Silk tutorial – Biomaterials from Biomechanics 3rd year course

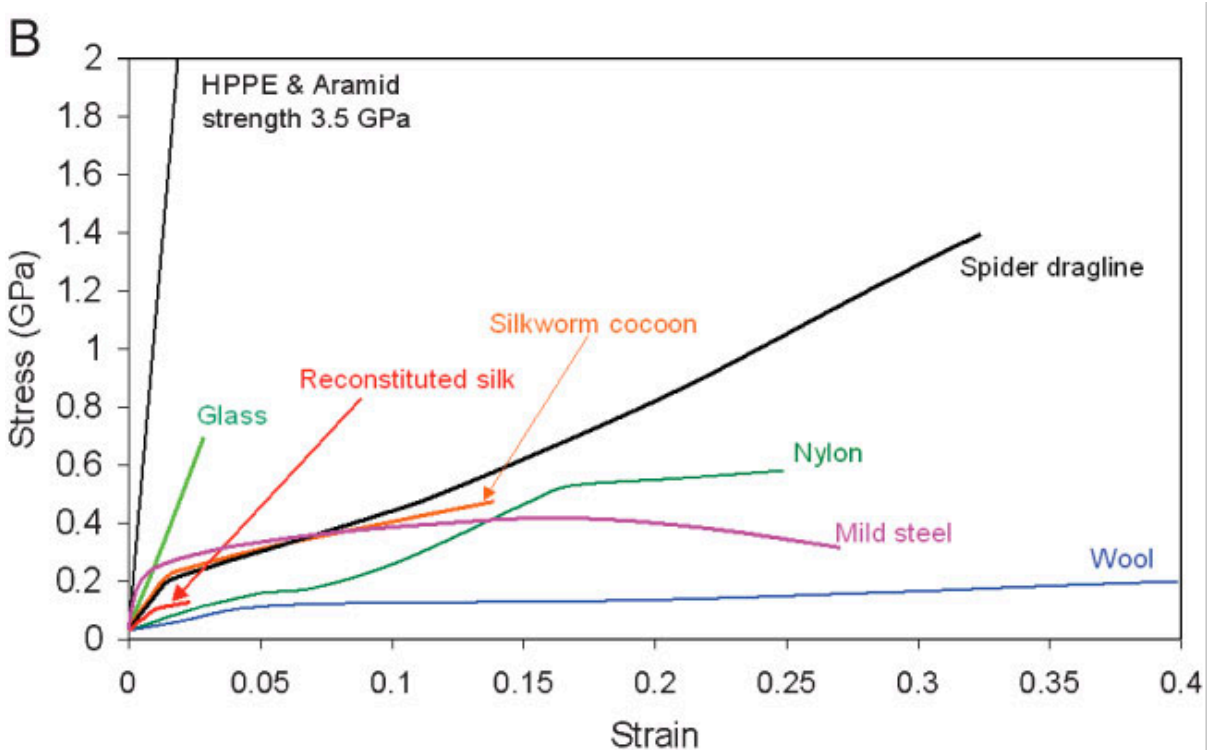

Figure 1. The (tensile) stress-strain of a number of different fibrous materials (spider dragline is taken from a golden orb weaver). Taken from Porter, D. and Vollrath, F., (2009), Figure 1B.

i. Explain how a stress-strain figure is generated, with reference to the machinery used to collect the raw data. (**5 marks**)

ii. Contrast the mechanical properties of wool and spider dragline silk. (**5 marks**)

   a. Explain these differences in terms of the evolution of these biomaterials. (**10 marks**)

   b. Explain these differences in terms of their protein structure and processing. (**10 marks**)

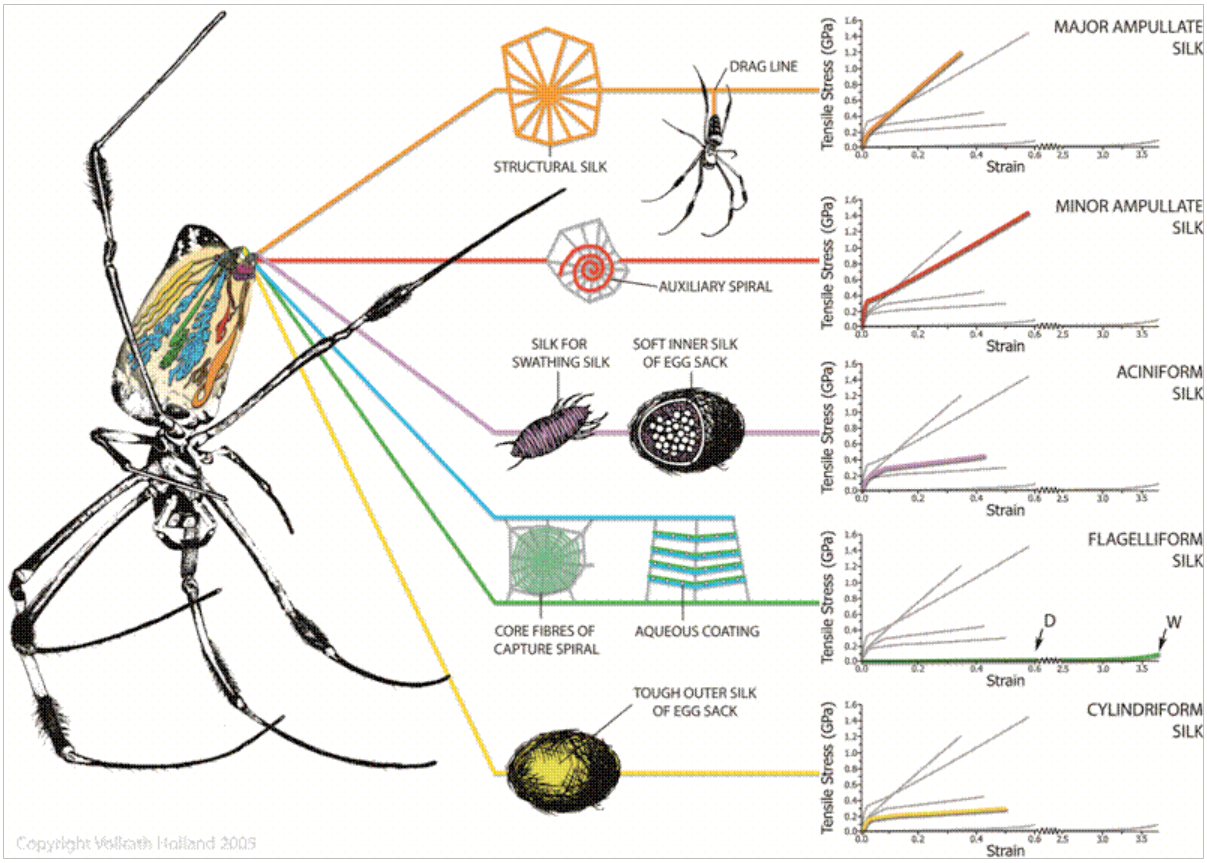

Figure 2. Spider silk diversity in a golden orb weaver, showing gland origin, ecological use and tensile stress-strain properties of the fibres. Adapted from Vollrath, F. and Porter, D. (2006), Figure 1.

iii. With reference to the data in Figure 2, how do spider silks' mechanical properties match their ecological function for orb weaver spiders? (**N.B.** 'orb weavers' refers to any member of the family Nephilidae – the golden orb weavers, or Araneidae – the true orb weavers.) (**30 marks**)

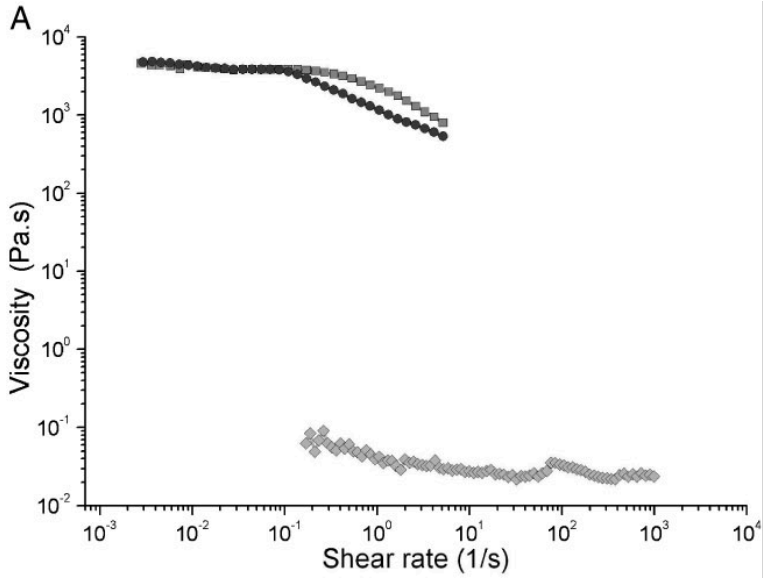

Figure 3. Rheological data from silkworm (black circles) and spider dope (grey squares) along with reconstituted silk (grey diamonds). Taken from Porter, D. and Vollrath, F., (2009), Figure 3A.

iv. Spider silk and silkworm rheology are extremely similar (Figure 3). What is the evolutionary significance of this? (**10 marks**)

v. What is reconstituted silk? What are the implications of their rheological profile, as shown in Figure 3? (**10 marks**)

vi. With reference to **all the figures** given, why would we want to copy spider silk? What are the main challenges in doing so? (**20 marks**)

Reading list

Before reading, make sure you understand the terms:

> Silk dope, stress, strain, initial modulus, breaking energy, tensile test, elastic, polymer, plastic, rheology, viscoelastic, toughness, stiffness, strength, non-newtonian fluid, composite. (**start with the Wikipedia page on spider silk** – it's fine, we wrote it). Use these words in your answers.

See attached video for an idea of the methods we use for looking at fibres.

Good review:

Vollrath, F. and Knight, D. P., (2001), Liquid crystalline spinning of spider silk, Nature, 410, pp. 541-548.

Structure of silk review and figures source:

Porter, D. and Vollrath, F., (2009), Silk as a biomimetic ideal for structural polymers, Advanced Materials, 21, pp. 487-492.

Don't worry about getting to grips with any modelling aspect, glass-transition or water-protein interaction.

Structure of wool:

http://resources.schoolscience.co.uk/unilever/16-18/proteins/Protch5pg5.html

Physical properties of silk review and figure source:

Vollrath, F. and Porter, D., (2006), Spider silk as archetypal protein elastomer, Soft Matter, 2, pp. 377-385.

This is pretty geeky in parts: just look at intro, first part of 'Structure-function relationships in silk' (p378), Figure 4, and 'Summary and challenges'.

Orb web function:

Blackledge, T. A. et al., (2011), The form and function of spider orb webs: Evolution from silk to Ecosystem. Chapter from Advances in Insect Physiology, Vol 41, edited by Casas, J. Elsevier.

Browse through what you think is relevant in the chapter. Don't cite this source, cite the original paper. Good list of primary literature references at the end.

Rheology and reconstituted silk:

Holland, C. et al., (2007), Natural and unnatural silks, Polymer, 48, pp. 2288-3392.

Introduction, section 2.1 and conclusions.

Shao, Z. et al., (2003), Structure and behaviour of regenerated spider silk, Macromolecules, 36, pp. 1157-1161.

Introduction, 'Amino Acid Compositions of Native Silk and Regenerated Silk', 'Mechanical properties of Regenerated spider silk', Conclusions.

Highlights of silk biomimetics:

Vollrath, F. et al., (2011), There are many more lessons still to be learned from spider silks, Soft Matter, 7, pp. 9595-9600.

Ignore any modelling or overly geeky stuff.

Teulé, F. et al., (2011), Silkworms transformed with chimeric silkworm/spider silk genes spin composite silk fibres with improved mechanical properties, PNAS, doi: 10.1073/pnas.1109420109.

Main labs for biomimetics:

http://sbc.usu.edu/htm/silk

http://sackler.tufts.edu/Academics/Degree-Programs/PhD-Programs/Faculty-Research-Pages/David-Kaplan

Please cite primary literature in your answers, as you would an essay. I'm expecting you to add more references to your section at the end of your answers. Be aware that a lot of the literature will be very geeky, so be picky in what you spend your time reading, as a lot of it will be too much detail (or modelling which we don't need to go into). Also be aware that a lot is unknown in the silk field and there are disagreements between labs, especially with the feasibility of biomimetic spider silk production.

Feel free to bring your own questions to the tutorial based on what you've read, but give all the questions a go.