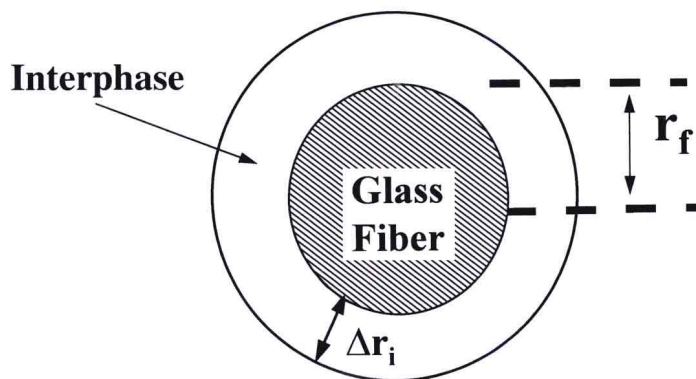


# HANDBOOK OF POLYPROPYLENE AND POLYPROPYLENE COMPOSITES



edited by  
**HARUTUN G. KARIAN**

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**HARUTUN G. KARIAN**

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*Brighton, Michigan*



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## Preface

There has been a major effort, particularly in the last five years, to develop polypropylene-based composites to replace metals and many types of engineering thermoplastics in high-performance applications. In addition to providing reduced cost per unit volume, interphase design of polypropylene composites can be tailored to suit a growing number of property specifications. The interphase region is defined as the polymeric coating surrounding any type of dispersed particulate incorporated in the polymer matrix, for example, mineral filler particles, glass fibers, or even dispersed elastomer droplets.

This handbook is a comprehensive guide to interphase design, describing key material ingredients that contribute to suitable thermal and mechanical behavior demanded by end-use requirements. I have identified interphase design as the foundation on which additives are the individual building blocks needed to develop a suitable material. The sequence of formation steps begins with the manufacture of polypropylene resins and culminates with the *aufbau* (“building up”) of the interphase design.

The molecular structure and morphology of individual polypropylene resins can be readily modified at the reactor stage via new catalyst systems. Postblends of available resins with various additives promote impact resistance, controlled rheology, thermal stability, and other desirable characteristics of the polymer matrix. The incorporation of chemical coupling agents and mineral-filler or glass-



fiber reinforcement into the modified polypropylene matrix to form a chemically coupled composite is the major final step in interphase design.

The final combination of ingredients promotes an adhesive bond between the polymer matrix and load-bearing glass-fiber reinforcement. Consequently, the physicochemical characteristics of the microstructure based on the interphase design determine the ultimate mechanical and other properties of filled or glass-fiber reinforced polypropylene resins.

By virtue of significant advances in chemical coupling and glass-fiber sizing technology, chemically coupled polypropylene composites can be manufactured to exhibit strength and stiffness required for elevated temperature applications, for example, in hot climates or under the hood in automobiles (60–150°C). At the other end of the temperature spectrum, elastomer modification plus filler addition to maintain stiffness provides the means for low-temperature impact resistance in subzero Arctic locations (–30 to –40°C).

Even at room temperature, there are many factors that can influence the service lifetime of a molded part. A material that is suitable for swimming pool pumps, for example, requires a wide spectrum of requirements: burst strength (tensile strength), recoverable strain (ductility) under pressure cycling or creep-fatigue resistance, moisture–chemical (chlorine gas) resistance, and combined weatherability under combined moisture exposure–ultraviolet radiation.

With the support of Mr. Russell Dekker, I have elicited contributors from globally recognized experts. The concept of interphase design is the central theme of this handbook. I have arranged the chapters in a stepwise manner to cover the material as if one were formulating individual ingredients into a polypropylene composite.

Chapters 1 and 2 provide information concerning the current technology of polypropylene resin manufacture with the desired structure–property attributes. Chapters 3, 5, 6, 7, 11, and 12 describe modification of polypropylene resins and microstructure by addition of various additives and postreactor processing.

The current state of mineral-filled and glass-fiber reinforcement technology is outlined in Chapters 8, 9, and 14 as a prelude to making composites of polypropylene. Chapter 8 deals with talc-filled polypropylene, while Chapter 14 provides attributes of mica reinforcement. A comprehensive treatise on glass-fiber technology is provided in Chapter 9 and the state-of-the-art reactive extrusion and compounding via twin screw equipment is described in Chapter 10. In Chapters 11 and 12, the concept of interphase design is discussed in detail. And in Chapter 12, mega-coupled-type chemical coupling is identified as the ultimate in interphase design in the class of engineering thermoplastics. In Chapter 13, the characterization of long-term creep-fatigue properties for glass-fiber-reinforced polypropylene composites is presented as the true gauge of mechanical response that represents the actual service lifetime of the molded part. The relationship

between sizing chemistry on glass fibers, which is a key element in interphase design, correlates with this long-term tensile behavior.

In addition to needing an appropriate interphase design in order to achieve the desired mechanical properties, the long-term endurance of molded parts depends on the prudent choice of stabilizer packages (antioxidants, UV stabilizers, metal deactivators, and so forth) to withstand elevated ambient temperatures and/or exposure to the combined effects of moisture and sunlight. Chapter 4 addresses the effects of environmental conditions as well as the need to attain effective stabilizer packages for flame-retardant polypropylene in order to enhance weatherability and prolonged service lifetime of a molded part.

Although the Internet has made information more readily accessible, the typical tight time frame for the development of optimal interphase design requires one to have a more practical source of basic information on a nearby bookshelf. Research scientists and technical service engineers alike will benefit from this handbook of pertinent and up-to-date information on polypropylene-based materials.

*Harutun G. Karian*

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# Growth of Polypropylene Usage as a Cost-Effective Replacement of Engineering Polymers

**Michael J. Balow**

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## 1.1 INTRODUCTION

Throughout the history of human civilization, improvements in materials of construction have been sought. Starting with the building of some of humankind's earliest monuments, mud was combined with straw to improve the performance and strength of the composite structure. Hence, the desire to use inexpensive materials to effectively upgrade the performance of commodity materials is not a new idea. Today, with strong competition between the various materials of construction, cost-effective materials have been continuously developed and expanded.

Polyethylene (PE) and polypropylene (PP) exemplify a class of materials called polyolefins. Composites based on these resins are relatively new by the standards of those early materials of construction. Recent efforts to use these types of materials combine inherent cost-effectiveness with a wide spectrum of end-use applications as film, fiber, and moldings. The impetus for this remarkable development is attributed to the ease of polyolefin manufacture with effective production and purification of the monomers from a variety of sources, ongoing improvements of the catalyst, and large well-controlled polymerization units. Consequently, a strong market demand for good performance and cost-effective materials have spurred a multibillion dollar industry.

**Table 1.1** Recent Historical Consumption of Polypropylene (ktons)

Region	1989	1991	1993	1995	1997 <sup>a</sup>
Europe	3,914	4,213	4,766	5,518	6,362
North America	3,022	3,435	4,202	4,928	5,750
Asia	3,621	4,711	5,404	7,023	8,457
South America	402	516	744	876	1,031
Middle East/Africa	383	425	618	813	915
Total consumption	11,342	13,300	15,734	19,158	22,515

<sup>a</sup> Estimation.

## 1.2 POLYPROPYLENE GROWTH AND USES

Polypropylene was initially produced commercially about 45 years ago after the successful development of a suitable stereo-specific catalyst, which enabled the polymer to have the kind of structural characteristics useful for rigid items. Tables 1.1 and 1.2 describe the historical and anticipated consumption of polypropylene. In Table 1.3 you can find the expected capacity growth by region for the future. The continuous growth of polypropylene is expected to continue into the next millenium as raw materials in an expanding number of end-use products for the automotive and film industries.

Earlier, the performance of polypropylene was considered only intermediate to polyethylene and polystyrene (PS). But, as of late, there is significant intermaterial competititon to replace engineering polymers as materials of construction by polypropylene base resins.

The significant growth of PP use is attributed to a combination of many factors besides a good balance in physical and chemical properties. Because of appropriate melt rheology and thermal behavior, PP-based materials are widely

**Table 1.2** Future Expectations of Global Consumption (ktons)

Region	1998	1999	2000	2001	AAGR <sup>a</sup> (%)
Europe	6,661	7,011	7,363	7,714	5.3
North America	6,089	6,482	6,874	7,266	6.5
Asia	9,745	10,654	11,562	12,471	9.6
South America	1,150	1,265	1,379	1,494	10.2
Middle East/Africa	969	1,043	1,116	1,189	7.6
Total consumption	24,614	26,455	28,294	30,134	7.6

<sup>a</sup> Average annual growth.

Source: Phillip Townsend Associates Inc.



**Table 1.3** Worldwide Polypropylene Production Capacity by Area (ktons)

Region	1998	1999	2000	2001	AAGR <sup>a</sup> (%)
Europe	8,365	9,105	9,773	9,983	4.5
North America	6,775	7,683	8,553	8,739	6.5
Asia	10,699	11,576	12,006	12,241	3.4
South America	1,190	1,390	1,465	1,465	5.3
Middle East/Africa	1,190	1,360	1,665	1,890	12.2
Total consumption	28,219	31,114	33,462	34,318	5.0

<sup>a</sup> Average annual growth.

Source: Phillip Townsend Associates Inc.

processable on a variety of different equipment ranging from injection molding to some designed for use in other industries, like calendaring and air-quenched blow film equipment. Additionally, by having the lowest density among commodity plastics at approximately 0.90 g/cm<sup>3</sup>, continued market penetration of PP at the current rate of growth is almost ensured on the basis of good mechanical properties at reduced cost per volume. Finally, because many major companies are designing their products, polypropylene stands out as the main product with the widest design flexibility and simplicity of recycling. Its excellent thermal stability, low density (assisting in separating from other materials), chemical and environmental inertness, and even its caloric content in the case of incineration all add to its attractiveness as the material of construction.

The global supply from several producers located throughout the world ensures good supply at competitive prices. From the mid-1990s to the end of the 20th century, significant capacity increases will occur. The supply and demand balance works favorably to the consumer's benefit. This keeps prices in check and ensures that suitable supply will be available. Additionally, in the next 10 years, significant amounts of polypropylene from recycled sources will be available. The quality of this recycled material varies widely in cleanliness but is thought to be suitable for a variety of applications, including automotive. Industrial waste streams are used today for compounding operations, and this will continue. Additionally, postconsumer waste primarily from packaging is becoming more available but often of lower quality (e.g., sometimes limited to black-pigmented products). Data on the major end uses in each region and the expected growth of the various end uses in each region are found in Tables 1.4 and 1.5.

### 1.3 RAW MATERIALS

Polypropylene homopolymer consists of molecular chains with repeating units of propylene monomer generated in the reactor. It is derived from three major