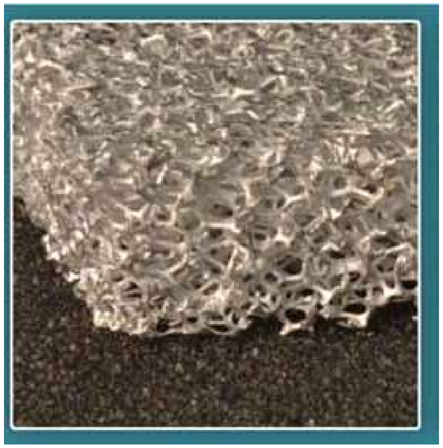
Composites

A short Introduction

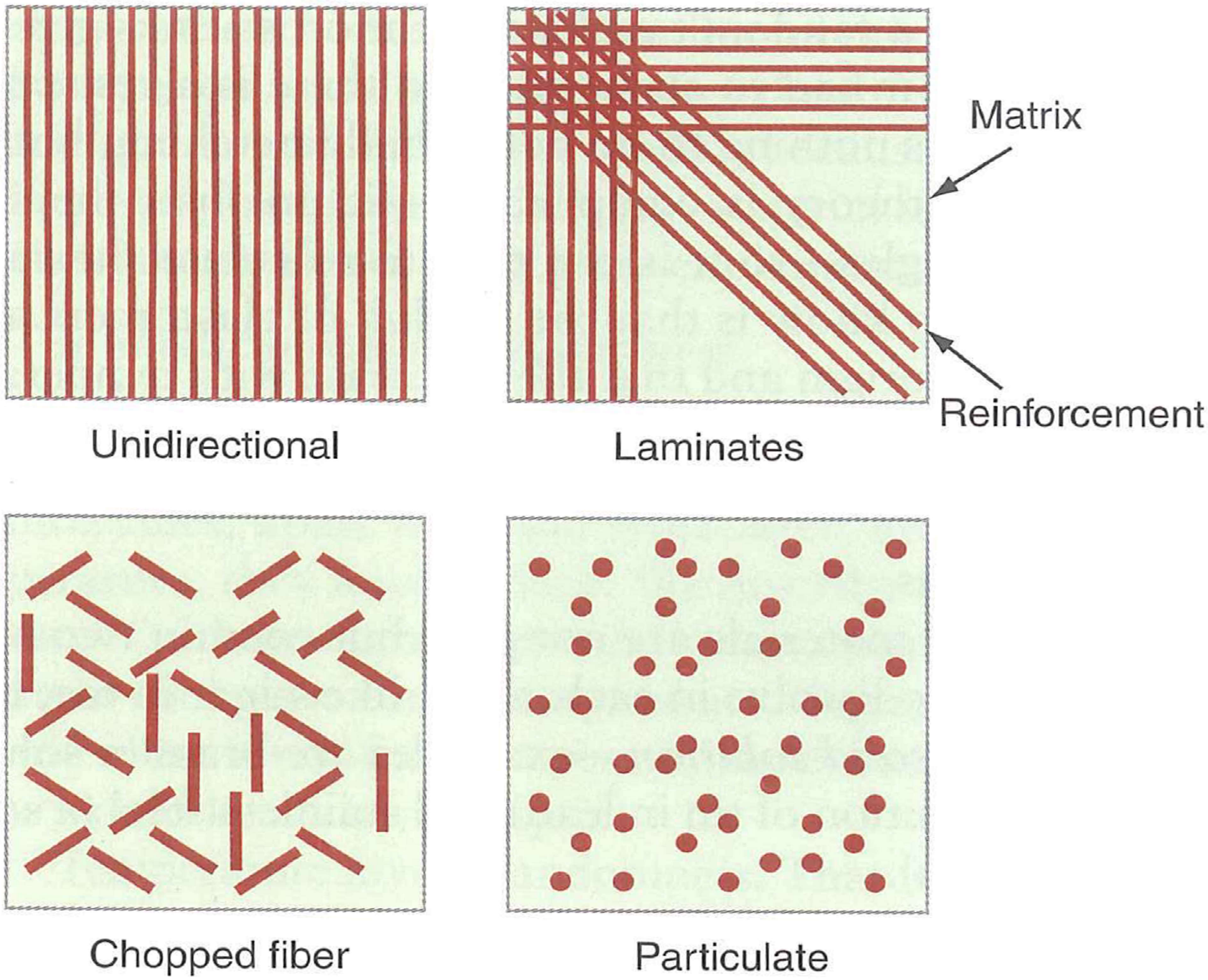
Introduction

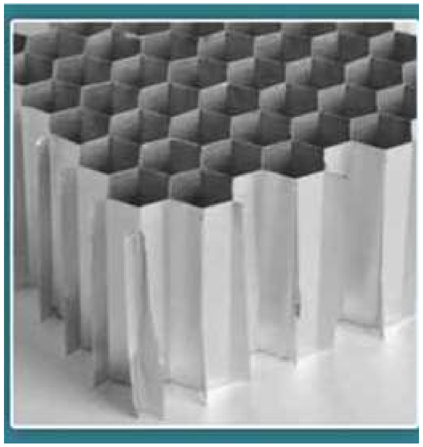
- Two main types of composites:
  - **Fibers composites**: fibers embedded in a continuous matrix (polymeric, metallic or ceramic)
  - **Foams** (or cellular solids): composites of a solid (polymer, metal or glass) and a gas
- Combine components with contrasting properties:
  - FIBERS COMPOSITE: stiff/brittle fibers embedded into a soft/ductile matrix
  - FOAMS: low density (weight) and high mechanical performance

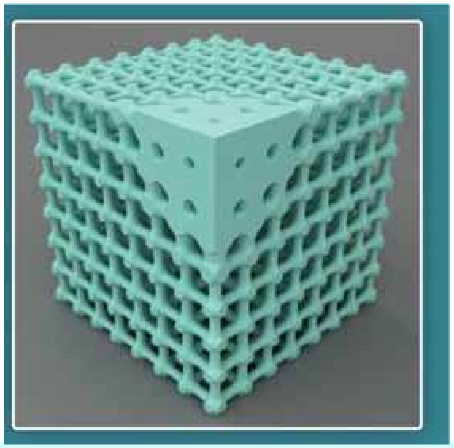
Foams



Fibers Composites







Fibers Composites

- GFRP: glass-fiber (soda glass) reinforced polymers
- CFRP: carbon-fiber (graphite) reinforced polymer
- KVRP: Kevlar-fiber reinforced polymers
- Fibers diameter: 1-100 µm

Table 28.2 Properties of Composites

Material	Density ρ ($Mg\ m^{-3}$)	Youngs Modulus E ($GN\ m^{-2}$)	Strength σ_y ($MN\ m^{-2}$)	Fracture Toughness K_c ($MN\ m^{-3/2}$)
Composites				
CFRP, 58% uniaxial C in epoxy	1.5	189	1050	32–45
GFRP, 50% uniaxial glass in polyester	2.0	48	1240	42–60
Kevlar epoxy (KFRP), 60% uniaxial Kevlar in epoxy	1.4	76	1240	–
Metals				
High-strength steel	7.8	207	1000	100
Aluminum alloy	2.8	71	500	28

GLASS
E: 74 GPa
Kc: 0.7 $MNm^{-3/2}$

Density

Density of the composite is given by rule of mixture (assuming no porosity):

ρ_f: density of fiber

ρ_m: density of matrix

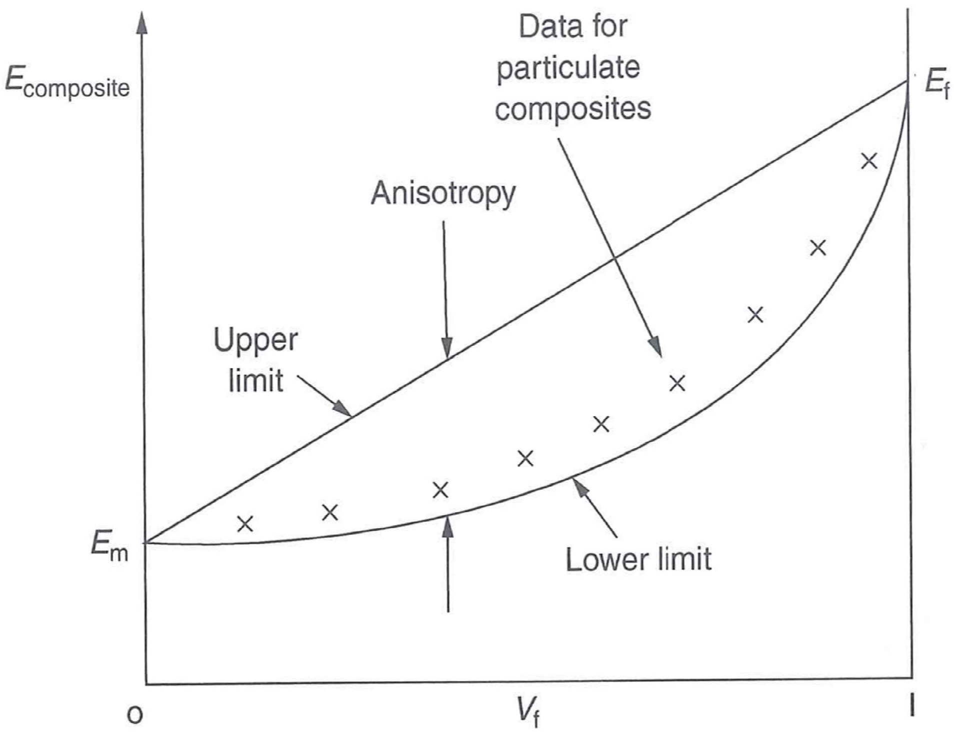
V_f: volume fraction of fiber

$1 - V_f$: volume fraction of matrix

$$\rho_C = V_f \rho_f + (1 - V_f)\, \rho_m$$

Young's Modulus

How can we estimate the Young's modulus of a fiber-reinforced composite?



Upper Limit:

$$E_C = V_f\, E_f + \left(1 - V_f\right) E_m$$

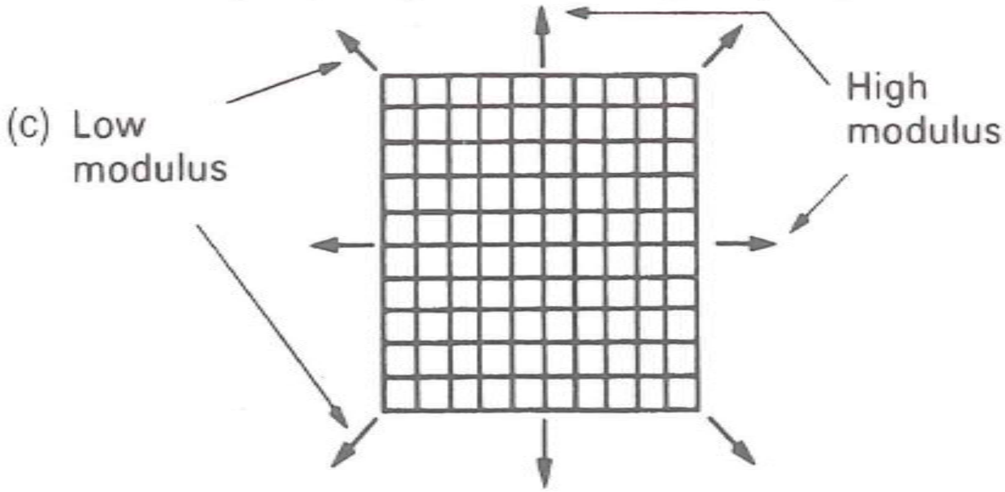
Lower Limit:

$$E_C = \left[V_f / E_f + \left(1 - V_f\right)/E_m\right]^{-1}$$

Unidirectional composites are extremely anisotropic

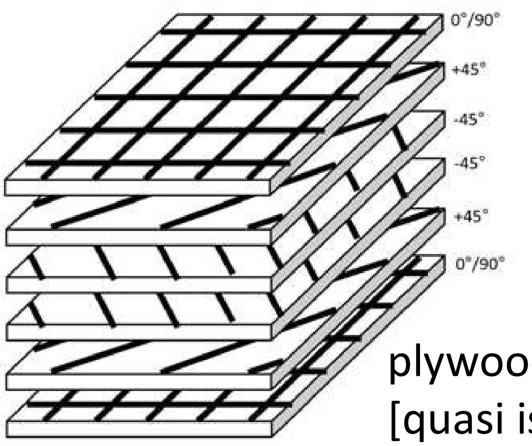
Young’s Modulus

How do we reduce anisotropy in fiber composites?



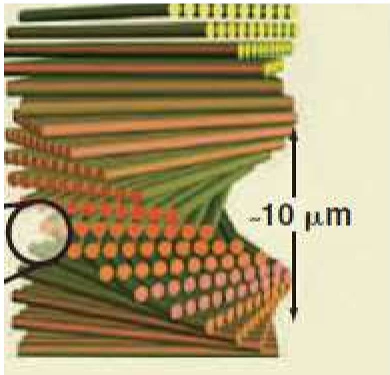
weak at 45° / 135°

cross-weave of fibers



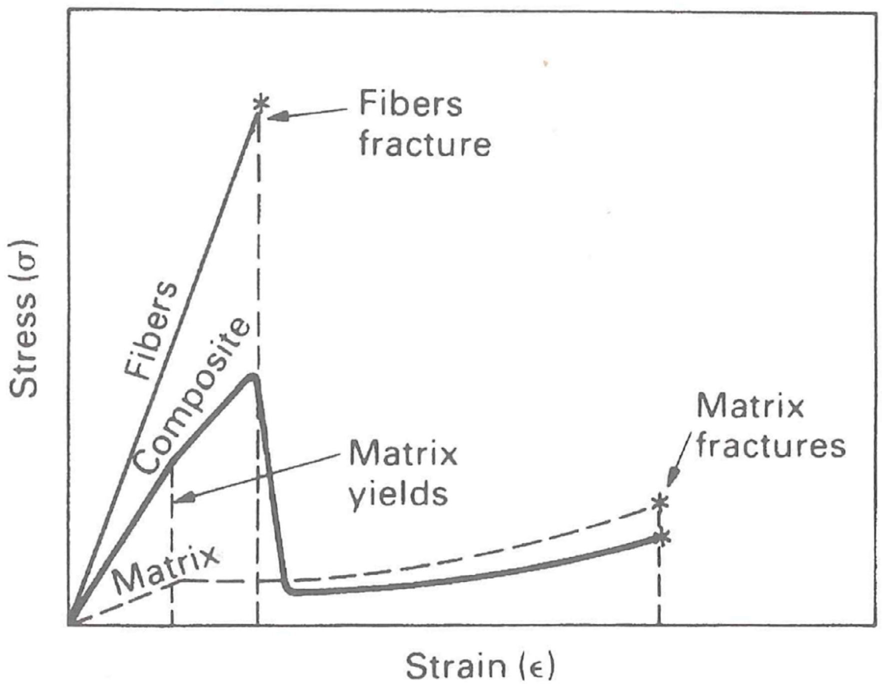
plywood like fiber laminate
[quasi isotropic properties]

lobster



Tensile Strength

Composite of stiff/brittle fibers into a soft/ductile matrix



<u>Main features of stress-strain plot</u>

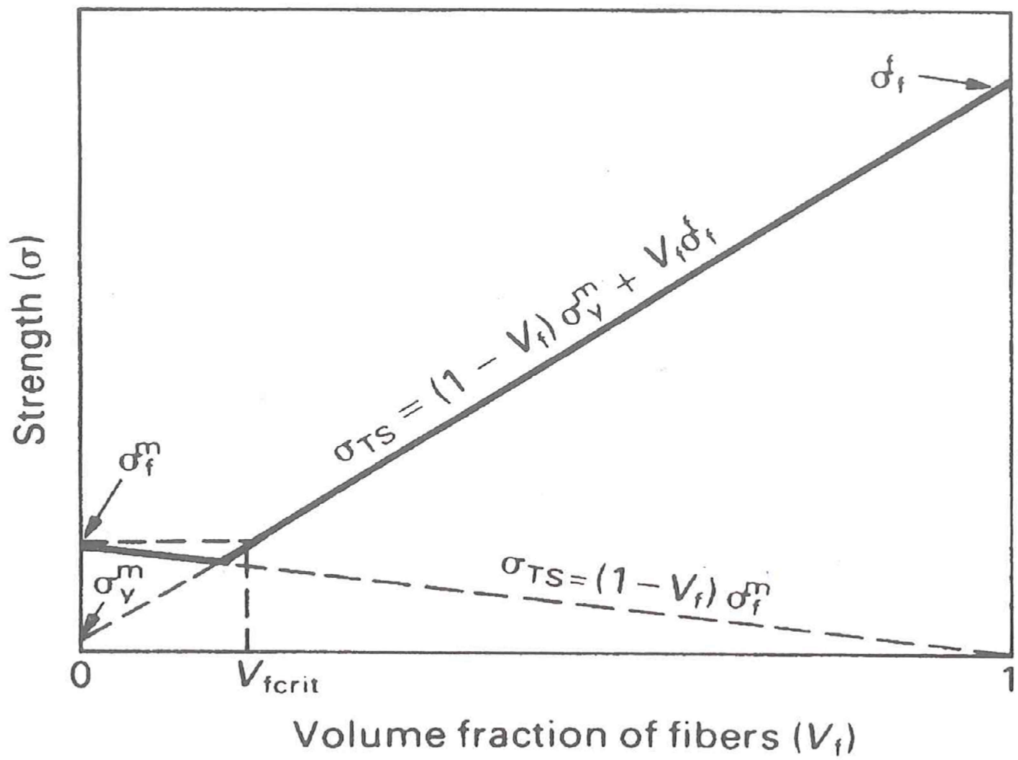
(parallel arrangement, constant (V_f))

- Linear (E_C) till matrix yield
- Fibers take up the load till they fracture
- Stress drops to yield strength of the matrix (sharp if all fibers brake at once)
- Matrix fractures and composite fails

Tensile Strength

Composite of stiff/brittle fibers into a soft/ductile matrix:

Strength versus Volume fraction



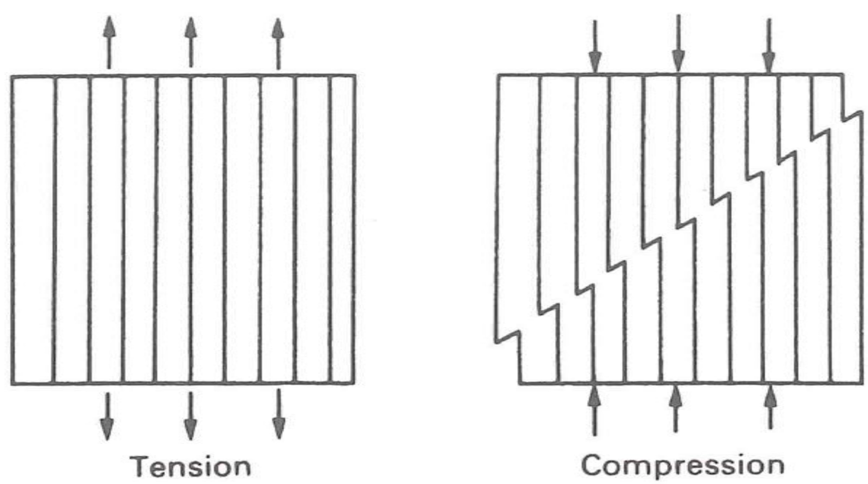
adding too few fibers is harmful

→ a critical volume fraction of fibers ($V_f$critical) must be exceeded to give effective increase in strength!

→ If too few fibers they reduce the strength of the material as they fracture before reaching peak stress

Compressive Strength

- Compressive strength of fibers composite is less than tensile strength
- Fibers are thin structural element which may fail in compression by buckling (kinking→ cooperatively buckling)



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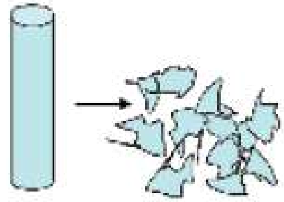
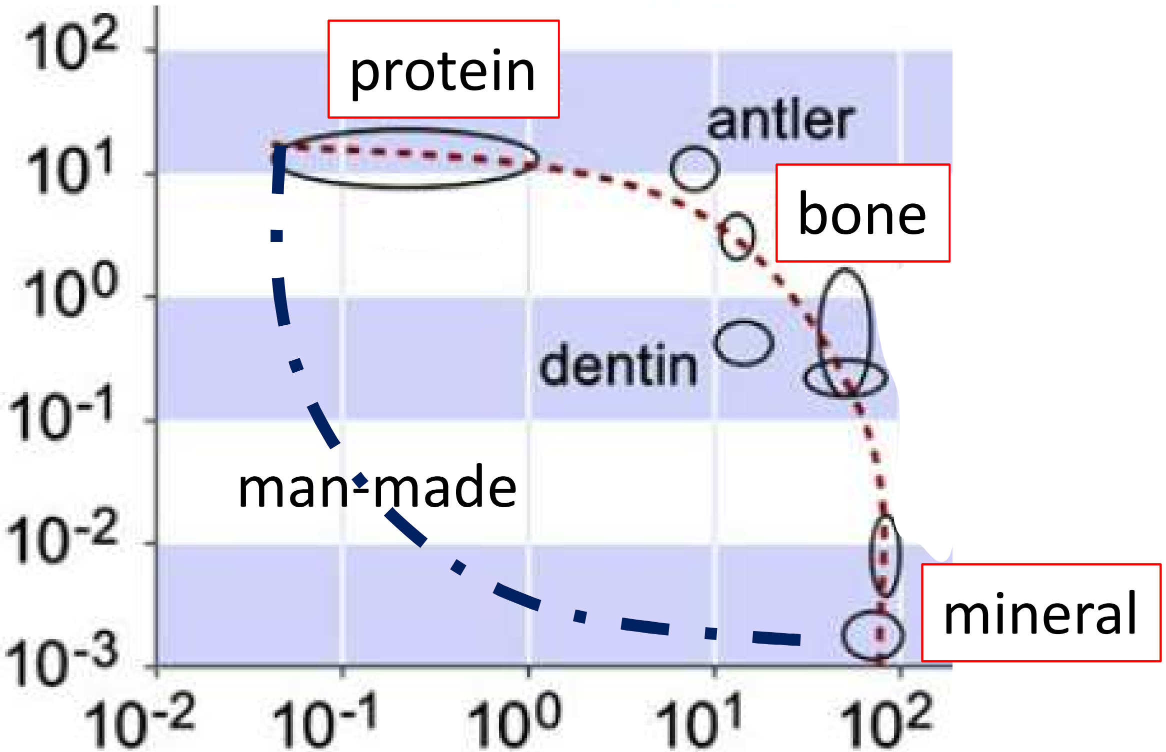
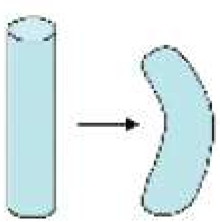
[Toughness]



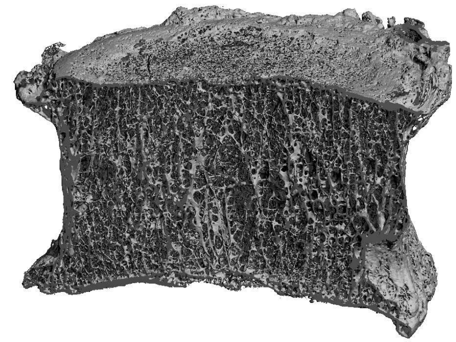
high energy
to break



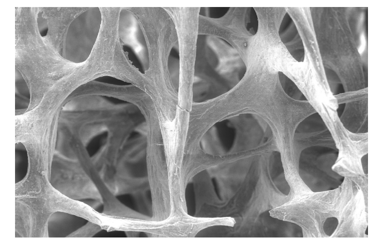
[Stiffness]



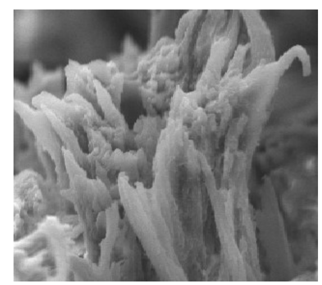
high force
to deform



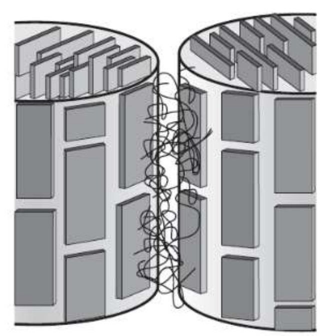
cm



mm



µm

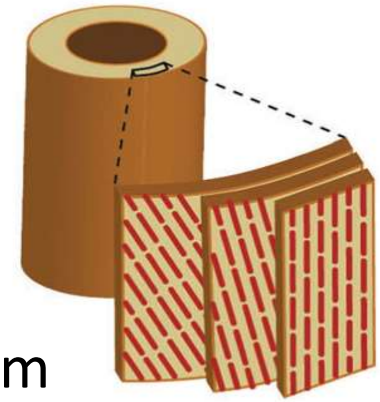


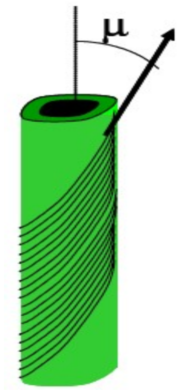
nm

Biologically Inspired Materials by 3D Printing

Biological Material

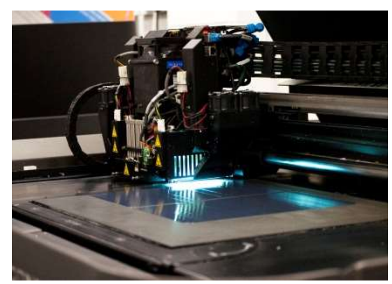
Construction Principle





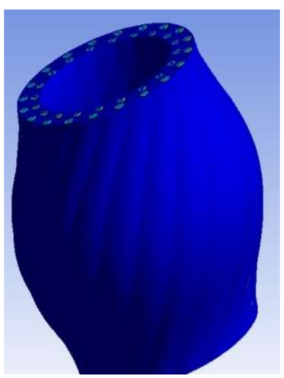
µm

Bioinspired Structure



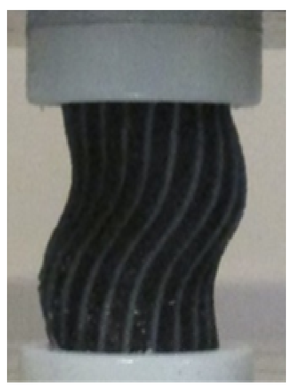
mm

Model



Connect & Compare

Experiment



Zorzetto & Ruffoni, Advanced Functional Materials 2018 https://onlinelibrary.wiley.com/doi/10.1002/adfm.201805888