Eco-Friendly Fiber

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The current trend in society is to become eco-friendly and the materials produced nowadays should be preferably bio-based, and after service life preferably be digested by nature (biocompostable) or else fully and easily recyclable, either mechanically or chemically viz. Back-to-feedstock.

Producers of high-performance fibers currently pursue a green image and for example DSM-Dyneema announced bio-based Dyneema fiber grades.

On their website one can read "In line with our commitment to a sustainable future, we have developed the first ever bio-based ultra-high molecular weight polyethylene fiber".

Teijin Aramid, the producer of the aromatic polyamide fiber Twaron, also announced recently that in the future the monomers for their aramid fiber could be derived from BioBTX (Benzene, Toluene, Xylene from biomass). Also, Solvay is pursuing bio-based acrylonitrile and hence in the future carbon fibers could become bio-based.

The problem, however, is that the above bio-based polymers in the fibers are the very same polymer molecules as in the fossil-based counterpart. The monomer building blocks are bio-based and, consequently, the polymer chains as well, but these bio-based or fossil-based fibers cannot be digested by nature.

No micro-organisms can attack and digest these highly crystalline fibers.

Whereas collecting after service life and subsequent recycling and/or re-use is still a major challenge to be solved.

Fortunately for the fiber producers, customers and public at large do not realize these details especially when these fibers come in nice green colours.

So the main question addressed in this chapter is whether bio-based high-performance fibers can be made which are biocompostable, either in the environment (on the long run) or in a composting plant?

There is no strict definition for a high-performance fiber, the term generally denotes fibers that give higher values when used in a range of applications. These values can be related to stiffness and strength and/or functional properties such as thermal and electrical conductivity. In this chapter the emphasis is on fibers possessing a high strength, typically >3 GPa, and a corresponding stiffness of typically >100 GPa.

*** Natural cellulose fiber**

Cellulose is the most abundant polymer on our planet and grows in nature in the order of 1012–1014tons/annum, depending on annual climate, to be compared with 3.5 × 108 tons of synthetic polymers/plastics per year, Nature uses its cellulose to reinforce the wall of cells in plants but can also be found in algae, fungi, bacteria with e.g. the well-known bacterial cellulose to be discussed below. Nature knows how to balance between the three most important properties viz. strength, stiffness and toughness in its applications.

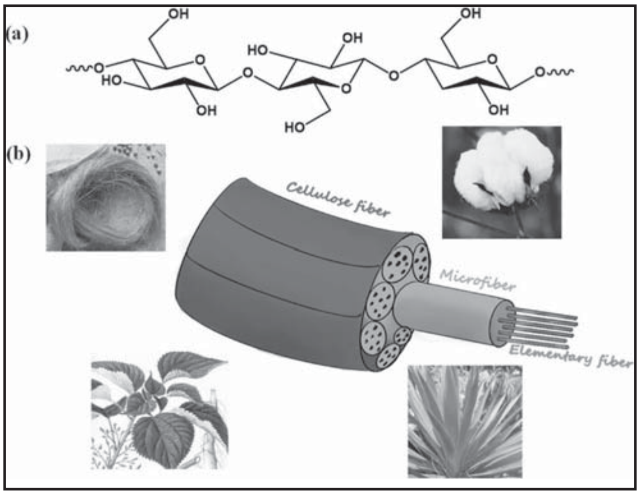
Cellulose is the only polymer which during growth forms extended-chain crystals, the growing chains align themselves in a parallel way in fibrils, which is quite unique for a flexible chain polymer molecule like cellulose.

An exception in this case for synthetic polymers is the growth of polyoxymethylene (POM) whiskers during cationic polymerization which contain POM molecules in an extended-chain conformation.

POM was the first polymer whisker, which consisted of extended-chain molecules to form needle-shaped crystal which was found in 1972 from a cationic polymerization system of trioxane in cyclohexane.

It was found that besides catalyst BF3, moisture or H2O was the key co-catalyst to initiate the reaction, and the concentration of catalyst/co-catalyst affects the POM crystal morphology significantly.

Needle-shaped POM crystal whisker was found in solution when the concentration of H2O/BF3 was between 0.01 and 0.1. As an ideal crystal form consisting of extended-chain molecules, it prompted the study of the structure and properties as well as the processing of polymers.



-(a) Chemical structure of cellulose, (b) structure of cellulose in nature.

*** Silk**

Silk has been produced for hundred millions of years by arthropods and used by human for at least 5000 years for all kind of applications ranging from textiles to wound dressings. The main source of silk is from the mulberry silk worm and faming started some 5000 years ago in China. The silkworm pupates in a protective cocoon, and cocoon silk is secreted from its salivary glands.

The cocoon silk is colourless and it is easily cleared of minerals, making it an ideal material for winding into a thread. The silk of spiders cannot be collected that easy as from silkworm cocoons but the nets of orb weaving spiders have also historically been employed for applications such as fishing lines and wound dressings.

Orb webs can be found anywhere in the world and the diameter ranges from a few centimeters to several meters or even up to 25 meters in length .

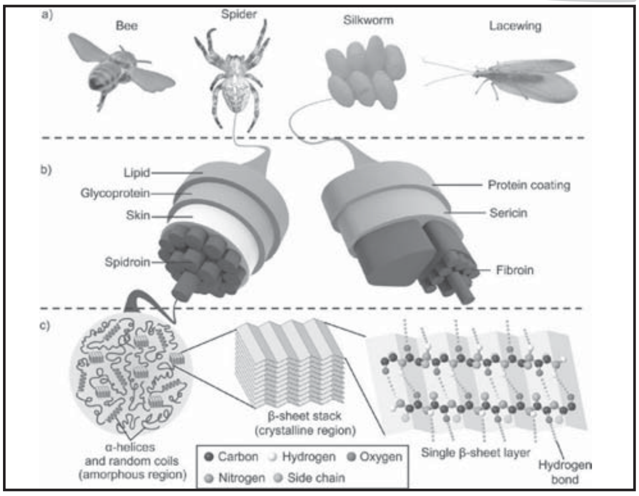
There are some differences in the structure of silk and spider silk., silk is composed of the core fibroin, the outer sericin and the outermost protein coating.

Fibroin is composed of amino acids arranged in β-sheets.

Two thirds are rigid crystal regions, and one third is amorphous regions.

The fibroin chains are alternately arranged by hydrophilic and hydrophobic parts.

There are physico-chemical effects between these areas giving the silk high strength. Sericin is a layer of hydrophilic protein that gives silk adhesion, stickiness and hydration.



- (a) Pictures of natural sources of silk, (b) cross section illustration comparing the different hierarchical structures of fibers from the spider and the silkworm, (c) schematics of the secondary structures of silk.

In addition to the core fibroin of similar structure, spider silk does not contain sericin layer. Their fibroin is wrapped by a layer of skin, and outer layer of glycoprotein and a layer of lipid in the outermost, which makes spider silk possess good antibacterial properties.

*** Polyester fiber**

Biodegradable polyester is a new type of environmentally friendly polymer, which has received increasing attention in recent years. Compared with petroleum-based polymers, bio-based polymers produce fewer greenhouse gases and lower carbon emissions during the production, which meets the national development requirements for carbon neutrality.

Common bio-based polymers include polylactic acid (PLA), polyhydroxyalkanoate(PHA), polyglycolic acid (PGA), polycaprolactone (PCL), poly (butyleneadipate-co-terephthalate) (PBAT), polybutylece terephthalate (PBT), etc. Polyester bio-based fibers can be produced by these polyesters through various spinning methods. This chapter selects PLA fiber and PGA fiber as the representative of bio-based polyester fiber, and its structure, preparation method, mechanical properties and application will be reviewed.

*** PLA (polylactic acid) fiber**

Polylactic acid (PLA) is next to cellulose the most studied bio-based polymer and is currently produced by many companies to replace petro-based polymers in packaging applications, notably single-use packaging.

*** Conclusion and perspective**

As a potential substitute for petroleum-based fiber, bio-based fiber has abundant raw material reserves and lower carbon emissions in production, which is beneficial to alleviating environmental pollution and achieving carbon neutrality.

Bio-based fibers already have important applications in the textile industry, biomedicine and other industries, and have become an indispensable part of the development of society.