Week 12

Biological Materials and Hybrid Materials

Exercise 1

Answer these questions by true or false:

1. Biological materials are always amorphous
   True/false
   There is semi-crystallinity in bio-polymers (for example cellulose) and biominerals which are crystalline

2. A protein has a polydispersity index of 1
   True/false
   Remember Polydispersity index: The structure of the protein is encoded by DNA and therefore very well defined, the polymerization of proteins is a very controlled process, both in sequence and length, different from polymerization of synthetic polymers, or other biopolymers such as polysaccharides

3. Sandwich structures are only used for high-tech applications such as helicopter blades
   True/false
   Also corrugated cardboard is a sandwich structure

4. A composite material contains always amorphous and crystalline material
   True/false
   Composite material are just mixtures of several phases, but both of them can be amorphous (example glass fibers in an epoxy) or crystalline (example of fcc/bcc metal composite)

Exercise 2:

Select the correct answer(s) (more than one answer can be correct)

1. DNA...
   a. is a polymer
   b. is stiff due to the double-helix structure
   c. follows the random coil model
      DNA would not have enough space if it would be a random coil (size 100um, a cell nucleus is only around 6 um), it is instead a complex hierarchical structure which includes proteins and supercoiling
   d. encodes proteins

2. Reinforced composites…
   a. Always contain long fibers
      Can contain particulate or flake composites, or short fibers
   b. Mechanical properties are given by the reinforcing component
      Properties of reinforcing compoment (for example the fibre), the property of the matriy (for example resin), the geometry and orientation of the reinforcing composites in the case of anisotropic shapes (fibers and flakes)
   c. Can produce materials with superior mechanical properties compared to the single components
   d. In biology always contain biominerals as reinforcement

Wood is a reinforced composite where a polymer matrix (lignin) is reinforced by still polymer fibers (cellulose), same for insect cuticles where the stiff polymer fiber is chitin.

Exercise 3: Biological materials

a) What are the 3 main polymer classes found in nature?
Nucleic acids (DNA, RNA), proteins, polysaccharides

b) What is the building block (monomer type) for each type in a)? (No need for details on the chemistry)
Ribonucleic acids (DNA and RNA): Consist of four different so called base-pairs in a certain sequence. Proteins: Consist of amino acids (about 20 different types). Polysaccharides, like starch and cellulose: Consist of sugars.

c) What makes spider silk to be so strong and ductile at the same time?
Crystalline parts and amorphous parts which are covalently connected. The different types of spider silk show that the stronger parts, such as the frame, contain much more of the crystalline elements, while the very flexible flag silk consists almost exclusively of amorphous regions.

Exercise 4: Self-assembly

The volume v of a linear hydrocarbon chain with n carbon atoms is given by $v = (27.4 + 26.9n) \times 10^{-3}$ nm^3, and its critical chain length is $l_c = (0.154 + 0.1265n)$ nm
An amphiphile has an anionic head-group with an optimum head-group area in aqueous solution of $a_0 = 0.65$ nm^2.

a) What shape of micelles are formed by amphiphiles with linear hydrocarbon tails with $n = 10$?
Using the formula for l_c and v:
$l_c = 0.154 + 0.1265 \times 10 = 1.419$ nm $v = (27.4 + 26.9 \times 10) \times 10^{-3}$ nm^3 = 0.2964 nm^3
The packing parameter is
$\frac{v}{a_0 l_c} = \frac{0.2964}{1.419 \times 0.65} < \frac{1}{3}$ this means spheres are formed

b) What is the average size and aggregation number of each micelle?
To get the radius (which is less than l_c)

$$4\pi r^2 = Na_0 \qquad \frac{4\pi r^3}{3} = Nv$$

$$\frac{Na_0 r}{3} = Nv \Rightarrow R = \frac{3v}{a_0} = \frac{3 \times 0.2964}{0.65} = 1.368 \text{ nm}$$

$$N = \frac{4\pi r^2}{a_0} = \frac{4\pi \times 1.368^2}{0.65} = 36.18$$

c) What happens if n increases?
The ratio of v and l_c does not change much with n (test values), and since a_0 is unaffected spheres will always form according to this model

Exercise 5. For hierarchical composite materials there seems to exist an optimal number of hierarchical levels, explain why it is not just the more levels the better.
With number of hierarchical levels toughness increases because a growing crack will encounter barriers at each hierarchy level to propagate. However, the strength will decrease due to the existence of flaws

Exercise 6: Give two application examples of composite materials and describe the relevant properties given by its structure.
See slides…