Composite Materials - II

Contents

- ✓ Fiber Reinforced Composites (Contd.)
  - Polymer Matrix composites
  - Metal Matrix composites
  - Ceramic Matrix composites
  - Carbon - Carbon composites
- ✓ Structural Composites

Fiber
Reinforced Composites
(contd.)

Polymer-Matrix Composites (PMC)

Matrix – Polymer resin
Fibers – reinforcing medium

A) ***Glass Fiber-Reinforced Polymer (GFRP) Composites***

Matrix – *Plastic* (most often epoxy, polyester resin)

Reinforcement – *Glass fiber/E-glass* (Diameter = 3-20 μm)

- ✓ Typically 55% SiO_2, 16% CaO, 15% Al_2O_3, 10% B_2O_3, 4% MgO.
- ✓ Easily drawn into high-strength fibers from the molten state.

GFRP (Fiber volume fraction = 0.6),Epoxy matrix		
Density	2100 kg/m^3 (Light weight)	
	Longitudinal	*Transverse*
Tensile Modulus (GPa)	45	12
Tensile strength (MPa)	1020	40

E-glass

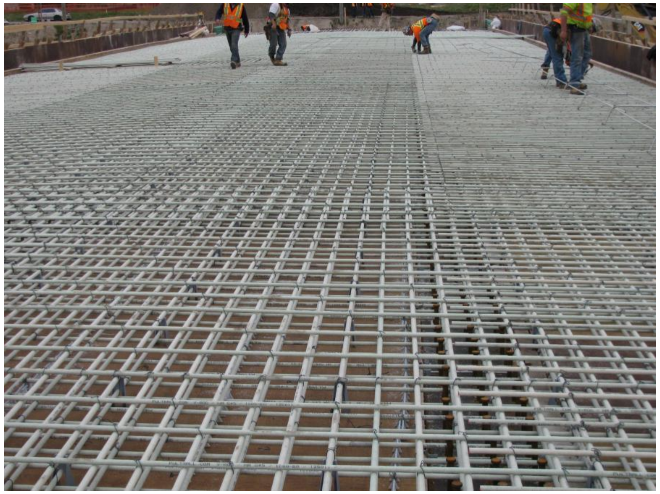
Limitation – Service temperature up to 200°C (above which polymer/matrix starts deteriorating).

APPLICATIONS

Automotive and marine bodies, plastic pipes, storage containers, and industrial floorings.

GFRP Chemical Containers

http://www.hhzy.chemchina.com/hhzye/



GFRP rebars used for making pedestrian bridges

www.vrodcanada.com

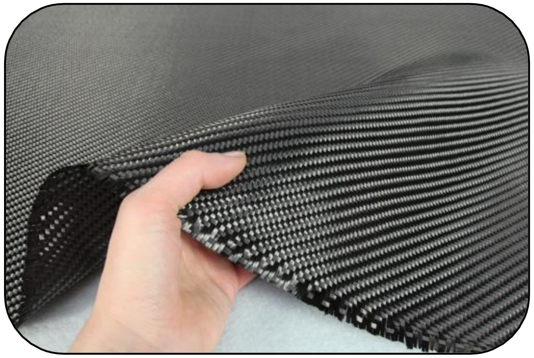
Polymer-Matrix Composites (PMC)

B) ***Carbon Fiber-Reinforced Polymer (CFRP) Composites***

Matrix – Polymer resin
Fibers – Carbon fiber (reinforcement)

- Carbon is a high-performance fiber material because
  - ✓ **Highest specific modulus** (E/ρ) and **specific strength** of all reinforcing fiber materials and **retain** same at **elevated temperature**.
  - ✓ At room temp. **not affected** by moisture or a wide variety of solvents, acids, and bases.
- Fiber diameters normally range between 4 - 10 µm.

CFRP (Fiber volume fraction = 0.6) ,Epoxy matrix		
Density	1600 kg/m^3 (Light weight)	
	Longitudinal	*Transverse*
Tensile Modulus (GPa)	145	10
Tensile strength (MPa)	1240	40



Carbon fiber

Reference: http://www.easycomposites.co.uk/

Carbon Fiber Wheel - BMW

Reference: http://www.tcbmw.com/carbon-fiber-reinforced-plastic-cfrp-wheels-announced/

Other applications - CFRP

Boeing 787 Dreamliner – nearly 50% frame of CFRP

Mountain bicycle frame

Racket

Lamborghini Aventador LP700-4

CFRP - Wheels, frame, seats

Reference: http://www.centralcarbonfiber.com/application/index.html

Polymer-Matrix Composites (PMC)

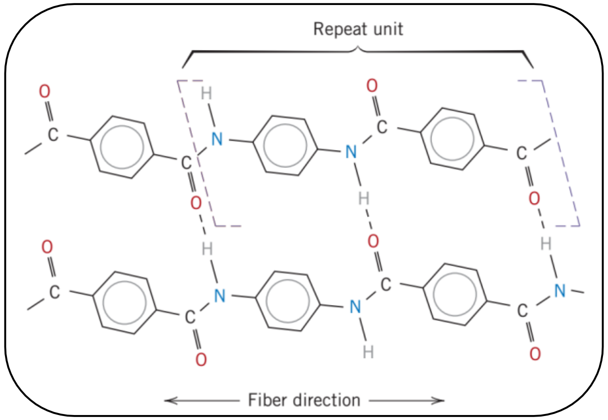
C) ***Aramid Fiber-Reinforced Polymer (AFRP) Composites***

- **Trade name** of most common Aramid fiber – **Kevlar**™ and **Nomex**™
- **Chemically**, this group of materials is known as **poly(paraphenylene terephthalamide).**
- Known for its toughness, impact resistance, and resistance to creep and fatigue failure.

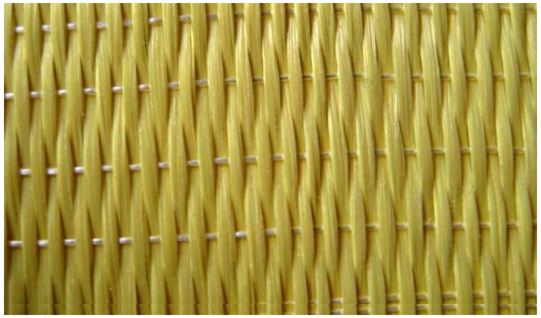
❖ Strong covalent bond axially, weak hydrogen bond transversely.

❖ Negative Coefficient of expansion due to kinks

❖ UV sensitive – degrades



Kevlar (Fiber volume fraction = 0.6) ,Epoxy matrix		
Density	1440 kg/m^3 (Light weight)	
	Longitudinal	*Transverse*
Tensile Modulus (GPa)	76	5.5
Tensile strength (MPa)	1380	30



Kevlar fibre

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Reference: W.D Callister, 7 Ed.

Typical applications

- Ballistic products (bullet proof vests and armor)
- Sporting goods
- Ropes
- Missile cases
- Replacement for asbestos in automotive brake and clutch linings, and gaskets.

Bullet proof Vest

www.kevlarxp.dupont.com

Comparison

(Fibre volume fraction = 0.6), Epoxy matrix

Material	Tensile Modulus (GPa)		Tensile Strength (MPa)	
	Longitudinal	Transverse	Longitudinal	Transverse
GFRP (2100 kg/m^3)	45	12	1020	40
Aramid (Kevlar-49) (1440 kg/m^3)	76	5.5	1380	30
CFRP (1600 kg/m^3)	230	10	1240	40

Metal-Matrix Composites (MMC)

Matrix – Ductile Metal (usually alloys of aluminum, magnesium, titanium, and copper)
Fibre - Carbon, Silicon Carbide, Boron, Aluminum oxide, etc.

Advantage over PMC includes:

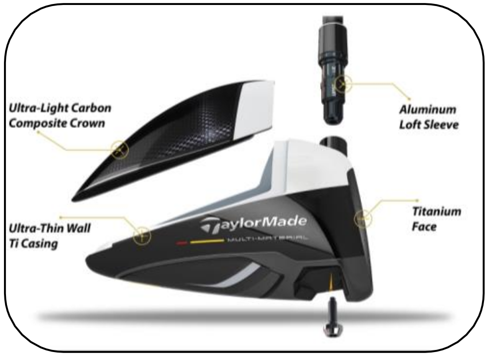
- ✓ Higher operating temperatures.
- ✓ Non-flammability.
- ✓ Greater resistance to degradation by organic fluids.

Demerit: MMCs are costlier than PMCs

Properties of Several Metal-Matrix Composites Reinforced with Continuous and Aligned Fibers

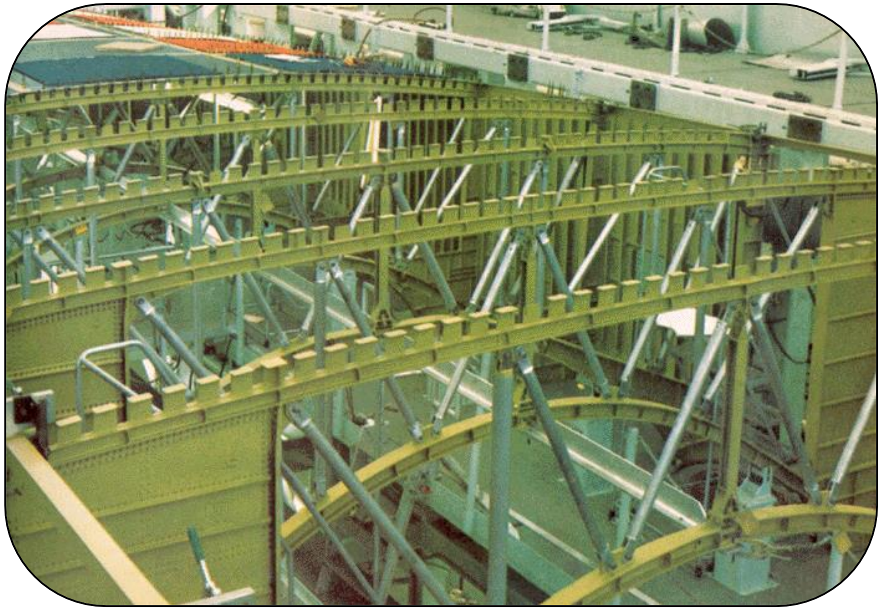
Fiber	*Matrix*	*Fiber Content (vol%)*	*Density (g/cm^3)*	*Longitudinal Tensile Modulus (GPa)*	*Longitudinal Tensile Strength (MPa)*
Carbon	6061 Al	41	2.44	320	620
Boron	6061 Al	48	—	207	1515
SiC	6061 Al	50	2.93	230	1480
Alumina	380.0 Al	24	—	120	340
Carbon	AZ31 Mg	38	1.83	300	510
Borsic	Ti	45	3.68	220	1270

Reference: W.D Callister, 7 Ed.



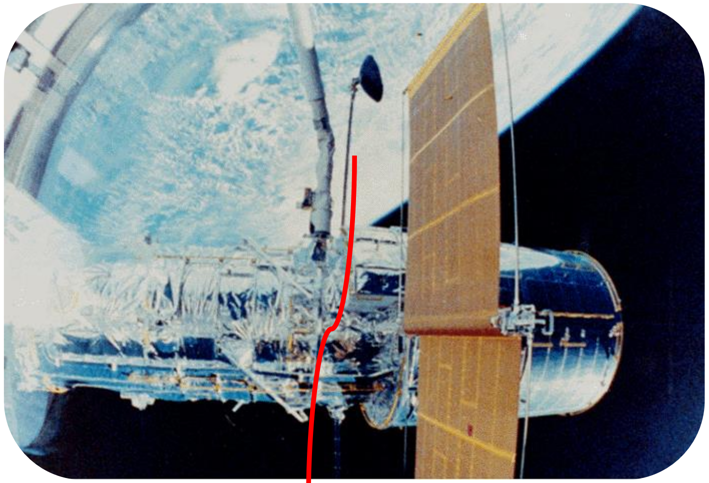
Golf

Tank Armor – MMC (recent advances)



B/Al tubular struts used as the frame and rib truss members in the mid-fuselage section

Space Shuttle



Antenna boom for the Hubble Space Telescope

(Graphite fibres in 6061 Al)

Reference: http://www.tms.org/pubs/journals/jom/0104/rawal-0104.html

Ceramic-Matrix Composites (CMC)

- **Ceramics** are **highly brittle** in nature. Thus, **low fracture toughness**.
- In general the fracture toughness of
  - ✓ **Ceramics** : 1 - 5 MPa $\sqrt{m}$
  - ✓ **Metal alloys** : 20 - 90 MPa $\sqrt{m}$
- By using **CMC**, fracture toughness can be increased to lie in the range **6 - 20 MPa $\sqrt{m}$** .
- **Crack initiation** normally occurs within **matrix phase**, whereas **crack propagation** is **hindered** by the **particles, fibers, or whiskers**.
- Exhibit **improved** high-temperature **creep behavior** and **resistance** to **thermal shock.**

SiC whisker in Al_2O_3 (matrix)

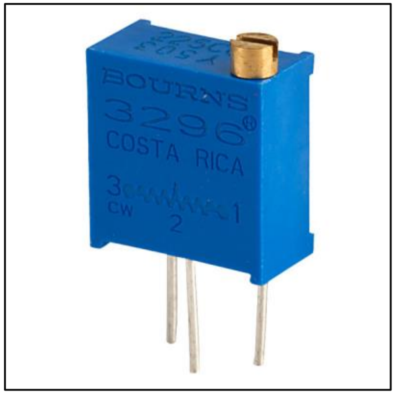
Whisker Content (vol%)	*Fracture Strength (MPa)*	*Fracture Toughness (MPa$\sqrt{m}$)*
0	—	4.5
10	455 ± 55	7.1
20	655 ± 135	7.5–9.0
40	850 ± 130	6.0

Brake disc of Ferrari Race Car
(Carbon fiber-reinforced in SiC matrix)

Cermets

Ceramic + **Met**al = Cermet

- Composites of **ceramic particles** (strong, brittle) in a **metal matrix** (soft, ductile).
- Has higher toughness and wear resistance than traditional materials.
- For instance, **tungsten carbide or titanium carbide ceramics** embedded in a matrix of a metal such as **cobalt or nickel**.
- Only about **10-15% metal volume.**
- They are used for **cutting tools** for hardened steels.
- **Electrical components** such as resistors and vacuum tubes (valves).



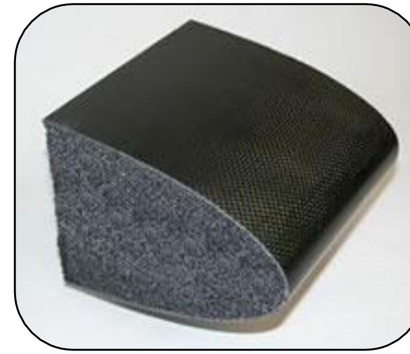
Cermet trimming potentiometer
(Small variable resistors, used in circuits for tuning and calibration)

Cermet inserts

Reference
www.ceramtec.com
http://global.kyocera.com/news/2008/1202.html

Carbon - Carbon Composite

- Both reinforcement and matrix are carbon – Very Expensive
- High modulus of elasticity (up to 200 GPa) and strength, even retained at around 2000°C.
- Low density (1830 kg/m^3)
- High thermal conductivity (100 W/m-K)
- Low coefficient of friction (in fiber direction).
- High abrasion resistance.



Carbon - Carbon Composite

Missile cone

Wing leading edges of the Space Shuttle

B2-Bomber aircraft

Image courtesy: Wikipedia

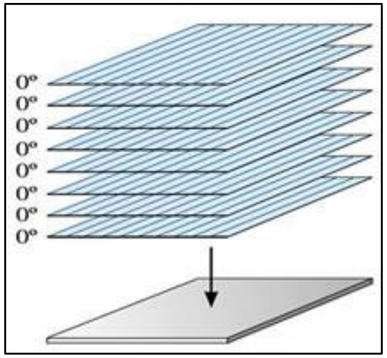
Structural Composites

1. Laminated Composites

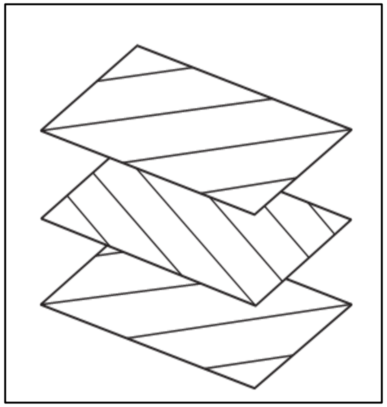
- A laminate is constructed by stacking a number of laminae.

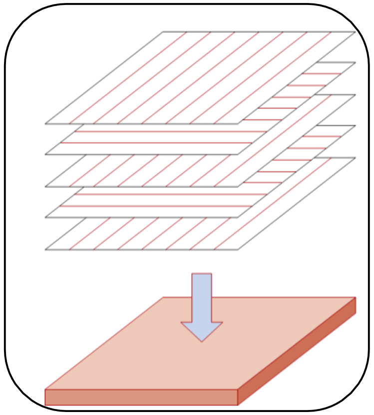
Examples

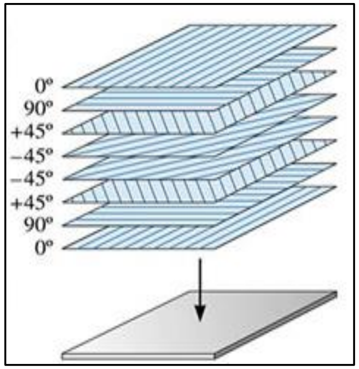
- *Unidirectional laminate*
  - ✓ Fiber orientation angles are the same in all laminas such as θ = 0º.
- *Angle-ply laminate*
  - ✓ Fiber orientation angles in alternate layers are / θ/- θ/ θ/- θ/ ,where θ ≠ 0º or 90º
- *Cross-ply laminate*
  - ✓ Fiber orientation angles in alternate layers are / 0º / 90º / 0º / 90º /.
- *Symmetric laminate*
  - ✓ Identical ply (in material, thickness, and fiber orientation angle) at an equal distance about centerline, i.e., θ(z) = θ(-z), where z is the distance from the mid-plane of the laminate.



Unidirectional laminate


Angle-ply laminate


Cross-ply Laminate



Symmetric laminate

1 2 3 4 5 6 7 8
[0/+90/+45/-45/-45/+45/+90/0]
Code: $[0/ 90/45/-45]_s$

- ***Symmetric laminate*** *(contd.)*
  - ✓ The bar over 90° indicates that the plane of symmetry passes midway through the thickness of the 90° lamina

    1 2 3 4 5
    $[0/+45/90/+45/0]$
    Code: $[0/45/\overline{90}]_S$

  - ✓ Adjacent +45° and -45° laminas are grouped as ±45°.

    1 2 3 4 5 6 7
    $[0/+45/-45/90/-45/+45/0]$
    Code: $[0/\pm45/\overline{90}]_S$

  - ✓ Four adjacent 0° plies are grouped together as 0_4.

    1 2 3 4 5 6 7 8 9 10 11 12 13 14
    $[0/90/0/0/0/0/45/45/0/0/0/0/90/0]$
    Code: $[0/90/0_4/45]_S$

  - ✓ Two adjacent ±45° plies are grouped as $(\pm45)_2$.

    1 2 3 4 5 6 7 8 9 10
    $[0/45/-45/+45/-45/-45/+45/-45/+45/0]$
    Code: $[0/(\pm45)_2]_S$

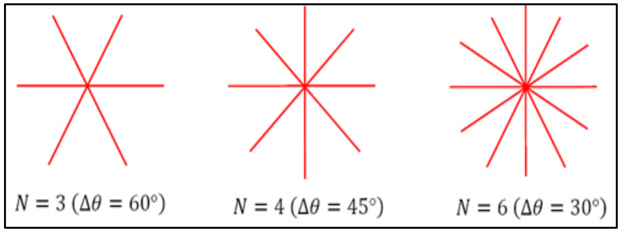
- ***Antisymmetric laminate***:

  Ref. : P. K. Mallick - Fiber-reinforced Composites Materials, Manufacturing, and Design-CRC Press (2008)

  - ✓ Ply orientation is antisymmetric about the centerline of the laminate, θ(z) = - θ(-z).

  Example : /+θ/-θ/+θ/-θ/ is an Antisymmetric laminate while /+θ/- θ/-θ/+θ/ is Symmetric laminate.

- ***Quasi-isotropic laminate***: Equal angles between each adjacent lamina.
  - ✓ If the total number of laminas is n, the orientation angles of the laminas are at an increments of π/n
  - ✓ Example: [0/+60/-60], [0/+45/-45/90]



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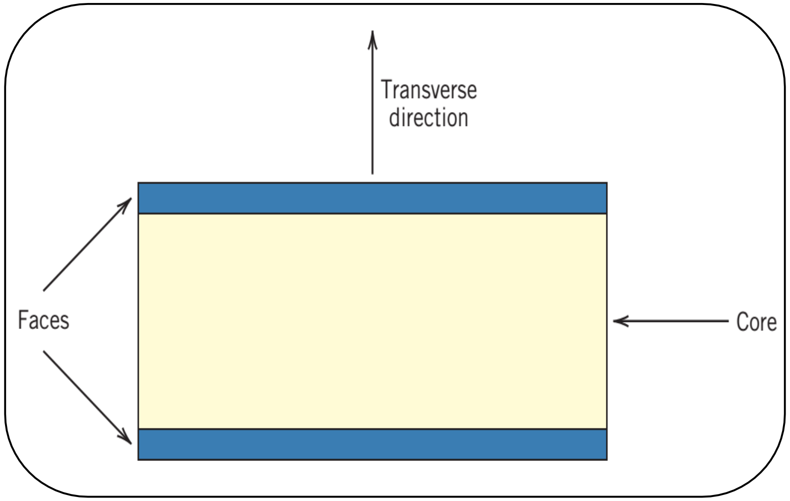
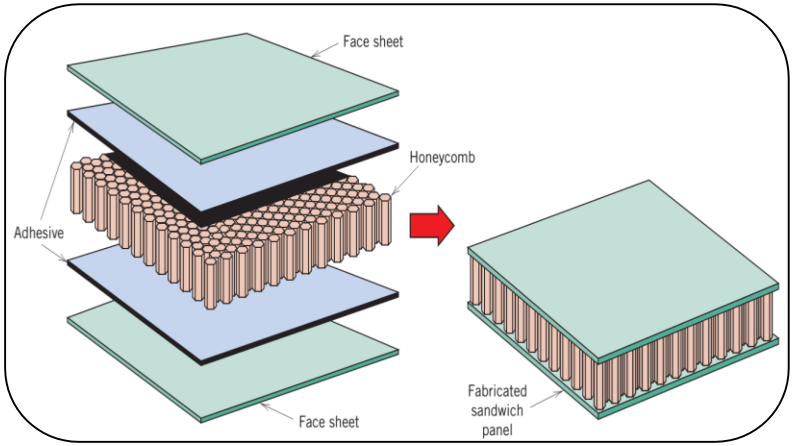
Ref.: http://nptel.ac.in/courses/101104010/lecture17/17_7.htm

2. Sandwich Panels

- Consist of two **strong and stiff sheet faces** that are separated by a **core material** or structure.
- Combine relatively high strengths and stiffness with low densities.
- **Outer sheet** - aluminum alloys, fiber-reinforced plastics, titanium, steel, or plywood.
- **Core materials** - Rigid polymeric foams (e.g., phenolics, epoxy, polyurethanes), wood (i.e., balsa wood), and honeycomb (hexagonal cells).





Balsa wood

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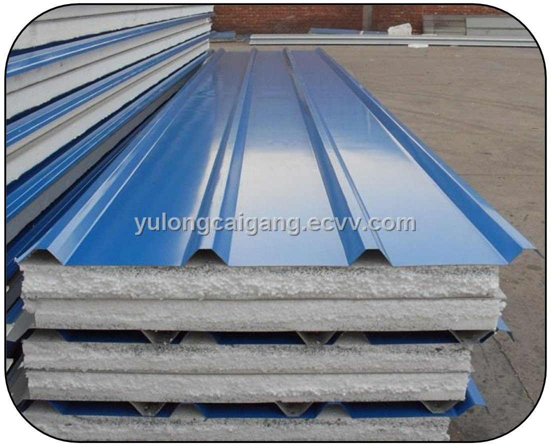
Reference: W.D Callister, 7 Ed.



Steel - Polystyrene Sandwich roof panel

Sandwich panels

1. Low water absorption
2. Good anti-corrosion
3. Good thermal insulated capacity

3. Hybrid Composites

- **Two or more** different kinds of **fibers** in a single matrix.

- For example using-
  - ✓ Carbon fibers - Strong and relatively stiff and provide a low-density reinforcement but **expensive**.
  - ✓ Glass fiber - Inexpensive and lack the stiffness of carbon.

- The glass–carbon hybrid is stronger and tougher, has a higher impact resistance.

- The fibers may all be **aligned and intimately mixed** with one another; or **laminate** may be constructed.

Hybrid laminate

$$[0_B/0_B/45_C/-45_C/90_G/90_G/-45_C/45_C/0_B/0_B]$$

$$\text{Code:}\quad [0_{2B}/(\pm 45)_C/90_G]_S$$

Where B, C, and G represent Boron, Carbon, and Glass fiber, respectively.

Ref. : P.K. Mallick - Fiber-reinforced Composites Materials, Manufacturing, and Design-CRC Press (2008)

Baseball bat

Ice Skates

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