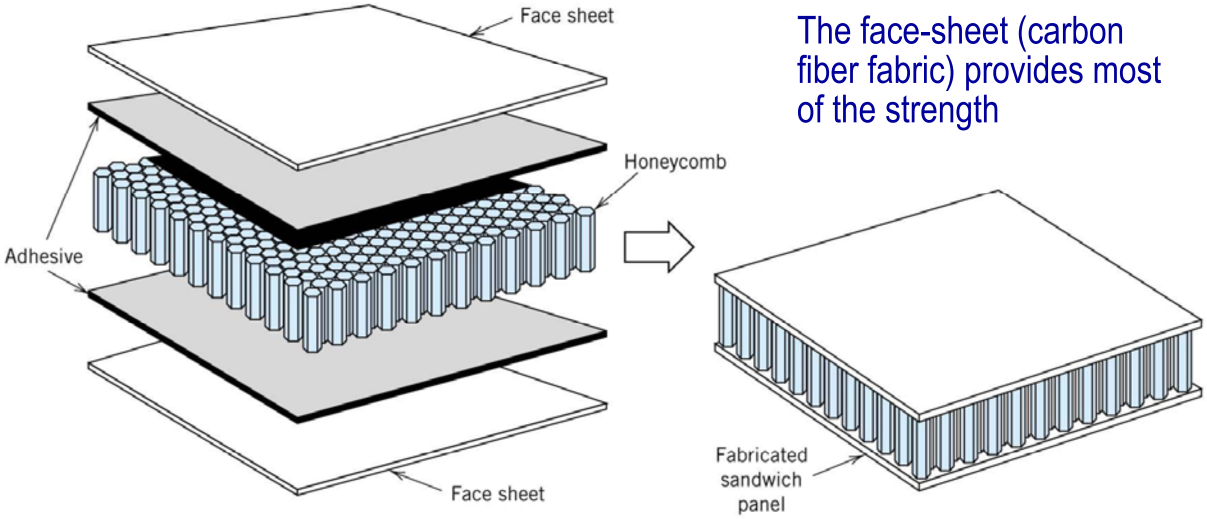


Prepreg for PMC for sheets uses partially cured resins

Pressure infiltration for MMCs with ceramic preform



Sandwich panels using honeycomb cores are common in structures requiring stiffness, thermal insulation and vibration damping capacities, e. g. aircrafts.



The face-sheet (carbon fiber fabric) provides most of the strength

So what is the effect of the honeycomb in the “flexural rigidity” of the panel?