Hans-Josef Endres
Andrea Siebert-Raths

Engineering Biopolymers
Markets, Manufacturing, Properties and Applications
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Preface

The biopolymer group of materials are not an entirely new type of material. Instead they are innovative polymer materials within the well-known class of plastics materials. Thus the very same relationships obtain between their microstructures and macroscopic processing, use and disposal properties as have been known from conventional plastics for a long time.

This book is intended to contribute to our understanding for innovative biopolymers as technical materials. In contrast to most of the book published previously on this topic, biopolymers will be comprehensively presented in the framework of this book from the perspective of materials engineering. With a view to the practical application as polymer materials, the engineering property profiles of the biopolymers will be described in detail by comparing them with conventional plastics. In addition to processing and use properties, the descriptions will include manufacture, chemical structure, microstructure, specific and meanwhile multifarious test standards as well as the corresponding regulatory circumstances and disposal properties of biopolymers within the topical context of sustainability.

In order to simply the interested user's ultimate search for suitable biopolymer materials and to ease contact with materials manufacturers, this book also contains an extensive description of the market in terms of the various commercially available biopolymer materials, their manufacturers and processors.

In the early 1980s, the newly developed biopolymers went through a euphoric phase as the future polymer materials independent of crude oil. However, since the materials properties were still unproven and the price:performance ratio of this first generation of biopolymers was sobering, the euphoria soon cooled off and was followed by the further development and/or optimization of the innovative biopolymer materials. In recent years, what is now the second generation of further developed biopolymers has meanwhile experienced dynamic, annual double-digit growth.

In Europe and America, developmental work and consequently also the use of biopolymer materials have concentrated also exclusively on the field of compostable packaging and other short-live products.

Starting in Asia, and meanwhile in Europe and USA as well, the availability issue for the raw materials used for biopolymers is increasingly supplanting compostability as the priority disposal option. For the third generation, instead of biodegradable materials, biobased and durable materials are being developed for engineering applications outside the field of packaging, too, e.g., for the automotive and textile industries.

There are virtually no data available yet on the long-term properties of biopolymers (e.g. creep resistance, stress relaxation, UV resistance, fatigue behavior, thermal resistance).

Also in terms of industrial processibility and the relevant rheological processing data, the information in the area of biopolymers is sketchy from the perspective of polymer engineering. Since there is a strong competitive attitude among biopolymers manufacturers, till today there are hardly no concerted efforts to collect and provide uniform, comprehensive and comparable materials information in the same place – as is the case for conventional plastics.
Parallel and supplementary to this book, a databank has been developed for biopolymers in cooperation with the M-Base Engineering + Software GmbH in analogy to the internationally known Campus polymer databank for conventional plastics. Since the end of 2009, it presents the properties of innovative, commercially available biopolymers as completely and comparably as possible. Nearly all biopolymers available on the market have been characterized by the authors according to the corresponding test standards. Some results from these investigations are already included in this book in condensed form.

In terms of materials development, biopolymers are still in their early phase. Future materials developments will, as they did with conventional plastics, not only concentrate on new monomers or innovative polymers, but also increasingly on the further development of existing polymers by generative co- and terpolymers, blending and additivizing. To this end, the extensive existing experience in the field of conventional plastics can and should definitely be reverted to.

Hans-Josef Endres, Andrea Siebert-Raths, Hanover, May 2011
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1 Introduction

1.1 Defining the Topic

The concept of biopolymers has become a buzzword. It is increasingly heard in the media, in politics, industry, in research and development in particular, and at numerous meetings of experts. While it has become a bit hackneyed, it has yet to be precisely defined (Fig. 1.1). That is why we should start out by differentiating the topic and by defining what we mean by biopolymers.

By contrast with green biotechnology (agriculture) and red (pharmaceutical) biotechnology, the notion of a “white biotechnology” is still rather new. Even though humanity has used it for millennia, e.g., for fermenting alcohol and lactic acid, this term still is not widely applied. White biotechnology stands for the industrial production or modification of basic organic or fine chemicals and active agents or biogenic energy sources using optimized species of microorganisms, enzymes, or cells [1]. However, this definition covers only parts of the biopolymeric whole, i.e., only the biotechnological production of polymer raw materials or additives for bio-based biopolymers. Conversely, the biotechnological production of chemicals can be covered here only insofar as these materials serve to produce biopolymers. Purely biotechnologically generated molecular materials, such as exopolysaccharides, xanthane, gellan gum, cordulan, alginate, hyaluronic acid, oligosaccharides, or various acids and vitamins, are not engineering biopolymers.

The concepts of biopolymers and white biotechnology coincide in the large group of biopolymers that are based on biotechnologically manufactured monomers or polymer raw materials such as lactic acid, bio-alcohols, or polyhydroxyalkanoates (Fig. 1.2). Biomolecules, such as the large group of polyamino acids, occur in living beings and natural organic substances are of course not engineering materials. Therefore, we do not regard these biogenic macromolecules as biopolymeric materials. One exception to this are biomolecules that can be biotechnologically further metabolized into raw materials for manufacturing
polymers. Other exceptions include polysaccharides as well as some bio-based acids (such as lactic acid or succinic acid), or vegetable oils that can be used directly as raw materials for biopolymers.

Currently, conventional wood-flour filled or natural fiber-reinforced polyolefins, such as polyethylene or polypropylene, are also often included in the concept of biopolymers [2–7], see Fig. 1.3.

However, we believe that this usage blurs the concept of biopolymers. For one, it is impossible to provide quantitative data on their minimum content of bio-based components. Thus it is quite possible to speak of a PP with only 10% natural fiber as a biopolymer. That is why this book does not include so-called WPCs (= Wood Plastic Composites) or (NFCs = Natural Fiber Reinforced Composites), that is, conventional polymers filled with wood-flour or natural fibers, respectively. On the other hand, if they have a biopolymer matrix, wood-flour filled or natural fiber-reinforced polymers will be covered here (Fig. 1.4).

![Figure 1.2](image1.png) Where white biotechnology and biopolymers coincide

![Figure 1.3](image2.png) Biopolymers and natural fiber-reinforced or wood-flour filled plastics
The term ‘bio-compatible’ generally designates materials that neither interact with nor have any negative effect on organisms they are in contact with. However, such materials are not necessarily biopolymers, e.g., medical thread or polylactide-based implants. Similarly, bioinert materials can also be bio-compatible, because their interaction with human tissue is minimal, e.g., ceramic and titanium-based implants or siloxanes, as well as special plastics (e.g., certain PEEK, PET, or PE-UHMW types) [8–10]. In fact, there is a certain overlapping of the concepts of biopolymers and bio-compatibility among bio-absorbable or bioactive polymers, which are also bio-compatible plastics. However, these concepts are far from congruent, because a large number of materials can be assigned to just one of these two areas or concepts (Fig. 1.5).

Traditional materials, such as wood or rubber, which can be classified as biopolymers according to this definition, are not treated in this context. Such materials are not innovative thermoplastic biomaterials and to include them would go beyond the scope of this book. As with conventional, petrochemical-based plastics, there are thermoplastic, elastomeric, and even thermosetting polymer materials among these various biopolymer groups, as shown in Fig. 1.6.

![Figure 1.4](image1.png)  
Figure 1.4  Natural fiber-reinforced biopolymer (in this illustration: wood fibers in a polylactide matrix)

![Figure 1.5](image2.png)  
Figure 1.5  Intersection of biocompatible materials and biopolymers