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Handbook of Fiber Science and Technology: Volume III

High Technology Fibers

Part A

edited by
Menachem Lewin
Jack Preston

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HIGH TECHNOLOGY FIBERS

Part A

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HIGH TECHNOLOGY FIBERS

Part A

INTERNATIONAL FIBER SCIENCE AND TECHNOLOGY SERIES

Volume 1: Handbook of Fiber Science and Technology (I): Chemical Processing of Fibers and Fabrics – Fundamentals and Preparation (in two parts), *edited by Menachem Lewin and Stephen B. Sello*

Volume 2: Handbook of Fiber Science and Technology (II): Chemical Processing of Fibers and Fabrics – Functional Finishes (in two parts), *edited by Menachem Lewin and Stephen B. Sello*

Volume 3: Carbon Fibers, *by Jean-Baptiste Donnet and Roop Chand Bansal*

Volume 4: Fiber Technology: From Film to Fiber, *by Hans A. Krässig, Jürgen Lenz, and Herman F. Mark*

Volume 5: Handbook of Fiber Science and Technology (III): High Technology Fibers (in two parts), *edited by Menachem Lewin and Jack Preston*

Other Volumes in Preparation

ABOUT THE SERIES

When human life began on this earth, *food* and *shelter* were the two most important necessities. Immediately thereafter, however, came *clothing.* The first materials used for it were fur, hide, skin, and leaves—all of them sheetlike, two-dimensional structures not too abundantly available and somewhat awkward to handle. It was then—quite a few thousand years ago—that a very important invention was made: to *manufacture* two-dimensional systems—fabrics—from simple monodimensional elements—fibers; it was the birth of textile industry based on fiber science and technology. Fibers were readily available everywhere; they came from animals (wool, hair, and silk) or from plants (cotton, flax, hemp, and reeds). Even though their chemical composition and mechanical properties were very different, yarns were made of the fibers by spinning and fabrics were produced from the yarns by weaving and knitting. An elaborate, widespread, and highly sophisticated art developed in the course of many centuries at locations all over the globe virtually independent from each other. The fibers had to be gained from their natural sources, purified and extracted, drawn out into yarns of uniform diameter and texture, and converted into textile goods of many kinds. It was all done by hand using rather simple and self-made equipment and it was all based on empirical craftsmanship using only the most necessary quantitative measurements. It was also performed with no knowledge of the chemical composition, let alone the molecular structure of the individual fibers. Yet by ingenuity, taste, and patience, myriads of products of breathtaking beauty, remarkable utility, and surprising durability were obtained in many cases. *This first era* started at the very beginning of civilization and extended into the twentieth century when steam-driven machinery invaded the mechanical operations and some empirical procedures—mercerization of cotton, moth-proofing of wool and loading of silk—started to introduce some chemistry into the processing.

The second phase in the utilization of materials for the preparation and production of fibers and textiles was ushered in by an accidental discovery which Christian Friedrich Schoenbein, chemistry professor at the University of Basel in Switzerland, made in 1846. He observed that cotton may be converted into a soluble and plastic substance by the action of a mixture of nitric and sulfuric acid; this substance or its solution was extruded into fine filaments by Hilaire de Chardonnet in 1884.

Organic chemistry, which was a highly developed scientific discipline by that time, gave the correct interpretation of this phenomenon: the action of the acids on cellulose—a natural fiber former—converted it into a *derivative*, in this case into a cellulose nitrate, which was soluble and, therefore, spinnable. The intriguing possibility of manipulating natural products (cellulose, proteins, chitin, and others) by chemical action and thereby rendering them soluble, resulted in additional efforts which led to the discovery and preparation of several cellulose esters, notably the cellulose xanthate and cellulose acetate. Early in the twentieth century each compound became the basis of a large industry: viscose rayon and acetate rayon. In each case special processes had to be designed for the conversion of these two compounds into a fiber, but once this was done, the entire mechanical technology of yarn and fabric production which had been developed for the natural fibers was available for the use of the new ones. In this manner new textile goods of remarkable quality were produced, ranging from very sheer and beautiful dresses to tough and durable tire cords and transport belts. Fundamentally these materials were not truly "synthetic" because a known natural fiber former—cellulose or protein—was used as a base; the new products were "artificial" or "man-made." In the 1920s, when viscose and acetate rayon became important commercial items polymer science had started to emerge from its infancy and now provided the chance to make *new fiber formers* directly by the polymerization of the respective monomers. Fibers made out of these polymers would therefore be "truly synthetic" and represent additional, extremely numerous ways to arrive at new textile goods. Now started the *third era* of fiber science and technology. First the basic characteristics of a good synthetic fiber former had to be established. They were: ready spinnability from melt or solution; resistance against standard organic solvents, acids, and bases; high softening range (preferably above 220°C); and the capacity to be drawn into molecularly oriented fine filaments of high strength and great resilience. There exist literally many hundreds of polymers or copolymers which, to a certain extent, fulfill the above requirements. The first commercially successful class was the *polyamides*, simultaneously developed in the United States by W. H. Carothers of duPont and by Paul Schlack of I. G. Farben in Germany. The *nylons*, as they are called commercially, are still a very important class of textile fibers covering a remarkably wide range of properties and uses. They were soon (in the 1940s) followed by the *polyesters*, *polyacrylics*, and *polyvinyls*, and somewhat later (in the 1950s) there were added the *polyolefins* and *polyurethanes*. Naturally, the existence of so many fiber formers of different chemical composition initiated successful research on the molecular and supermolecular structure of these systems and on the dependence of the ultimate technical properties on such structures.

As time went on (in the 1960s), a large body of sound knowledge on structure-property relationships was accumulated. It permitted embarkation on the reverse approach: "tell me what properties you want and I shall *tailor-make* you the fiber former." Many different techniques exist for the "tailor-making": graft and block copolymers, surface treatments, polyblends, two-component fiber spinning, and cross-section modification. The systematic use of this "macromolecular engineering" has led to a very large number of *specialty fibers* in each of the main classes; in some cases they have properties which none of the prior materials—natural and "man-made"—had, such as high elasticity, heat setting, and moisture repellency. An important result was that the new fibers were not content to fit into the existing textile machinery, but they suggested and introduced substantial modifications and innovations such as modern high-speed spinning, weaving and knitting, and several new technologies of texturing and crimping fibers and yarns.

This third phase of fiber science and engineering is presently far from being complete, but already a *fourth era* has begun to make its appearance, namely in fibers for uses *outside* the domain of the classical textile industry. Such new applications involve fibers for the reinforcement of thermoplastics and duroplastics to be used in the construction of spacecrafts, airplanes, buses, trucks, cars, boats, and buildings; optical fibers for light telephony; and fibrous materials for a large array of applications in medicine and hygiene. This phase is still in its infancy but offers many opportunities to create entirely new polymer systems adapted by their structure to the novel applications outside the textile fields.

This series on fiber science and technology intends to present, review, and summarize the present state in this vast area of human activities and give a balanced picture of it. The emphasis will have to be properly distributed on synthesis, characterization, structure, properties, and applications.

It is hoped that this series will serve the scientific and technical community by presenting a new source of organized information, by focusing attention to the various aspects of the fascinating field of fiber science and technology, and by facilitating interaction and mutual fertilization between this field and other disciplines, thus paving the way to new creative developments.

Herman F. Mark

INTRODUCTION TO THE HANDBOOK

The Handbook of Fiber Science and Technology is composed of five volumes: chemical processing of fibers and fabrics; fiber chemistry; high technology fibers; physics and mechanics of fibers and fiber assemblies; and fiber structure. It summarizes distinct parts of the body of knowledge in a vast field of human endeavor, and brings a coherent picture of developments, particularly in the last three decades.

It is mainly during these three decades that the development of polymer science took place and opened the way to the understanding of the fiber structure, which in turn enabled the creation of a variety of fibers from natural and artificial polymeric molecules. During this period far-reaching changes in chemical processing of fabrics and fibers were developed and new processes for fabric preparation as well as for functional finishing were invented, designed, and introduced. Light was thrown on the complex nature of fiber assemblies and their dependence on the original properties of the individual fibers. The better understanding of the behavior of these assemblies enabled spectacular developments in the field of nonwovens and felts. Lately, a new array of sophisticated specialty fibers, sometimes tailor-made to specific end-uses, has emerged and is ever-expanding into the area of high technology.

The handbook is necessarily limited to the above areas. It will not deal with conventional textile processing, such as spinning, weaving, knitting, and production of nonwovens. These fields of technology are vast, diversified, and highly innovative and deserve a specialized treatment. The same applies to dyeing, which will be treated in separate volumes. The handbook is designed to create an understanding of the fundamentals, principles, mechanisms, and processes involved in the field of fiber science and technology; its objective is not to provide all detailed procedures on the formation, processing, and modification of the various fibers and fabrics.

Menachem Lewin

PREFACE

This volume concentrates on fibers recently developed and potentially available commercially in the near future, rather than on high-volume commodity fibers. While numerous prior works dealt with fibers for classical textile applications, the present series deals only with fibers for wholly new applications. Thus, in this volume, one can find information brought together by experts in their fields on recent developments in high-modulus fibers, heat and chemically resistant fibers, fibers for use in biomedical applications, elastomeric fibers, and fibers from polyblends. Emphasis is on the preparation, properties, and end uses of the fibers. Although no fibers presently produced are intentionally modified to be biodegradable, a chapter is devoted to biodegradable polymers because of the potential importance of such fibers.

Since the chapters have been written by acknowledged experts on the several fibers, the truly significant developments are highlighted for the reader wishing to gain insights on the present status and the future course of developments for these fibers. A future volume will deal with such subjects as optical fibers, ceramic fibers, hollow fibers for separation of gases and liquids, and metal fibers. The editors wish to thank the contributors for sharing their expertise and making possible this book which, it is hoped, will stimulate increased end-use applications of fibers from this rapidly expanding area of technology.

Menachem Lewin
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FUNDAMENTALS AND PREPARATION PART B

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