

Book of Fiber Science and Technology: Volume II  
Mechanical Processing of Fibers and Fabrics

# FUNCTIONAL FINISHES

Part B

*edited by*

Menachem Lewin    Stephen B. Sello

**Handbook of Fiber Science and Technology: Volume II**  
**Chemical Processing of Fibers and Fabrics**

# **FUNCTIONAL FINISHES**

**Part B**

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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 were 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; specialty 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

## INTRODUCTION TO VOLUMES I AND II

Textiles have undergone wet chemical processing since time immemorial. Human ingenuity and imagination, craftsmanship and resourcefulness are evident in textile products throughout the ages; we are to this day awed by the beauty and sophistication of textiles sometimes found in archaeological excavations.

The objectives of the chemical processing, while basically unchanged over the centuries, have in recent times been diversified and expanded. Comfort and esthetics, durability and functionality, safety from fire and health hazards, easy care performance, such as washability, soil release, water and oil repellency, and stability against biological attack are examples of the objectives of chemical treatments of fibers and fabrics. Before these treatments can be applied, the textile materials have to be prepared by appropriate chemical procedures such as sizing, desizing, scouring, bleaching, and mercerization.

The array of fibers used at present is highly diversified. The advent of polyester, nylon, acrylic, and polyolefin fibers in recent years has greatly increased the complexity of the treatments as well as the range of the chemicals used. It became clear that approaches such as those practiced until 3 decades ago cannot continue to serve the solution to the wide range of problems facing chemists and technologists in the industry today. This realization coincided with rapid developments in polymer science and technology and brought about a surge in research and development activities in textile chemistry.

The studies carried out in the last 3 decades yielded a staggering amount of new data and not only a better understanding of the fibers and fiber assemblies and of the chemical interactions and structural changes, but also a large number of innovative ideas were created and put forward. Many of these ideas were developed into new processes.

**machines, and instruments, and culminated in a remarkable reshaping of the textile industry.**

**In these books an attempt is made to review and summarize the most important developments in this field. The emphasis is placed on the chemical aspects of the problems discussed. While technological aspects as well as industrial applications of the processes are being dealt with, only a brief treatment is given to factory layouts and to the machinery used.**

***Chemical Processing of Fibers and Fabrics* is divided into two major areas. The first area, the fundamentals underlying the chemical treatments of fibers and fabrics and the preparation processes are presented in Vol. I, Parts A and B. The second area, the functional finishes of textiles are discussed in Vol. II, Parts A and B.**

**The need for a new comprehensive book in the field of chemical processing of fibers and fabrics has been felt for a long time. The vast amount of information accumulated in recent years in this field necessitated the preparation of the present books. They are intended for scientists and technologists both in the field of textiles and polymers as well as for students and researchers in other fields of human endeavor.**

**It is hoped that these books will not only further the knowledge and understanding of the complex field of textile chemistry, but will also bring about an interaction between people dealing in this field and people of other disciplines and will trigger off new and innovative developments for the benefit of all humanity.**

**Menachem Lewin  
Stephen B. Sello**



## PREFACE

The advent of the new man-made fibers and the introduction of fiber blends on the one hand and of the diverse treatments of textiles with chemical finishes on the other has brought about the development and appearance of many new textile products with well-defined bulk and surface characteristics.

For centuries the finishing procedures had been based on empirical approaches, but after World War II many of these were replaced by procedures developed after systematic and detailed scientific studies. It is beyond the scope of this book to present all detailed chemical finishing procedures developed, to list all chemicals used, and to present the synthesis of these chemicals. Its objective is rather to lead to an understanding of the underlying principles of these developments, and of the mechanisms by which the chemical finishes act, by discussing the most important recent developments in the field.

This book reviews flame retardant treatments of natural and synthetic textiles, and covers many aspects of wool finishing. Surface treatments such as water and oil repellency, soil release applications and electroconductive finishes are discussed in detail. Modern energy-saving technology such as the use of radiation is the subject of the last chapter of this book.

The authors of the various chapters of this book have a worldwide reputation in their respective fields. They present the mechanistic concepts and principles of functional finishes and review the state of the art critically.

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**Menachem Lewin  
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# 1

## FLAME RETARDANCE OF FABRICS

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## 1. INTRODUCTION

### 1.1 Importance of Problem

Flammability of fibrous products is one of the major problems posed to scientists and technologists at the present time. The U.S. national projection for fires caused by textiles per year based on averages computed for 1977-1978 is 214,800 [1]. These fires would cause 3500 deaths and 8800 injuries, and up to \$656 million in direct losses and \$2 billion in fire-related expenditures. Although all fiber and textile products may be involved in starting of fires as well as materially contributing to the flame, mattresses, upholstered furniture, and bedding are the most prominent with regard to the number of fires. They are followed in this order by nonworn clothing, curtains, carpets, and worn clothing [1]. Fires involving worn clothing, however, appear to be the most dangerous and show the highest rate of deaths per fire. It was recently concluded by Tovey and Katz [1] that most textile fires "start because someone misused a source of heat or misused the material ignited. But this does not relieve the textile industry from the responsibility for working to reduce the flammability of textile products."

Hazards from flammable fabrics were recognized for many centuries and repeated attempts have been made to cope with them [3]. One of the first recorded efforts in this direction was made in 1735 by Jonathan Wyld of England, who patented a flame-retarding mixture of alum, ferrous sulfate, and borax [4]. Gay-Lussac [5] in 1821 developed a flame-retarding finish for jute and linen based on borax, ammonium phosphate, and chloride. Perkin [6] in 1912 precipitated stannic oxide within the fiber and obtained a durable flame resistance albeit with a severe afterglow.

Many further attempts were made by the military during World Wars I and II to reduce fire hazards by introducing fire-retardant treatments and suitable clauses in fabric specifications [7].



## 1.2 Legislation and Flame Retardant Development

Only in 1952, following a number of deaths from garment fires, were the hazards from flammable fabrics viewed for the first time as a general consumer problem, which brought about the Flammable Fabric Act of 1951, regulating flammability of textile products purchased directly by consumers [8, 9]. Subsequently the 45° angle test was accepted as a commercial standard in the United States [10] with the aim of indicating textiles used for apparel "which ignite easily and, once ignited, burn with sufficient intensity to be hazardous when worn." Similar standards were subsequently adopted in Britain [11], Switzerland [12], Canada [13], and Japan [14].

Further developments led to the Ammended Flammable Fabric Act of 1967 [9], which gave to the U.S. government, e.g., to the Secretary of Commerce, the authority and duty to "set mandatory flammability standards as needed to protect the people against unreasonable risk." It also authorized investigation of deaths and inquiries, research, and development of test methods and devices. The Act related to standards applicable to wearing apparel and interior furnishings for homes, offices, and places of assembly or accomodation. The standards according to this Act should be "reasonable and practicable." This meant that they had to be acceptable to all sectors of the industry and the public, i.e., producers, distributors, consumers, enforcement offices, and politicians. It was also realized that compromises would have to be reached between the degree of protection and the cost of protection. Tribus [15] illustrated this trade-off (see Fig. 1.1) as an exercise in risk-taking: the reduction in the number of burns expected for a given standard is plotted against the severity of the tests required by it and against the cost.

The philosophy has subsequently changed with the passing of the Consumer Product Safety Act and the establishment of the Consumer Product Safety Commission (CPSC) in 1972. According to this Act, the government is empowered to issue standards protecting the public from unreasonable hazards even without prior interaction with industry.

At about the same time, new Federal Standards were issued by the Department of Commerce for the surface flammability of carpets in 1970 [16, 17]. Although these did not require the addition of special chemicals to carpets, except alumina trihydrate, they did increase the awareness of the consumers and industry to the need of testing. The most important change in the attitude of the industry was produced by the 0-6X Children Sleepwear Standard DOC [18-20] FF-3-71. The standard was developed as a result of an extensive collection and analysis of data pertaining to fabric flame accidents, which enabled the decision on priorities for flammability standards by end-use item [17]. This standard introduced in 1972 was supplemented with a sampling plan covering both fabrics and garments. The plan went into effect