Introduction to Aerospace Engineering

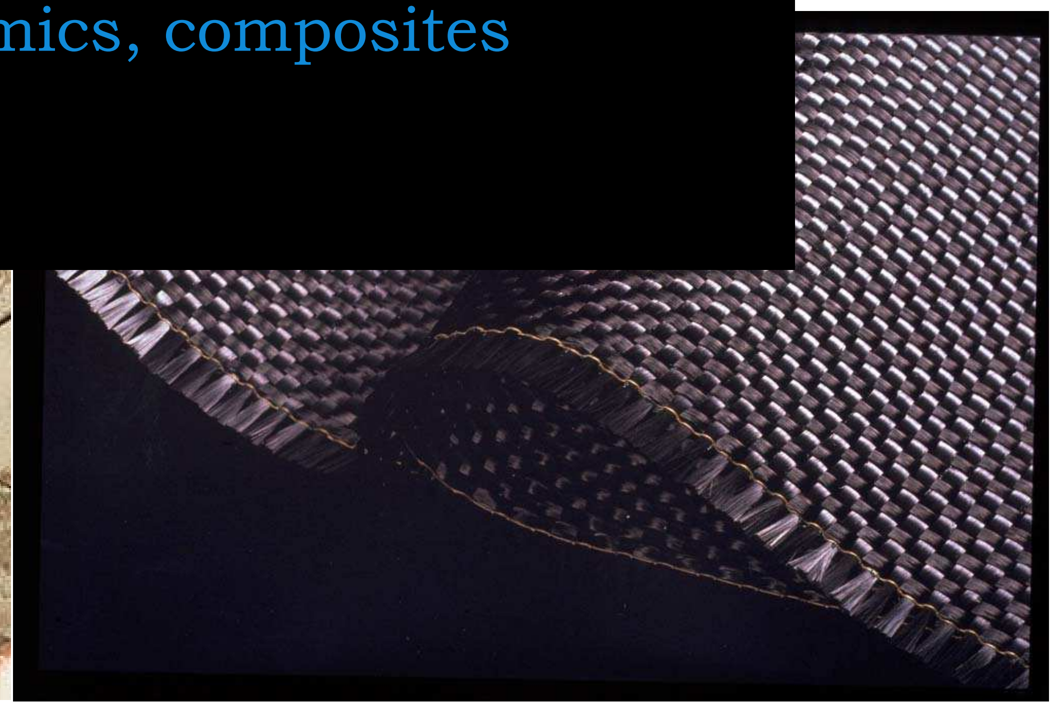
Lecture slides

Material types

Metals, polymers, ceramics, composites

Faculty of Aerospace Engineering

6-12-2011



Learning objectives

Student should be able to...

- Describe the characteristics of typical aerospace materials
- Describe the groups of different materials
- Estimate composite material properties based on its constituent properties

Materials

Overview of materials

- Recall
  - Metals/metal alloys
    Alloying & heat treatments *(composition & condition)*
  - Polymers
    Insufficient properties (low strength & stiffness)
  - Ceramics
    Brittle materials
  - Composites
    Composed materials (fibres, resin, metals)

Metals

Typical applications

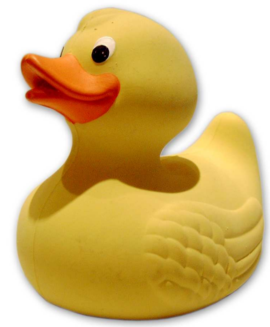
- High strength structures (tension & compression)
  - Aircraft, bridges, towers
- Components & products (high volume production)
  - Cars, cans, etc
- Reinforcement
  - Cables



Polymers

Typical applications

- Elastomers
  - Rubbers
- Plastics
  - Thermoplastic
  - Thermoset
- Fibres
  - Natural fibres
  - Synthetic fibres
  - Nylon



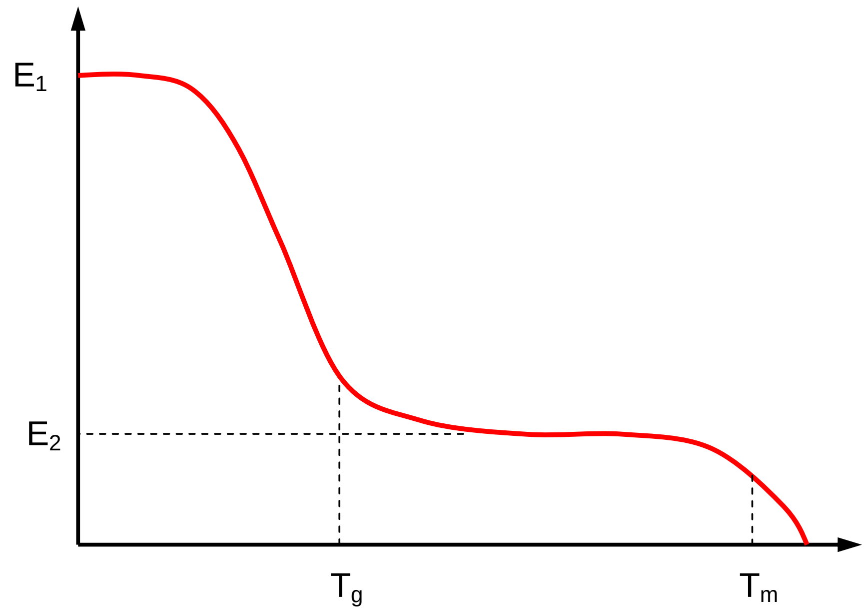


Polymers

Properties

Mechanical properties depend on temperature, strain rate & environment

- Low temperatures
  - Elastic and brittle behaviour
- Medium temperature
  - Rubbery behaviour
  - Glass transition temperature
- High temperature
  - Viscous (liquid)



Ceramics

Types and properties

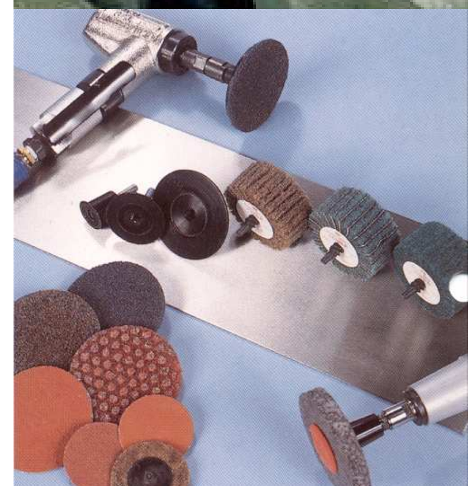
- Ceramics often consist of (metal) oxides and metals
  - Ionic bonds between the different atoms

- Properties
  - Hard and brittle (limited toughness - small failure strain)
  - High strength and stiffness feasible (depends on composition - porosity)
  - Able to sustain high temperatures (strong bonds)
  - Wear resistant

Ceramics

Typical applications

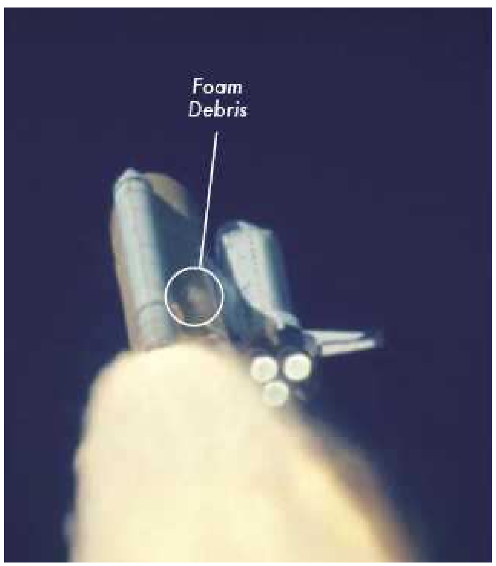
- Glass
  - Window panes, lenses, fibers, ...
- Clay
  - Porcelain, bricks, ...
- Cements
  - Cement, lime, ...
- Other
  - Cutting tools and abrasive materials
  - Armor reinforcement
  - Heat resistant (1600 – 1700 °C) materials for engines and space shuttle heat protection system



Ceramics

Space Shuttle Columbia

- Crashed February 1, 2003
  - Crew of 7 killed
  - During lift-off and mission no apparent problems
  - Explosion during re-entry

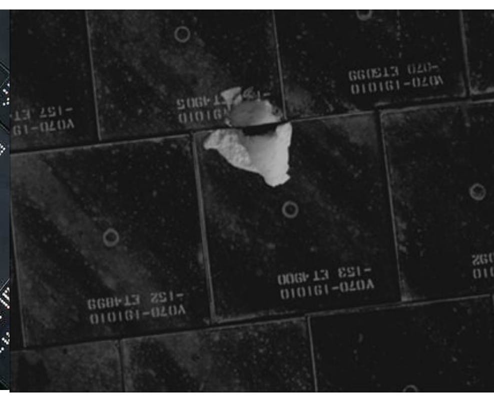


Ceramics

Space Shuttle Columbia

- Analysis:
  - Piece of foam detached from tank hits leading edge during lift-off
  - Foam damages heat resistant ceramic skin

- Importance of heat protection!

Composites

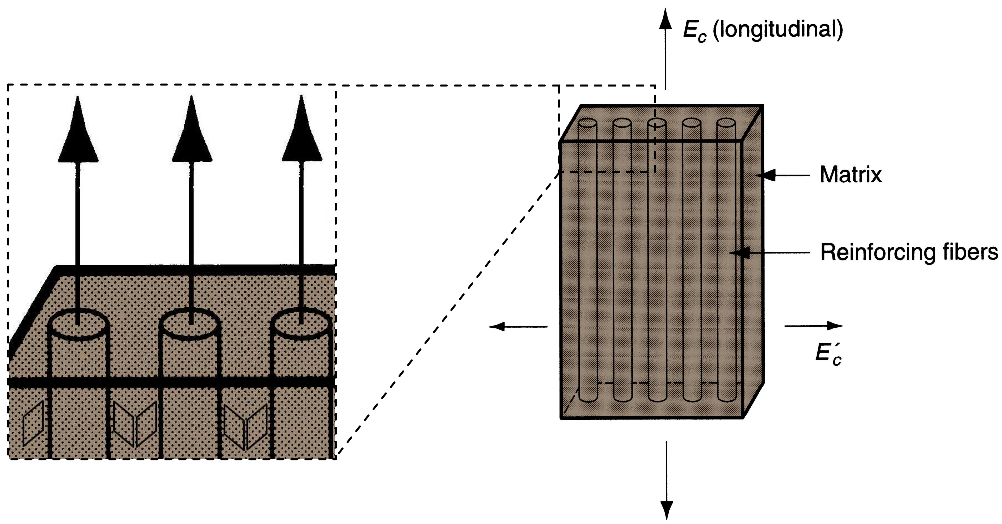
Definition

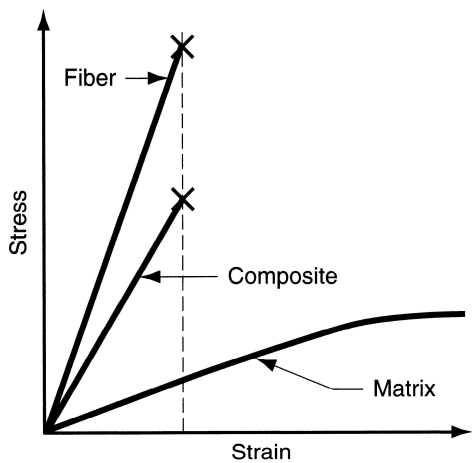
- Composites are engineering materials in which two or more distinct and structurally complementary substances with different physical or chemical properties are combined to produce structural or functional properties not present in any individual component

Composites

Example 1: Fibre reinforced polymer composite

- Two distinct structurally complement materials:
- Fibres
  - Function: Reinforcement, carry main portion of load
- Polymer
  - Functions: Transfer load to/from fibres in shear; protection, support



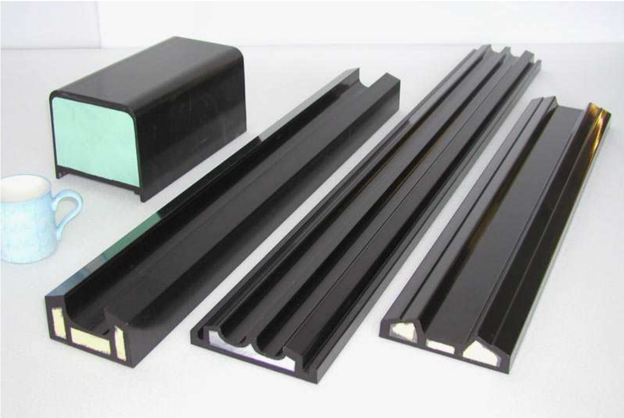


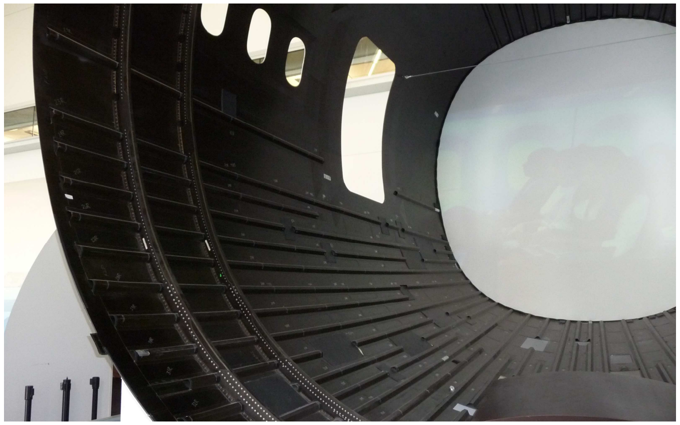
Composites

Properties

- Properties of fibre reinforced polymers
  - High specific properties (strength and stiffness)
  - Elastic until failure (no ductility)
  - High directionality (anisotropic)

    - enables tailoring to specific load applications (beams, cables, columns)
    - requires multiple orientations to cope with bi-axial load applications



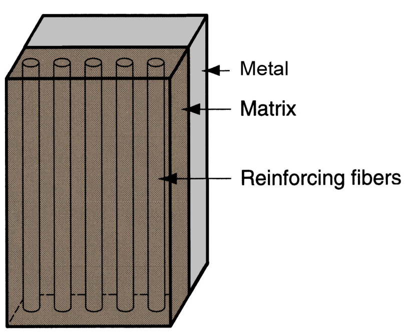


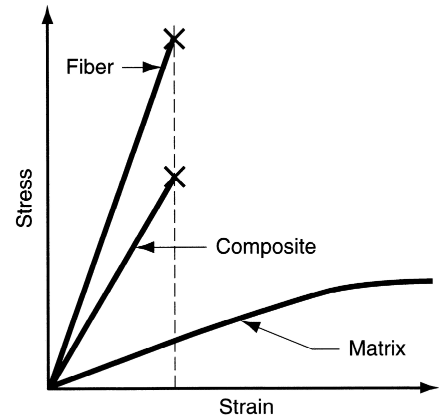
Composites

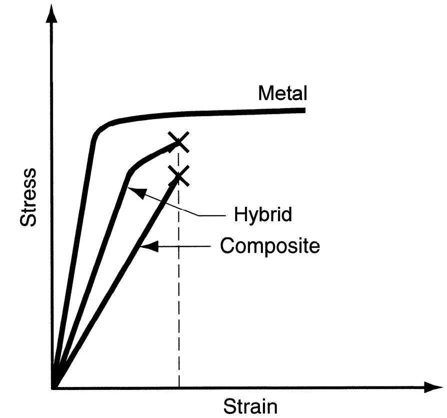
Example 2: Hybrid materials

Three distinct structurally complement materials:

- Metal
  - Function: Ductility, isotropic strength/stiffness
- Fibres
  - Function: Reinforcement, carry significant portion of load
- Polymer
  - Function: Transfer load between fibres and metal in shear







Composites

Elastic property estimation

Rule of mixture

- Simple relations to estimate properties of a composite based on the properties of its constituents
- Caution: not accurate

- Example: fibre reinforced polymer composite
  - Total mass = density x volume

$$M_{FRP} = M_F + M_M \quad \rightarrow \quad \rho_{FRP} V_{FRP} = \rho_F V_F + \rho_M V_M$$

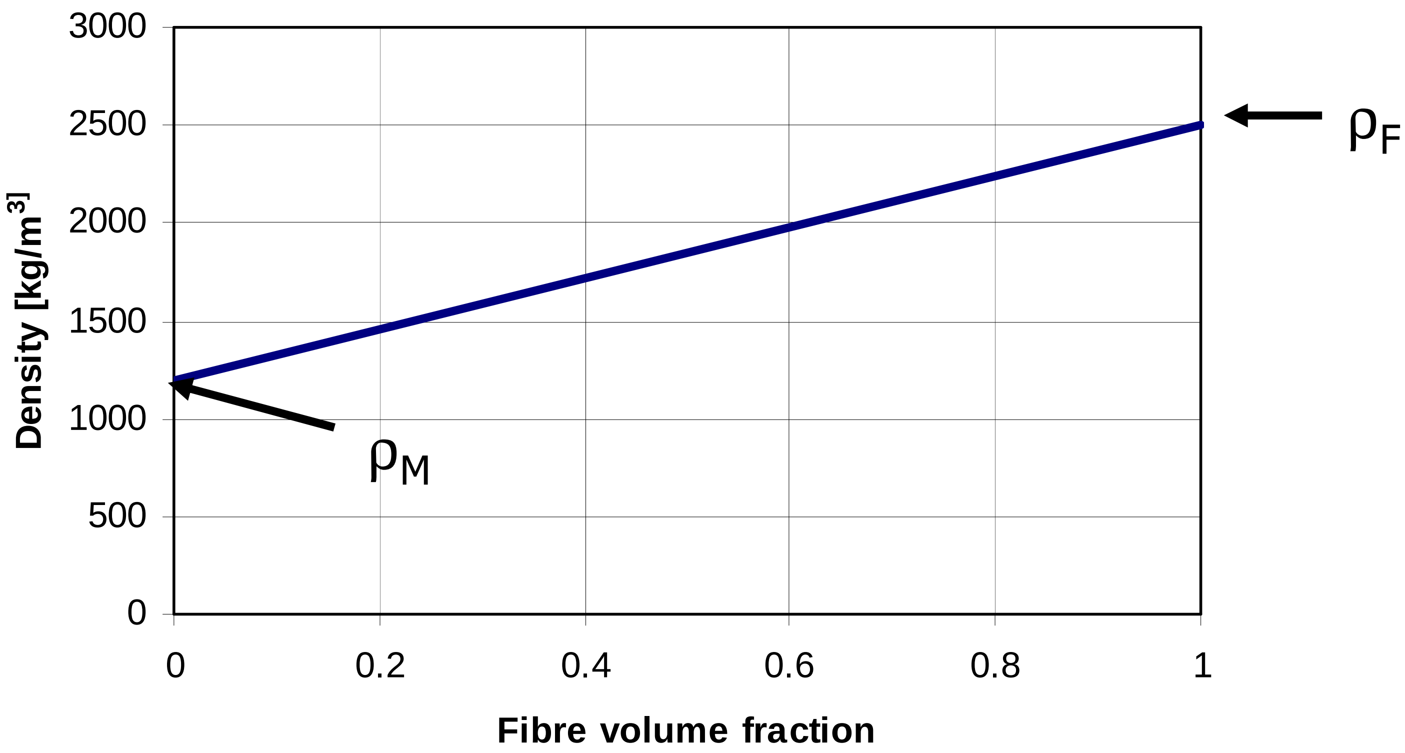
  - Formulated as volume fractions

$$\rho_{FRP} = \rho_F \frac{V_F}{V_{FRP}} + \rho_M \frac{V_M}{V_{FRP}} \quad \rightarrow \quad \rho_{FRP} = \rho_F \mathrm{v}_F + \rho_M \mathrm{v}_M$$

Composites

Elastic property estimation

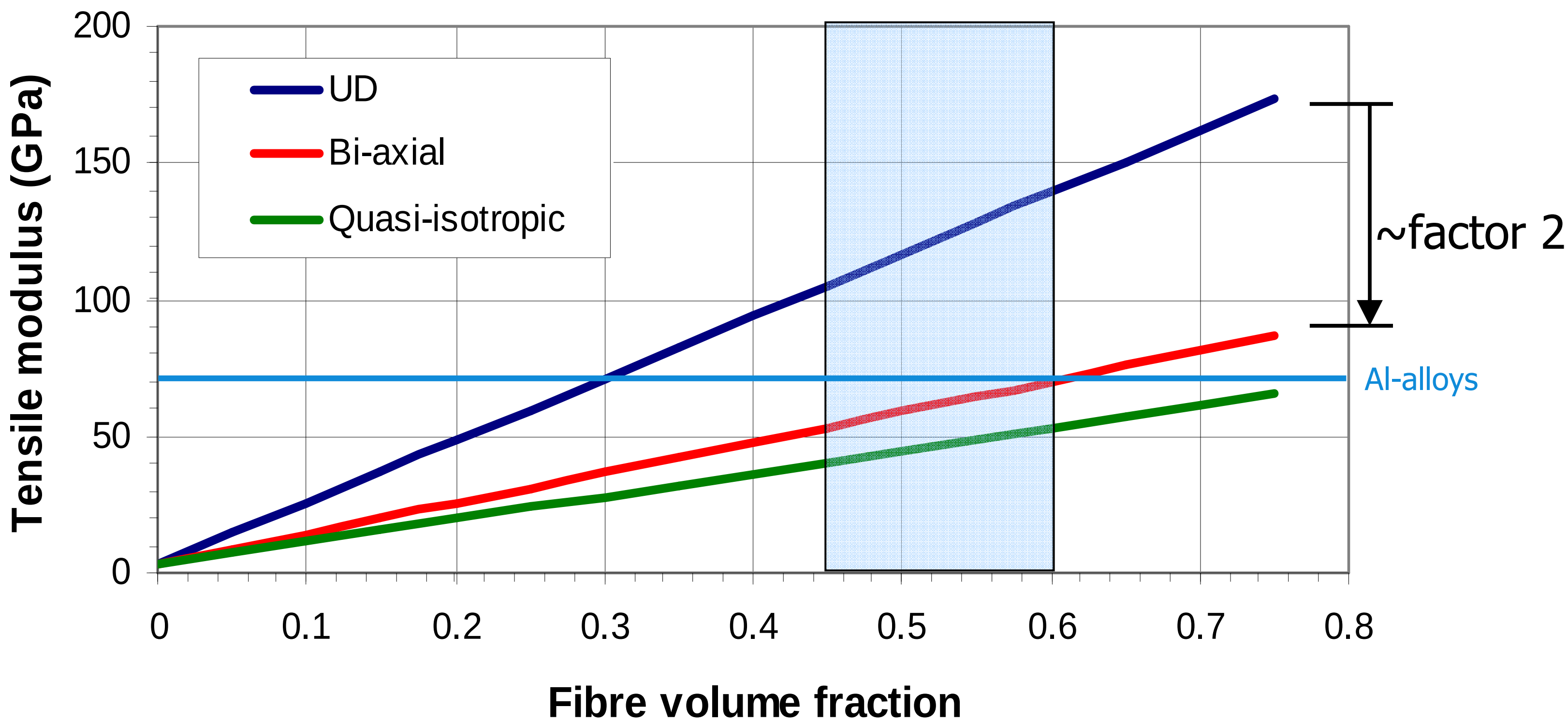
Rule of mixture: density of glass/epoxy composite



Composites

Elastic property estimation

Rule of mixture example: Tensile modulus (T300 carbon fibre)



Composites

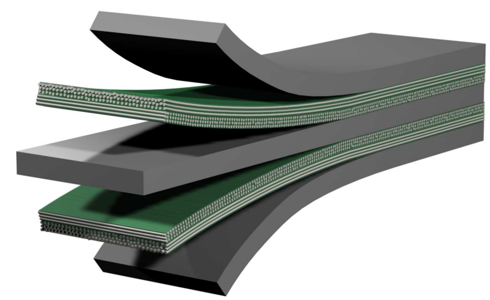
Elastic property estimation

- Rule of mixture example: Fibre Metal Laminate
  - FML → Metal sheet, Composite
    - Composite → Fibres, Matrix

See previous slides

- Metal volume fraction v_M

$$S_{FML} = S_M v_M + S_{FRP} v_{FRP} = S_M v_M + S_{FRP} (1 - v_M)$$



Composites

Properties

Material	Specific strength	Failure strain	Electrical conductivity	Flame resistance	UV resistance	Chemical resistance
Glass fibre reinforced composite	High	Medium	Low	High	High	Low
Carbon fibre reinforced composite	High	Low	High	High	High	Low
Aramid fibre reinforced composite	High	Medium	Low	High	High	Low
Fibre Metal Laminate	High	Medium	High	High	High	Medium

Composites

Typical applications

- Glass fibre composites
  - Wind turbine blades, sail planes, pressure tanks & vessels, etc.
- Carbon fibre composites
  - Automotive, aerospace, sailboats, (motor) bikes, sport equipment, etc.
- Aramid/kevlar composites
  - Armor & bullet proof products, etc.
- FMLs
  - Aerospace

Summary

Material types

- Typical aerospace materials are
  - Metals
  - Polymers
  - Ceramics
  - Composites
- With their own characteristic properties and applications