Physics in Life Science

Lecture 20

Silk: High Performance Materials
Recap: color fading

Color: the colors we see are the colors reflected by objects.
Recap: color fading

Adsorption of light by pigment

Pigment molecule

Excited state

Excited state

Excited state

Ground state

Absorption of energy

UV: Photochemical reaction; Bleaching agent, O₂, etc.

+ΔE₁ = hf₁

Oxidized pigment molecule

+ΔE₁ = hf₁
Outline

- Silks: spider silks and silk work silks
- Silk protein and structure
- Structure vs Properties
- Applications
Physics Concepts

- Normal Stress

$$\sigma = \frac{F}{A}$$

Unit: $N/m^2 \rightarrow Pa$

- Normal Strain

$$\gamma = \frac{\Delta L}{L}$$

Unit: %
Physics Concepts

- For an ideal (Hookeian) solid
  - $\sigma = G_o \gamma$
  - $(G_o$: Static elastic modulus$)$
  - Apply to the linear region of the $\sigma \sim \gamma$ curve
- Breaking Stress Strain, and Energy
Comparisons between different fiber

![Graph](Diagram.png)
Experimental setup
Tensile strength

To stop a B747 in flight or to make a bullet proof vest?
Structure of Silks

If I drop a bit faster, the silk might be stronger!
Simulation of the formation of dragline of spider silks

Experimental set up.
Reeling speed and the strength of silks

\[ \sigma = G_0 \gamma \]

Stress at yield = “yield stress”
Strain at yield = “yield strain”

Tensile strength
Stiffness = resist deformation
Toughness = work to break

beyond this point – less solid-like, more liquid-like
extensibility
Structure and Mechanical properties

\[ \sigma = G_0 \gamma \]
Structure and Mechanical properties

10 mm s\(^{-1}\) is the “dragging” speed of spiders
Reeling speed and the strength of silks

If I drag faster, the silk will be stronger!
Hey, what happens? Tell me the trick.
Structure and Mechanical properties
Synthesis of spidroin

The primary structure does not play a key role…
Stress-strain curves of recombinant silk

- Produced soluble recombinant (rc)– dragline silk proteins with molecular masses of 60 to 140 kilodaltons by expressing in mammalian cells the dragline silk genes (*ADF-3/MaSpII* and *MaSpI*) of two spider species.
- Spun monofilaments from a concentrated aqueous solution of soluble rc–spider silk protein under modest shear and coagulation conditions.
- The spun fibers exhibited toughness and modulus values comparable to those of native dragline silks but with lower tenacity (?).
Stress-strain curves of recombinant silk
Stress-strain curves of recombinant silk

Graph showing stress-strain curves for Kevlar 49, PBO, Cocoon silk, Spider silk (Argiope), Spider silk (Nephila), and Synthesized spidroin.
600 gallons of milk → 5 pounds
Turn Silk Worm Silk into “Spider Silk”

About 100,000 Tones/per year of silk worm silks are produced around the world.

I wish I could become a spider..
Turn Silk Worm Silk into “Spider Silk”

- Challenge: Spiders can’t be raised. The source of the silk is very limited!
- Solution1: Genetic engineering

If you can transfer your gene to me, I may produce “spider silk”.

DBS, NUS
Turn Silk Worm Silk into “Spider Silk”

- Ordering of macro-$\beta$ Sheet
- Size of $\beta$ Sheet
- Mesh size of protein network $\xi$
Turn Silk Worm Silk into “Spider Silk”

Can we learn something from spiders?

Leave me alone…
Turn Silk Worm Silk into “Spider Silk”
Turn Silk Worm Silk into “Spider Silk”

Our results (NUS)
Review

- Breaking stress, strain and energy
- The structure of spider silks and the mechanical properties
- Different methods to achieve "super" silks.