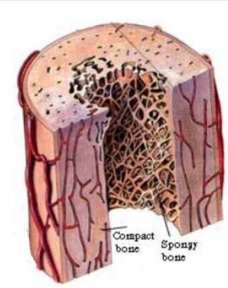
Composites I

Composites

- Composite materials have been used throughout history
  - ancient building materials
  - straw/mud huts still used today
- The human body relies on a natural composite
  - bone
  - hard brittle hydroxyapatite and soft protein collagen
- Wood is also a natural composite
  - strong and flexible cellulose fibres are surrounded by lignin matrix
- The use of modern composites allows us to
  - produce materials with unusual combinations of properties
  - that cannot be met by conventional materials

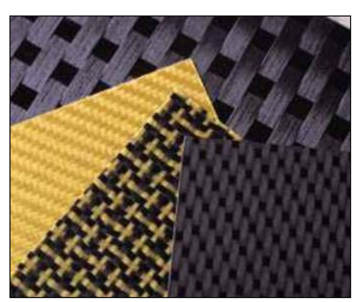


Composites

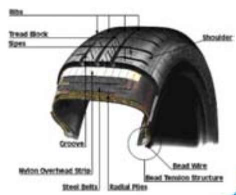
- Composite materials have been especially useful in aerospace, underwater and transport applications
- This is because composite structural materials have
  - low densities
  - high stiffness
  - can be abrasion and impact resistant
  - and are not easily corroded
- What is a composite?
  - In general it is a structural material made of two or more different materials

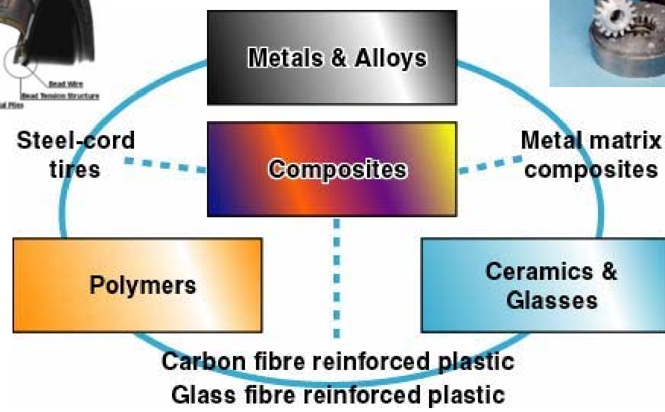
Composites

- Many composite materials are composed of just two phases
  - one termed the **matrix**
  - the other the **dispersed** or **reinforcing** phase
- The properties of the composite are a function of
  - the properties of the constituents
  - their relative amounts
  - and geometry of the reinforcing phase



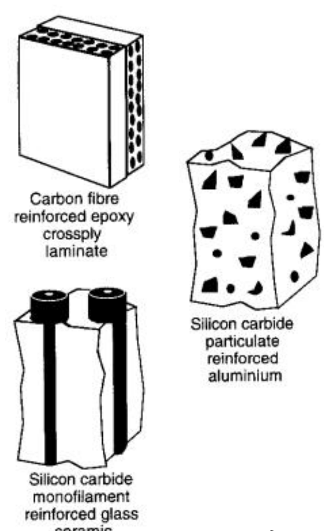
Classification





The Structure of Composites

- Consist of two distinct phases
  - matrix and a reinforcing phase
- Matrices can be
  - metals (Al, Ti)
  - ceramics (Al_2O_3, ZrO_2)
  - polymers (epoxy, polyester, phenolic)
- Reinforcing phases can have different shapes
  - fibres, whiskers, particulates
- Technologically, fibre composites most important
  - glass, carbon, Spectra (PE), Kevlar (aramid)



Fibre composites

- Usually combinations of ceramic, polymer or glass fibres in a polymer matrix
- Typically 40-60 % fibre by volume
- Utilize the very good properties of the fibres
- Fibre composites have a good combination of stiffness, density and fracture toughness
- However they are often expensive
- They may be difficult to process
- Often difficult to detect damage (cracks)

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Properties of Fibres

- High strength of materials can be achieved due to low probability of flaws in individual fibres
- Polymers may be oriented into fibres (Spectra or Kevlar) to utilize the strong C – C bonds of polymer backbone
- For carbon fibres, graphite plate structure can be oriented to take advantage of strong bonding

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Table 17.4 Characteristics of Several Fiber-Reinforcement Materials

Material	*Specific Gravity*	*Tensile Strength [GPa (10^6 psi)]*	*Specific Strength (GPa)*	*Modulus of Elasticity [GPa (10^6 psi)]*	*Specific Modulus (GPa)*
		Fibers			
Aluminum oxide	3.95	1.38 (0.2)	0.35	379 (55)	96
Aramid (Kevlar 49)	1.44	3.6–4.1 (0.525–0.600)	2.5–2.85	131 (19)	91
Carbon[a]	1.78–2.15	1.5–4.8 (0.22–0.70)	0.70–2.70	228–724 (32–100)	106–407
E-Glass	2.58	3.45 (0.5)	1.34	72.5 (10.5)	28.1
Boron	2.57	3.6 (0.52)	1.40	400 (60)	156
Silicon carbide	3.0	3.9 (0.57)	1.30	400 (60)	133
UHMWPE (Spectra 900)	0.97	2.6 (0.38)	2.68	117 (17)	121

Properties of Matrix

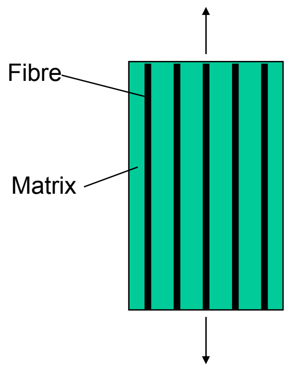
- The matrix binds the fibres together and protects them from external damage
- It transmits external loads to the fibres
  - the matrix itself usually carries only a small fraction of the load
- It separates the fibres and stops cracks from propagating directly from fibre to fibre
- It supports the fibres laterally under compression loading
- It is usually has a low density to produce a composite with a low density
- It is advantageous if the matrix has some ductility
  - reinforcing phase often very stiff

Deformation of Aligned Long Fibre Composites

- Long fibre composite materials are highly anisotropic
- Let's look at two extreme cases

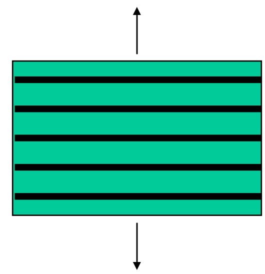
Isostrain

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$



Isostress

$$\sigma_c = \sigma_m = \sigma_f$$



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Isostrain Analysis

- Isostrain represents the best possible properties: our composite structure has been optimised for loading direction (Upper Bound)
- Assume that under load:

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

- Total load = load carried by fibres + load carried by the matrix

$$F_c = F_f + F_m$$

$$\sigma_c A_c = \sigma_f A_f + \sigma_m A_m$$

- Therefore

$$\sigma_c = \sigma_f A_f / A_c + \sigma_m A_m / A_c$$

- Since the length of the fibres = length of matrix = length of composite

$$\sigma_c = \sigma_f V_f + \sigma_m V_m$$

- Remembering that

$$E_c \varepsilon = \sigma_c$$
$$E_f \varepsilon = \sigma_f$$
$$E_m \varepsilon = \sigma_m$$

- We can rearrange to find the modulus of elasticity

$$E_c = E_f V_f + E_m V_m$$

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Isostrain Analysis

- Let's now consider the fraction of the load carried by the fibres

$$\frac{F_f}{F_m} = \frac{\sigma_f A_f}{\sigma_m A_m} = \frac{\sigma_f V_f}{\sigma_m V_m} = \frac{\varepsilon_f E_f V_f}{\varepsilon_m E_m V_m}$$

- Therefore

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

- Thus the load carried by the fibre is

$$\frac{F_f}{F_c} = \frac{\varepsilon_f E_f V_f}{\varepsilon_f E_f V_f + \varepsilon_m E_m V_m}$$

$$\frac{F_f}{F_c} = \frac{E_f/E_m}{E_f/E_m + V_m/V_f}$$

- Notice that the ratio of the loads depends on E_f/E_m
- Therefore a high modulus fibre is best.
- However, a high modulus fibre normally has a lower strain to failure, so there is a tradeoff

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Isostress Analysis

- This is the lower bound, the worst case for long fibre aligned composites
- Assume that under load:

$$\sigma_c = \sigma_m = \sigma_f$$

- Strain in the composite is given by

$$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$$

- Therefore

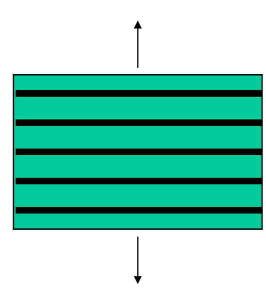
$$\frac{\sigma}{E_c} = \frac{\sigma}{E_m} V_m + \frac{\sigma}{E_f} V_f$$

- Dividing by σ

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

- or

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



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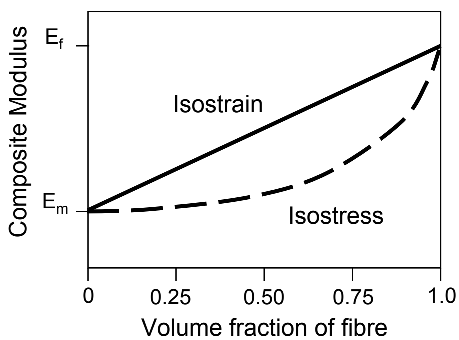
Example

- Data:
  - Carbon fibre
  - Epoxy matrix
  - $V_f = 0.5$
  - $E_f = 400$ GPa,
  - $E_m = 4$ GPa



- For Isostrain (loaded parallel to the fibres)

$$E_c = E_f V_f + E_m V_m$$
$$E_c = 400 \times 0.5 + 4 \times 0.5$$
$$E_c = 202 \text{ GPa}$$

- For Isostress (loaded perpendicular to the fibres)

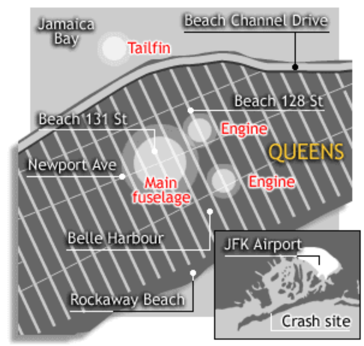
$$E_c = \frac{E_m E_f}{E_m V_f + E_f V_m}$$
$$E_c = \frac{400 \text{ x } 4}{4 \text{ x } 0.5 + 400 \text{ x } 0.5}$$
$$E_c = 7.9 \text{ GPa}$$

Why Use Composite Parts?

- Weight Savings
  - They weigh 20 percent to 25 percent less than aluminum parts of the same shape. Less weight, less fuel needed.
- Thermal Expansion
  - Composite parts do not expand or contract as much with temperature changes (e.g. aircrafts sits on runways in the tropics and then climbs into the freezing stratosphere).
- Corrosion Resistance
  - Composite parts do not corrode due to moisture in the air, like some metals.
- Fatigue Resistance
  - They are less likely to suffer fatigue problems than metals

AmericanAirlines
Flight 587

- American Airlines Flight 587 crashed on November 12th 2001 near Kennedy Intl. Airport, NY
- The airliner crashed into a neighborhood in Belle Harbor, New York.
- The engines and some tail components were found some distance from the main wreckage site
- 260 people killed on the aircraft
- 5 fatalities on the ground



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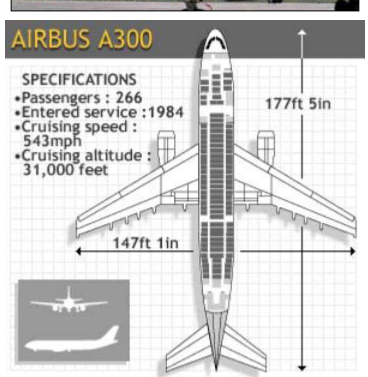
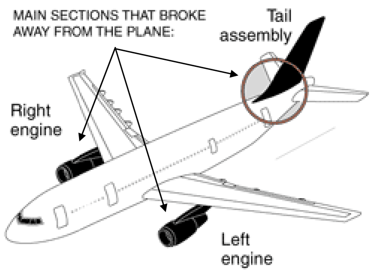
AmericanAirlines
Flight 587

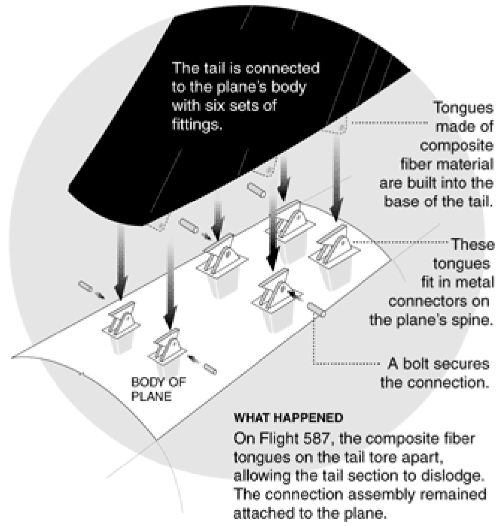


- The twin-engined A300 is a reliable aircraft
- This particular model is an early version of the Airbus (A300-600). American Airlines had 35 in service and there are 250 in operation around the world
- No evidence was found of an uncontained engine failure, loss of blades, bird strike or in-flight fire. The thrust reversers were in the stowed position.
- NTSB investigation is still ongoing
- "Although the flight data recorder showed significant rudder movement during the last moments of Flight 587, it is not known what caused the movement -- whether it was either mechanically induced or pilot activated -- or what role, if any, the movement played in the separation of the vertical stabilizer," according to an official NTSB update on the crash investigation

What Happened?

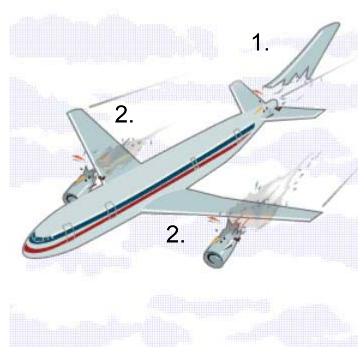


Source: National Transportation Safety Board.



Sequence of Events

- AA587 Encountered two wake vortices from JAL 47
- Experienced a large lateral acceleration after wake encounter (0.1g)
- After wake encounter the plane experienced three strong lateral accelerations corresponding to rudder movements (0.3 – 0.4 g)
- Rudder data becomes unreliable, however the engines can still be heard



NTSB Photographs

Human Error?

- National Transportation Safety Board announced that many pilots are unaware that their maneuvering can cause part of an airplane's tail fin to break off
- The NTSB calculated that certain rudder inputs by pilots made during certain stages of a flight can cause catastrophic failure of an airline's vertical stabilizer
- The NTSB now recommends special training after interviewing pilots of the Airbus A-300, who were unaware it was possible to make rudder movements that can cause catastrophic stress on the vertical stabilizer.
- The concern was not limited to Airbuses.

More Info on AA587

http://www.ntsb.gov/events/2001/AA587/default.htm

As NTSB investigation progresses they will post updates

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