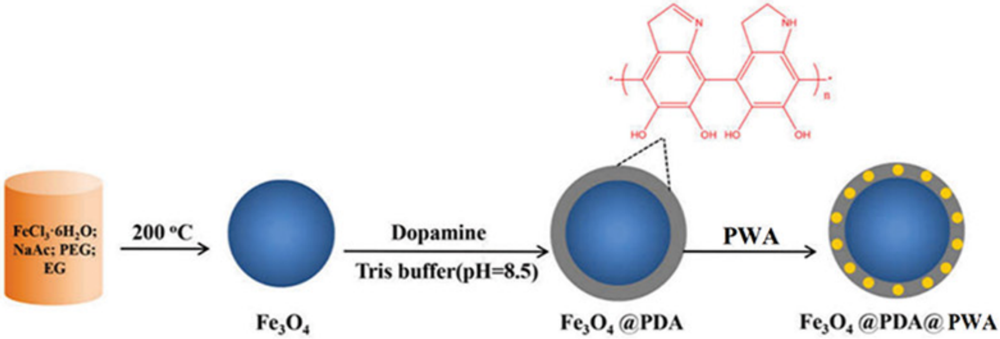

New Polymeric Products

Fundamentals, Forming Methods and Applications

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Preface

Polymer science and engineering is a rapidly evolving and multidisciplinary field critical in developing advanced materials with unique properties and processing techniques. The design, synthesis, and processing of polymers involve challenges related to material properties, processing methods, characterization, and application-specific requirements. Despite these challenges, researchers and engineers have made tremendous progress in this field, quickly developing new polymer products and their processing methods.

This book aims to provide an overview of the latest developments in new polymer products and their processing methods. It covers a broad range of topics, such as the basics of polymer science, the design and synthesis of new polymers, processing techniques, characterization methods, and applications. The book focuses on cutting-edge research and industrial applications of new polymer processing, case studies, and real-world examples.

The book is divided into six chapters that cover different aspects of polymer processing. Chapter 1 briefly introduces the fundamentals of polymer science, including their development, characteristics, and molding methods. It covers the history and application prospects of polymer materials and introduces new and functional materials, such as polymer separation membranes, magnetic and operatic polymers. The chapter also explores the molding and processing methods used for different types of rubber, plastics, and fibers. Chapter 2 explores the application of polymer materials in the field of rubber, which is divided into three parts. The first part covers the basic chemical structure and background of traditional rubber varieties and the latest research progress. The second part focuses on the development status and prospects of a new type of bio-based rubber. The third part discusses the production and processing equipment of tire rubber products. Additionally, the chapter concludes with a discussion of the future direction of tires, including the spherical tire.

Chapter 3 covers the application of new polymer materials in the field of the fuel cell. It is mainly divided into fuel cell proton exchange membrane material and fuel cell fiber catalyst layers. The content includes the working principle of the above energy devices, the types of applied materials and preparation methods, the latest research progress, and future development prospects. Chapter 4 focuses on several high-performance fiber materials, including carbon fibers, aramid fibers, ultrahigh molecular weight polyethylene fibers, and nanofibers. The main properties, advantages, and preparation techniques of these high-performance fiber materials, as well as their applications and prospects in the aerospace, industry, and daily life, are introduced. In particular, the detailed preparation process and various performance characterizations of a high-performance shock-resistant vesicle are presented, and the excellent performance characteristics of high-performance fibers are expressed.

Chapter 5 focuses on the most widely used lens resin materials, including CR-39, polymethylmethacrylate, polycarbonate, and contact lens material. These lens parameters and characteristics, such as light transmittance, wear resistance, strength, and ultraviolet blocking, are mainly described. Several new contact lens materials are also introduced, their performance and processing characteristics are compared, and the future development trend of contact lenses is proposed. Chapter 6 presents the application of polymer materials in biomedicine. It is divided into six parts: artificial blood vessels, antituberculosis drug carrying fibers, wound dressings containing dragon blood, fiber plasters, controlled-release fibers, and antibacterial masks. This chapter mainly introduces the characteristics of polymer materials used in varied fields and the characteristics of biomedical polymers, such as biocompatibility, mechanical strength, application principle, preparation, and performance characterization of polymer materials. The application prospects and the latest research results are introduced. The last section introduces the antibacterial mask-copper oxide mask, which can effectively prevent novel coronavirus infection.

Overall, this book is intended for researchers, engineers, students, and professionals interested in polymer processing and its applications. It is written by experienced experts in the field who have academic and industrial expertise in the subject. The book aims to provide a comprehensive overview of the latest developments in polymer science, design, processing, and applications. We hope it will serve as a valuable resource for the advanced study of polymer processing. We want to thank all the authors, especially for Chapter 1, Miss Han Guo; Chapter 2, Mr. Tiancheng Ge; Chapter 3, Miss Jingyi Sun; Chapters 4 and 5, Mr. Xin Qu; Chapter 6, Miss Jing Ge. All the previous students who contributed to this book are gratefully thanked. The editors and staff at the publisher who helped bring this project to fruition are sincerely appreciated.

Yong Liu

CHAPTER 1

Introduction

Contents

1.1 Brief history of polymer materials

Materials are crucial for scientific and industrial development, and the emergence of new materials can bring revolutionary advances to technology and society [1,2]. Despite its relatively short history, polymer materials science has become an essential field of new materials alongside metals and inorganic nonmetals. Polymer materials have had a significant impact on human civilization and are now one of the three pillars of contemporary science and technology.

1.1.1 Status and function of polymer materials

In contemporary society, the role of materials in human life, survival, and development is undeniable. One essential material in modern times is polymer, which is increasingly used in various industrial fields and is becoming comparable with metals in its widespread use. To ensure the continued development of polymer materials in the future, it is necessary to analyze and study their current usage status. This study can play a crucial role in promoting the overall development of polymer materials [3–5].

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Polymer materials possess unique and excellent properties that make them indispensable basic materials in various industrial fields, such as machinery, chemical industry, transportation, aerospace, and civil life. Moreover, polymer materials significantly influence the development of related fields. For instance, the use of fluorinated polymer materials with good corrosion resistance has effectively solved the storage problem of enriched uranium for the industry. Another example is the use of high-temperature and corrosion-resistant phenolic resin materials in the production of spacecraft, artificial satellites, intercontinental missiles, and other cutting-edge international products. Presently, various high-tech fields increasingly depend on polymer materials. However, with the continuous harsh application conditions, the properties of polymer materials must meet higher requirements [6].

Polymer materials have a widespread natural existence, and before the emergence of humans, various animals and plants in nature were primarily composed of polymers such as protein, nucleic acid, and polysaccharides (starch and cellulose) [7]. Since the emergence of humans, they have been utilizing these natural polymers, such as thatch, wood, and bamboo for housing construction, paint and natural rubber for vehicles, and cotton, hemp, silk, wool, leather, and horn, among other materials, with a long history of human use. Polymer materials play a special role in human survival and development.

1.1.2 Development of polymer materials

The utilization of natural polymer materials by humans has been a long-standing practice. However, due to the limitations of material science and technology, the polymer industry and science began to develop relatively late [8—10]. The chemical modification of natural polymers did not commence until the mid-19th century with the advent of rubber vulcanization, nitrocellulose, and other products. Synthetic polymer products did not emerge until the 20th century [11]. The modern concept of polymers was established and recognized in the 1930s. Subsequently, with the rapid and abnormal development of the petrochemical industry, the synthetic polymer industry grew rapidly, and the application of polymer materials became increasingly widespread, particularly since the 1950s. By the early 1980s, the annual production of synthetic polymer materials, such as plastics, synthetic fibers, and synthetic rubber, had exceeded 100 million tons worldwide, surpassing the total volume of all metals. Today, polymer materials are indispensable, ranging from everyday necessities to cutting-edge high-tech products, and polymer science is the most rapidly developing field of materials science [12].

To provide readers with a comprehensive understanding of the development history of polymer materials, we have summarized the key developmental events of polymer materials in Table 1.1.

Prior to 1949, China had no synthetic fiber or synthetic rubber industry, with only a few small plastic factories processing Bakelite, producing a cumulative output of less than 400 t. However, after the founding of the People's Republic of China, the country began to research polymer science gradually, established national academic organizations [13,14], published academic journals, formulated development plans, conducted professional education and academic exchanges both domestically and abroad, introduced large- and medium-sized technical equipment, and established the polymer material industry.

In the 1950s, research work in China was innovative, focusing on synthesis based on domestic resources and establishing test and characterization modes. This process led to the cultivation of a large number of technicians for production and research, which laid a foundation for in-depth research. In the 1960s, many special plastics, including fluorosilicone polymer, heat-resistant polymer, polycarbonate, polyformaldehyde, polyacrylamide, polypropylene, and other general engineering plastics, were developed to meet the needs of new technology. Rubber chemistry, physics, and other major varieties also rapidly developed during this time [15–17]. In recent years, research has been deepened, focusing on the synthesis method and mechanism of general polymers and the synthesis and application of functional polymers. By exploring the relationship between structure, performance, and processing with advanced technology and testing means, new varieties and theories with Chinese characteristics have been formed [18,19].

1.1.3 Development prospect of polymer materials

Polymer materials have established their versatility and potential in numerous fields and are expected to continue evolving in the future. These materials possess unique application properties, making them ideal for use in everyday life, military, medicine, construction, among others [13,20–22]. Polymer materials are not only products of technological advancements but also novel materials for polymer synthesis that hold

Table 1.1 Development history of polymer materials.

Age and development characteristics	Polymer industry		Polymer science
Processing and utilization of natural polymers before the 19th century	Food protein, starch, cotton, hemp, wood, bamboo, paper, paint, natural rubber, and other natural polymers		In 1833, Berzelius proposed the term "Polymer" (including aggregates linked with covalent, noncovalent bonds)
Chemical modification of natural polymers in the middle of the 20th century	Vulcanization of natural rubber	1838 year	In 1870, it began to realize that cellulose, starch, and proteins were macromolecules In 1892, the structure of isoprene was determined
	Nitrocellulose	1845 year	
	Nitrocellulose plastics	1868 year	
	Rayon factory	1889 year	
The preparatory period for the establishment of Polymer Materials Science in the early 20th century	Phenolic resin Sodium butadiene rubber	1907 year 1911 year	In 1902, it was recognized that proteins are polypeptide structures composed of amino acid residues In 1904, it was confirmed that cellulose and starch were composed of glucose residues In 1907, the concept of molecular colloids was presented In 1920, the study of cellulose crystallization began In 1920, the modern polymer concept of covalent bond-linked macromolecules was proposed
	Ester acid fibers and plastics	1914 year	
	Polyvinyl polyester, alkyd resin, PVA, PMMA, UF	1929 year	

(*Continued*)

Table 1.1 (Continued)

Age and development characteristics	Polymer industry		Polymer science
The founding period of polymer materials science from the 1930s to the 1940s	Plastic		In 1930, after the cellulose relative molecular mass determination study, the modern polymer concept was recognized In 1932, "The Polymer Organic Compound" was published In 1929–40, the polycondensation reaction theory was put forward In 1932–38, the rubber elasticity theory was verified In 1935–48, the chain polymerization reaction and copolymerization theory were proved From 1942 to 1949, the polymer solution theory and various solution methods for measuring the relative molecular mass were established In 1945, the primary structure of insulin was established Era 40, to determine the theory of emulsion polymerization
	PVC, PS, PCTFE, PVB, LDPE, PVDC	1931–40	
	UP, EP, PTFE, ABS, HDPE	1941–50	
	Fiber		
	PVC, PA66, PU	1931–39	
	PA6, pet, vinyl on, pan	1941–50	
	Rubber		
	Neoprene	1931year	
	Butyl rubber	1940–42	
	Butadiene styrene rubber	1940–42	

(*Continued*)

Table 1.1 (Continued)

Age and development characteristics	Polymer industry		Polymer science
The 1950s witnessed the establishment of the modern polymer industry and the great development of polymer synthesis	HDPE	1953–55	In 1953, the Ziegler–Natta catalyst and coordination anion polymerization were funded In the 1950s, the development of anionic active polymerization, cation ionic polymerization, and crystalline polymer research was open In 1957, the acquisition of a polyethylene single crystal was realized In 1958, the mesosphere prion structure was determined In 1951, the protein A helix structure was proposed In 1953, H. Staudinger received the Nobel Prize in Chemistry
	PP	1955–57	
	POM	1956 year	
	PC	1957 year	
	CIS polybutadiene rubber	1959 year	
	Many new products are emerging		
In the 1960s, polymer physics developed greatly	Emergence and development of engineering plastics		From 1960 to 1969, the further development of crystalline polymer, polymer viscoelasticity, rheology research, and the application and development of various modern research methods in the study of polymer structure, such as NMR, GPC, IR, thermal spectroscopy, force spectroscopy, and electron microscope, and the piezoelectric study of PVDF were realized In 1963, Ziegler and Natta won the Nobel Prize in Chemistry
	PI	1962 year	
	PPO	1964 year	
	Polysulfone	1965 year	
	PBT	1970 year	
	Development of high temperature resistant polymers		
	PBI	1961 year	
	Nomex fiber	1967–1972	
	Polyacrylamide		
	Isoprene rubber	1962 year	
	Ethylene propylene rubber	1961 year	
	SBS	50 years	

(*Continued*)

Table 1.1 (Continued)

Age and development characteristics	Polymer industry	Polymer science
The great development of Polymer Engineering Science in the 1970s (high efficiency, automation, and large-scale production)	Polymer blends (ABS, MBS, hips, NORYL, etc.) Polymer composites (such as large-scale production of glass fiber-reinforced resin matrix composites)	In the 1970s, PE, PP highly efficient catalyst was developed In 1971, a polyacetylene thin film was developed In 1972, neutron small-angle scattering was applied In 1973, Kevlar fibers and polymer blending theory were developed In 1974, P.J. Flory received the Nobel Prize in Chemistry In 1977, the metal conductivity was doped with polyacetylene
	3,010,000 ton PE and PP plants, bulk polymerization of PVC, use of large polymerization reaction equipment and new processes, the emergence of large processing equipment, and establishment of new synthesis methods	
In the 1980s, research on high-performance materials developed fine polymers, functional polymers, and biomedical polymers		The molecular design was proposed In 1983, the group transferred polymerization was developed

substantial significance for the future of the material industry. In the future, polymer materials are expected to develop toward high performance by reinforcing their temperature and corrosion-resistant characteristics, which will undoubtedly become the focus of research and development. In various industries, polymer materials play an important role and have a significant impact.

Environmental pollution is currently a major issue, causing disruptions to people's daily lives. Green polymer materials can effectively prevent further environmental pollution by utilizing modern science and technology to study their eco-friendly characteristics, significantly improving their application and promoting their multiple uses, thereby reducing the waste of resources [23–25]. The development of green polymer materials is essential for future research.

Polymer materials are extensively used in various fields [26], and their advantages and characteristics make them the focus of future development in the material industry, creating more value. In the medical field, polymer materials have a significant advantage over cermet materials, as they can be matched with natural teeth in appearance and enable esthetic repair [27,28]. The most commonly used dental polymer materials include denture-making materials with methyl methacrylate as the main component and composites with polymerizable resin as the matrix and inorganic filler or fiber as the reinforcing material. Zirconia is often used as a porcelain veneer for teeth, as shown in Fig. 1.1 [29].

Anticaries materials are dental products that help prevent tooth decay by blocking the pit and fissure spaces of teeth, blocking bacteria from entering or improving the acid resistance of enamel. These materials are categorized as resin-based pits, fissure sealers, and fluorine-containing materials according to their mechanism of action. Fluorine-containing materials contain natural resins, such as fluorocarbon paint, ethyl acetate coating material, and fluorinated foam [30]. Fluoride is an essential component in the prevention of dental caries as fluoride ions can inhibit the

Figure 1.1 Schematic diagram of zirconia repairing enamel defect [29].

adhesion and aggregation of cariogenic bacteria, weaken the acidic environment of the tooth surface, and reduce the likelihood of demineralization on the tooth surface. Fluorapatite, formed by replacing hydroxyl ions with fluorine, is more stable than hydroxyapatite, making it more resistant to the erosion caused by acid-producing bacteria and thus effectively preventing dental caries.

1.2 New polymer materials

Polymer materials are composed of compound molecules with relatively large molecular masses and can be classified into natural, synthetic, and semisynthetic materials based on their origin. These materials include plastics, synthetic fibers, synthetic rubber, coatings, adhesives, and polymer matrix composites [31]. Despite their rapid development since the introduction of phenolic resin in 1907, conventional polymers have limitations in terms of mechanical strength, rigidity, and heat resistance, which restricts their use in modern engineering technology. Therefore the development and application of new polymer materials with high performance, such as conductive, biomedical, biodegradable, high temperature resistance, high strength, high modulus, high impact, and extreme conditions, are crucial to advance the field of polymer materials toward functionalization, intelligence, and refinement [32–34]. These advanced materials can address the challenges faced by conventional polymers and actively promote their development in new directions.

The demand for high-performance polymer materials has been increasing in various industries. For instance, the automotive industry requires polymer materials with excellent mechanical properties and heat resistance, and the aerospace industry demands materials that can withstand extreme temperatures and harsh conditions. The use of polymer materials in electronics and energy applications requires them to be conductive and have high dielectric properties. Moreover, biomedical and biotechnological applications require materials that are biocompatible, biodegradable and possess desirable physical and chemical properties. Therefore developing and applying high-performance polymer materials in these industries are a critical step toward improving product performance, reducing costs, and increasing sustainability. Furthermore, the use of recycled and sustainable polymer materials, such as bioplastics and biodegradable polymers, can mitigate environmental issues and promote circular economy principles.