POLYOXYMETHYLENE HANDBOOK

Structure, Properties, Applications and Their Nanocomposites

Sigrid Lüftl , Visakh P.M., and Sarath Chandran

Scrivener Publishing

WILEY

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Scrivener Publishing
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Beverly, MA 01915-6106

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Edited by

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Cover design by Russell Richardson

Library of Congress Cataloging-in-Publication Data:

ISBN 978-1-118-38511-1

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Contents

Preface

Polyoxymethylene Handbook: Structure, Properties, Applications and Their Nanocomposites summarizes many of the recent technological and research accomplishments in the area of polyoxymethylene (POM). Included in the book are presentations on state of art in the area, polyoxymethylene structure, morphology, processing and applications, and new challenges and opportunities. Also discussed are the polymerization and manufacture of polyoxymethylene and various types of additives. Other topics covered are the structure and crystallization behavior of POM and its thermal, physical, mechanical, flame retardant, chemical, electrical and optical properties. The environmental impact of POM is also addressed. As the title indicates, the book emphasizes various aspects of polyoxymethylene and their nanocomposites for the scientific community.

This handbook serves as an up-to-date record on the major findings and observations related to polyoxymethylene. It is intended to serve as a "one stop" reference resource for important research accomplishments on the subject. The various chapters in this book are contributed by prominent researchers from industry, academia and government/private research laboratories across the globe. The handbook is a very valuable reference source for university and college faculties, professionals, post-doctoral research fellows, senior graduate students, and researchers from R&D laboratories working in the area of polyoxymethylene.

Chapter 1 is an overview of the state of art in the area and also presents new challenges and opportunities for polyoxymethylene and their nanocomposites. An overview of the polymerization and manufacture of polyoxymethylene is presented in Chapter 2. Its author explains monomers and discusses other topics such as comonomers, polymerization, homopolymerization, copolymerization, block copolymers and terpolymers. In Chapter 3, several different types of additives used for the synthesis and manufacturing of polyoxymethylene are discussed. There is an analysis of many types of agents such as UV stabilizers, impact modifiers, nucleating agents, pigments, flame retardants, antistatic and lubricating agents, fillers and other additives

The main focal point of Chapter 4 is the different types of processing methods such as injection molding, extrusion, and blow molding, among others, for polyoxymethylene and their nanocomposites. Also reported in this chapter are topics related to POM products such as highly oriented products, recycling of production waste, machining, assembling of moldings and semi-finished parts. A survey on applications of polyoxymethylene is provided in Chapter 5. Many explanatory topics and subtopics are used by the chapter's authors such as automotive, electronic and consumer applications, white goods, mechanical engineering, plumbing and water installation. A discussion about the structure and morphology of polyoxymethylene is presented in Chapter 6. This chapter mainly discusses the crystalline structure of POM; orthorhombic, hexagonal phases, crystal structure determination, morphology of orthorhombic, hexagonal POM, morphology of rubber-modified POM and structure-property relationships. Microscopically-viewed crystal structure and crystallization behavior of POM are discussed in Chapter 7. In this chapter the author's review of physical and thermal properties is based on X-ray scattering, vibrational spectroscopy and lattice dynamical theory. The physical properties of polyoxymethylene homopolymers and copolymers are discussed in Chapter 8. Among the topics covered are density, hardness, heat capacity, melt flow behavior and other tribological properties, as well as water absorption and gas permeability

In Chapter 9, the mechanical properties of polyoxymethylene are presented in two major parts. The first part is devoted to short-term mechanical properties such as elastic properties as a function of temperature and morphology aspects, and failure properties and the different strategies to improve them. The intent of the second part is to present long-term properties such as creep behavior and modifications induced by aging, which lead to the embrittlement of POM, thereby limiting its lifetime. Thermal properties and flammability are discussed in Chapter 10. Among the topics are glass transition, melting temperature, coefficient of linear thermal expansion, thermal conductivity, thermo-oxidative aging, and testing of long-term heat aging.

Chemical resistance is discussed in Chapter 11. The authors explain the different types of chemical changes and chemical properties of polyoxymethylene. Included in the many topics and subtopics are degradation and oxidation mechanisms in polyoxymethylene, depolymerization, thermal oxidation, photothermal oxidation, polyacetal degradation mechanism, resistance to chemicals, theoretical recall on polymer interaction with solvents and typical resistance of polyoxymethylene in the presence of alkalis, acids or solvents. Chapter 12 explains the electrical response of polyoxymethylene (POM) homopolymer. This chapter includes various discussions about interactions between POM, electromagnetic waves, dielectric response of POM, effects of water on dielectric response of POM, dielectric properties of POM-based composites, interactions between POM, arc plasma, low energy applications and high energy applications. Different aspects of electrical and optical properties are explained in Chapter 13 such as conductivity, dielectric properties, dielectric loss factor, microwave dielectric measurements and resistivity applications.

Next, Chapter 14 on nanocomposites of polyoxymethylene explores the subject using many subtopics such as methods of fabrication of POM-based nanocomposites, modification of nanoparticles towards preparation of POM-based nanocomposites, preparation and structure of POM-based nanocomposites, properties of polyoxymethylene-based nanocomposites, POM blends as matrices in nanocomposites and POM nanostructures-electrospun POM nanofibers. Finally, the future developments in POM are discussed in Chapter 15 along with its environmental impact and suppliers; in particular, specialty resins, performance improvement by copolymerization of polyoxymethylene and polymer alloy technology, technology for improving heat stability, high viscosity (high molecular weight) POM, safety (regulations and approvals), and commercial grades of POM.

Lastly, the editors would like to express their sincere gratitude to all the contributors of this book who provided excellent support throughout the successful completion of this venture. We are grateful to them for the commitment and the sincerity they have shown towards their contributions to the book. Without their enthusiasm and support, the compilation of a book would not have been possible. We would like to thank all the reviewers who have taken their valuable time to make critical comments on each chapter. We also thank the publisher Wiley-Scrivener for recognizing the demand for such a book and for realizing the increasing importance of the area of polyoxymethylene and their nanocomposites, and also for starting such a new project on which not many other publishers have yet to put their hands.

Sigrid Lüftl
Visakh P. M.

1

Polyoxymethylene: State of Art, New Challenges and Opportunities

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Abstract

Polyoxymethylene (POM) is a semicrystalline polymeric material belonging to engineering thermoplastics because of its low friction and wear characteristics and its excellent balance of mechanical properties and chemical resistance to most solvents, chemicals and fuels at room temperature. Hence, such polymers are used to serve as an alternative to metals. As formaldehyde was initially the raw material used in the manufacturing of commercial POM it is also referred to as polyformal or polyacetal. Among the polymers obtained from the polymerization of aldehydes, POM is the only one that could reach commercial significance. Polyoxymethylene resins have traditionally covered homopolymers (POM-H) and copolymers (POM-C), and more recently ter- and block-copolymers have been developed. Today, most of the POM resins manufactured worldwide are used in the production of automotive parts followed by electrical and electronic parts, and industrial parts. Hence, at present most of the POM is manufactured and consumed in Asia. However, besides Asia, manufacturing sites with high production capacities are also located in Germany and the USA.

Keywords: Polyacetal, engineering thermoplastic, automotive industry, production capacity

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Sigrid Lüftl, Visakh P.M., and Sarath Chandran, Polyoxymethylene Handbook, (1–20)

1.1 Scope

Because of its low friction and wear characteristics, excellent balance of mechanical properties and chemical resistance to most solvents, chemicals and fuels at room temperature, polyoxymethlene (POM) is an engineering thermoplastic material whose typical applications as of today include cover sliding and guiding elements, gears, housing parts, brewing units of espresso machines, loudspeaker grills, fastener release buttons, impellers, springs, chains, screws, nuts, insulators, coils, fittings, zippers; parts of pumps, valve bodies, televisions, windows, locks, door lock systems, hinges, joint covers, insulin pens, powder inhalers, etc.

In principle, polyacetal resins can be processed by all methods suitable for thermoplastics. However, the most important methods are injection molding and extrusion. Lightly crosslinked grades can be used to produce hollow moldings by blow molding. Extrusion applies to the manufacture of semi-finished parts like film, sheet, rods, pipes, and profile sections, most of which are further machined by means of cutting tools to form finished parts. Even the most complicated moldings can be mass produced very economically by injection molding.

In the past the demand in this resin has increased steadily by 5–7% per year.

1.2 History

Polyoxymethylene (POM) dates back to 1859 when the Russian chemist Aleksandr Mikhailovich Butlerov published his findings on working with 1,2-diiodoethane. He identified a structure which he thought was composed of $C_4H_4O_4$ and called it “dioxymethylene” [1]. The synthesized dioxymethylene was white and had a melting point of 152 °C, it was odorless at room temperature but developed a pungent smell upon heating. The beginning of a thermooxidative degradation could be noticed at 100 °C, but a complete gasification occurred only beyond the melting point. Further, when the dioxymethylene was boiled in water, ether or alcohol for a short time no dissolution could be observed. However, storage at 100 °C in water in a sealed glass container for a few hours resulted in its complete dissolution. Of course at that time nobody knew what to do with the synthesized dioxymethlene and it remained an object of laboratory studies for a while. Later on, Butlerov became one of the first chemists to systematically study polymerization reactions, and in particular reactions with formaldehyde. Synthetic polymers were niche products only and hardly known, mostly as rubber materials. Further, neither knowledge on how to process this new kind of material as plastics nor appropriate processing technologies existed.

At the beginning of the 20th century, Auerbach and Barschall succeeded in synthesizing polyoxymethylene by polymerizing aqueous formaldehyde solutions with sulphuric acid. They obtained polyoxymethylenes that exhibited a different resistance against diverse chemical agents, specifically in view of the resulting degradation behavior. This led at the time to a categorization of polyoxymethylenes different from that of today; polyoxymethylenes were separated into α-polyoxymethylene, β-polyoxymethylene, γ-polyoxymethylene and δ-polyoxymethlylene. The α-polyoxymethylene corresponds to a polyoxymethylene with both ends composed of OH-groups (polyoxymethylene dihydrate), while the β-polyoxymethylene corresponds to a sulphuric acid ester of the polyoxymethylene dehydrate; the name γ-polyoxymethylene is assigned to a polyoxymethlylene dimethyl ether. The δ-polyoxymethlylene is in fact a γ-polyoxymethylene having adjacent C-C-bonds because of a rearrangement of some formaldehyde molecules [2–7].

In the 1920s, Hermann Staudinger and his coworker started extensive investigations on polyoxymethylenes since they thought that they could use them as a kind of model to derive the structure of more complex cellulose [8]. As a result, a series of up to 40 publications from 1925 to 1971 dealing with the different properties they found in the course of their work with these formaldehyde-derived polymers was published from the 14th communication on under the serial title "Mitteilung über Polyoxymethylene" (Communication on Polyoxymethylenes) in different journals at the beginning, but later on specifically in *Die Makromolekulare Chemie* and today in *Macromolecular Chemistry and Physics*.

At the beginning of their works on the polymerization of formaldehyde to polyoxymethylene Staudinger and his coworker could obtain polymers having a polymerization degree in the range of 50 to 100 only, but with these low molar mass polymers a considerable gain in knowledge on polymer structures and polymerization know how could be generated. Specifically, the role of the polymer chain end groups on the degradation behavior could be elucidated. Later on the workgroup could synthesize a polyoxymethylene diacetate with a melting point around 150 °C to 170 °C [6, 7, 9–12]. In those days it was also found that even small amounts of hydroxyl ions are able to catalyze the cleavage of the polyoxymethylene hydrate chain into formaldehyde, while sodium hydroxide solutions do not deteriorate polyoxymethylene dimethyl ether [13, 14].

The working group of Staudinger was primarily focused on determining the structure of polymeric materials as previously mentioned.

Unfortunately, polyoxymethylene with higher molar mass could hardly be dissolved in those days without using harsh conditions (e.g., temperature in the range of the melting and beyond) that eventually caused degradation in this material. Further, with the drawback of thermal instability due to the OH-group at the end of the macromolecular chain, POM was not a promising candidate for commercial exploitation [12, 15, 16].

However, in the 1940s E.I. Du Pont de Nemours & Co. in Wilmington, Delaware (USA) started extensive research on a process to obtain pure formaldehyde, and later on a resin derived from it. As a result, Robert N. McDonald could synthesize polymers that had a higher thermal stability than previous polyoxymethylenes. Ultimately, in 1954 F.C. Starr submitted a patent application "process for the polymerization of formaldehydes employing metal carbonyl initiators" and obtained the patent in February 1956, while MacDonald received his patent for "Polyoxymethylene" in October 1956 [17–19]. Hence, DuPont announced the production of a commercial POM-H with the trade name Delrin®. By the end of the 1950s the first production plant of Delrin with a capacity of ca. 11.000 metric tons (20 million pounds) per year was installed at Parkersburg, West Virginia, and production started in 1960 [19, 20] (Fig. 1.1).

With their commercialization, POM-H polyacetals, became the focus of other research institutions and chemical companies, and as a result several papers dealing with polymerization, structure and thermal stability were

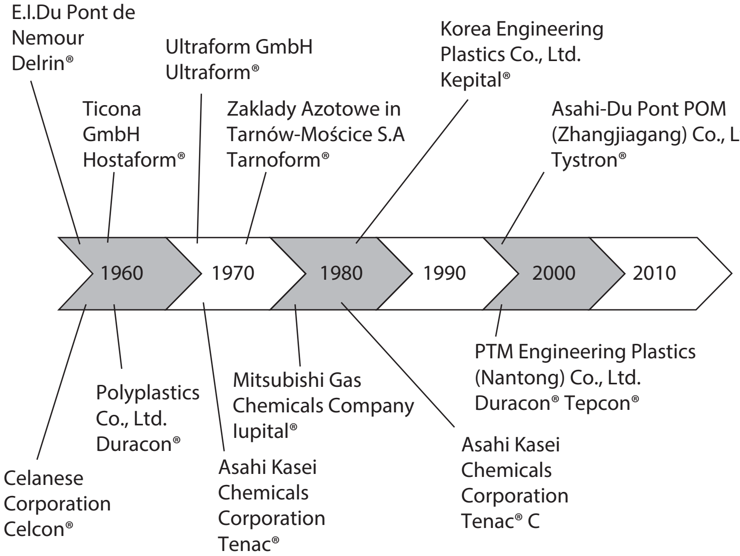


Figure 1.1 Manufacturing and commercialization of POM resins from 1960 to present.

published, specifically in the former Soviet Republic, Japan and Germany [e.g., 21–59] from 1960–1970. Despite extensive research on the polymerization of other higher aldehydes [16, 20], none of this polymers made it out of the laboratory or reached a commercial significance as POM.

Further, in 1960 another chemical company in the USA, the Celanese Corporation, applied for a patent disclosing a process to manufacture a polyoxymethylene copolymer by polymerizing trioxane and cyclic ethers in cyclohexane using boron fluoride etherate as a catalyst. The copolymer obtained by this process exhibited higher thermal stability than the homopolymer. The Celanese Corporation received the patent in 1962 [60] and called the copolymer Celcon®.

In 1961, the Celanese Corporation and Hoechst AG of Germany signed a joint venture to create Ticona Polymerwerke GmbH in Kelsterbach (Germany) for the purpose of producing and marketing a POM-C under the trade name Hostaform®. The production of Hostaform started in 1963. Moreover, in 1964 the Celanese Corporation signed a joint venture with Daicel Chemical Industries, Ltd. (Current name: Daicel Corporation) of Japan and founded Polyplastics Co., Ltd., to manufacture POM-C in Japan under the trade name of Duracon®. Later on in 1987, Hoechst took over the Celanese Corporation, which was then merged with the American Hoechst Corporation to form the Hoechst Celanese Corporation in the US. One year after that event, Hoechst Celanese was involved in a new joint venture uniting Hoechst Celanese, Hoechst AG, Polyplastics (the Chang Group of Taiwan and Hoechst Taiwan) to create TEPCO (Taiwan Engineering Plastics Company). Finally, in 1999 after the restructuring of Hoechst AG, the Celanese AG as well as Ticona were spun off. Today Ticona represents the high-performance plastic materials business part of the Celanese Corporation [20, 61].

The German companies BASF AG and Degussa AG decided in 1971 to found Ultraform GmbH to manufacture a POM-C (Ultraform®) that contains oxybutyl-units from the comonomer [20, 62, 63].

The Asahi Kasei Chemicals Corporation of Japan was begun in May 1972 with the production and sales of homopolymer resins (Tenac®) and in December 1985 for copolymer resins (Tenac®C). Asahi Kasei is at present the worlds only producer of both POM-H and POM-C with a capacity of 44.000 t/a (20.000 t/a homopolymer, 24.000 t/a copolymer) [64].

A further European polyacetal producer, the Polish Zakłady Azotowe in Tarnów-Mościce S.A., started with the production of a POM-C (Tarnoform®) in Tarnów in 1976 [20].

A third Japanese company, the Mitsubishi Gas Chemical Company,was launched in 1981 with the production of a POM-C (Iupital®) in Yokkaichi.

The capacity of the plant was 10.000 t/a [20]. The polyacetal business was outsourced to a separate company in 1994 with the founding of the Mitsubishi Engineering-Plastics Corporation. Moreover, in 1987 Mitsubishi Gas Chemical Company, Inc., Mitsubishi Corporation in Korea and Tongyang Nylon Co., Ltd. (Hyosung Corp. since 1998) established Korea Engineering Plastics Co., Ltd. (KEP) as a joint venture. The first commercial production began in 1988 under the brand name Kepital®. The production capacity of 65.000 t/a in 1998 covered about 10% of the world consumption in polyacetal resins [65].

For the purpose of manufacturing and selling POM resins in China, in December 2001 a joint venture of Polyplastics Co., Ltd., Mitsubishi Gas Chemical Company, Inc., Korea Engineering Plastics Co., Ltd., and Ticona PTM Engineering Plastics (Nantong) Co., Ltd. was founded [66].

A joint venture between DuPont China Holding Company and Asahi Kasei Chemicals Corporation was established on August 8, 2002 which founded the Asahi-DuPont POM (Zhangjiagang) Co., LTD., located in Jiangsu Zhangjiagang Yangtze River International Chemical Industrial Park. The polyacetals are called Tystron® and their production started in 2004 in a plant with an initial capacity of 20.000 t/a [67].

A further joint venture between Celanese Corporation and Saudi Basic Industries Corporation (SABIC) announced in April 2010 the construction of a 50.000 t/a POM production facility in Saudi Arabia in the frame of their National Methanol (Ibn Sina) co-operation started in 1981. The key feedstock methanol for synthesizing POM is to be produced at Ibn Sina. The facility was envisaged to go on-stream by 2013 [68, 69], but it seems that it will only begin commercial operation in 2015 [70].

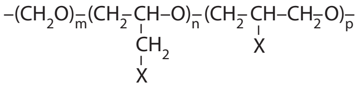
Besides the typical POM-H and POM-C resins, POM block copolymers were commercialized by Asahi Chemical in 1987 [71]. According to ref. [72], block copolymers with oxymethylene segments can be obtained in different ways. In the so-called chain-transfer copolymerization, trioxane is polymerized in the presence of oligomers or polymers with end groups allowing a chain transfer with the growing oxymethylene-cation. This process leads in dependence of the number of reactive end groups to diblock- or multiblock-copolymers.

Another process uses oxymethylene blocks carrying reactive end groups that can link to other polymer blocks via polycondensation or polyaddition reactions [72].

In the Asahi process, formaldehyde is polymerized in the presence of a functional polymer with the structure $R(X)_m$-OH with an active hydrogen atom (Fig. 1.2). In this formula, R is conventionally a long-chain alkyl group and X an oxyalkylene group. The functional group on the acetal

$$n\,CH_2O + R(X)_mOH \rightarrow R(X)_m{-}O(CH_2O)_n{-}H$$

Figure 1.2 Chemical reaction to polymerize an acetal block copolymer.



$$-(CH_2O)_m-(CH_2-\underset{\substack{|\\ CH_2\\ |\\ X}}{CH}-O)_n-(CH_2-\underset{\substack{|\\ X}}{CH}-CH_2-O)_p-$$

X ... hydroxyl or ester radical; m,n,p ... integers
such as that m+n+p is between 5 to 20.000

Figure 1.3 Structural formula of an acetal terpolymer [73].

block copolymer can be varied, e.g., the use of an elastomeric functional polymer leads to a toughened acetal block copolymer [71].

Further POM terpolymers have been developed that can be obtained, e.g., by cationic polymerization of trioxane and a substantially equal molar mixture of *α*,*α*- or *α*,β-isomers of glycerol formal or their ester-functionalized derivatives. Therefore, the resulting terpolymer carries side-chain functionality (i.e., hydroxyl or ester functional groups pendent from the backbone of the polymer) in contrast to simply blended block copolymers (Fig. 1.3). This provides greater functionality, since such acetal terpolymers may be reacted with other resins and/or chemical moieties so as to enable synthesis of acetal block copolymers with desired chemical and/or physical properties [73].

In comparison with a conventional trioxane-ethylene oxide copolymer, the functionalized terpolymer shows an increased thermal stability above 200 °C. The crystallinity is greater than about 40% [73].

1.3 Commercial Significance

Polyoxymethylene as an engineering thermoplastic is used for a huge number of applications ranging from big functional parts in the automotive and mechanical engineering industry to tiny precision parts in drug delivery systems. Since the beginning of commercialization in the 1960s, POM has been developed as a plastic material used specifically in technical applications with high demands on mechanical properties as well as good dimensional stability and sliding properties (Table 1.1).

The current POM market is supplied by six major manufacturers that provide about 70% of the worldwide production (Table 1.2). Further, POM manufacturers with lower market shares are, for instance, Mitsubishi Engineering-Plastics Corporation (Tokyo, Japan, POM-C Iupital®), Asahi Kasei Chemicals Corporation (Tokyo, Japan, POM-H and POM-C Tenac®),

Table 1.1 Typical properties of POM resins (without consideration of special types).

Advantages	Disadvantages
• Excellent short-term mechanical properties in terms of high tensile strength, rigidity and toughness	• Poor thermal stability without appropriate stabilizer system for POM-H
• Excellent long-term mechanical properties like low tendency to creep and fatigue	• Poor chemical resistance to strong acids, bases and oxidizing agents, and to certain metal ions
• Good mechanical and electrical properties up to 140 °C (short-term) and 90 °C (long-term)	• Reduced resistance to hot water (specifically in the presence of chlorine)
• Good mechanical properties over a large temperature range even at low temperatures down to −40 °C	• Can be stained by strong discoloring food (tea, coffee, red wine)
• Excellent chemical resistance against most chemicals, organic solvents and fuels at room temperature	• Flammable without flame retardants because of the high oxygen content in the polymer chain
• Not susceptible to environmental stress cracking • Excellent dimensional stability	• Release of toxic gases (e.g., formaldehyde) when subjected to high temperature or burning
• Low permeability to many chemicals, fuels and gases • Low water absorption	• Difficult to bond or decorate without surface preparation because of the low surface energy and polarity
• Excellent tribological properties like low static and dynamic coefficient of friction, and high resistance to abrasion	• For outdoor applications appropriate UV-stabilizers are needed, further POM is sensitive to radiation
• High hardness in comparison with other thermoplastics • Glossy and smooth molded surfaces	• Special types are required for medical and food applications, further not recommended as implant material by different manufacturers
• Can be processed in general on all standard processing machinery for thermomplastics	

Table 1.2 Major manufacturers of POM and their market share in 2011 [74].

Company	Site, Country	Resin type, Trade name	Market share
Ticona GmbH	Kelsterbach, Germany	POM-C Hostaform® Celcon®	20–21%
Polyplastics Co., Ltd.	Tokyo, Japan	POM-C Duracon® Tepcon®	17–18%
E.I. Du Pont de Nemour & Co.	Wilmington, USA	POM-H Delrin®	15–16%
Korea Engineering Plastics	Seoul, Republic of Korea	POM-C Kepital®	7–9%
BASF SE	Ludwigshafen, Germany	POM-C Ultraform®	6–8%
Asahi-DuPont POM (Zhangjiagang) Co., Ltd.	Zhangjiagang, China	POM-C Tystron® POM-H Delrin®	6–8%

or Zakłady Azotowe w Tarnowie-Mościcach S.A. (Tarnów, Poland, POM-C Tarnoform®) [74]. But due to ongoing formation and dissolution of joint ventures among the different POM manufacturers it becomes difficult to estimate the real market shares of the diverse companies.

POM resins are produced in different grades with various degrees of polymerization resulting in different properties. In general the individual grades differ from one another in their flow behavior (melt mass-flow rate) and in the type and concentration of additives used. Thus, POM resins can usually be separated into the following categories [75–81]:

- Basic or standard grades: These grades differ primarily in their melt flow rate to meet the requirements of different processing methods and conditions.
- Grades with improved slip/wear properties: These grades are modified with special additives (e.g., MoS_2, graphite, PTFE, chemical lubricants, mineral filler, etc.) which enhance slip properties and/or abrasion resistance.
- Reinforced grades: These grades typically contain glass fibers or glass spheres, some special grades with carbon fibers are also on the market. Depending on the type and content

of filler they differ from the basic grades in their higher ultimate tensile strength and/or higher rigidity.

- High-impact or toughened grades: These resins are blends with elastomers (e.g., rubber, thermoplastic polyurethane) in order to obtain a higher impact strength than the basic grades.
- Special grades: This group includes all grades which cannot be assigned to one of the above groups, e.g., grades with special additives against weathering or chemical agents like fuels, electrical conductive grades, medical grades, low emission grades, etc.

The price for basic grade pellets currently ranges from 900 US$/t to 1800 US$/t; special grades can reach prices >100.000 US$/t. Recycling POM (purity 92–96%) can be obtained at a price ranging from 800 US$/t to 1.000 US$/t depending on the grade and amount of contaminants. Semi-finished parts (rods, sheets, boards) from basic grades may be purchased at a price ranging from 1.000 US$/t to 6.000 US$/t, while the price range of semi-finished parts from special grades is 4.000 US$/t to >100.000 US$/t.

A continuous increase in the consumption of POM over the years can be observed (Fig. 1.4). Average growth rates in the range of 5–7% are reported [74, 82–85] over the period depicted in Figure 1.4. However, in

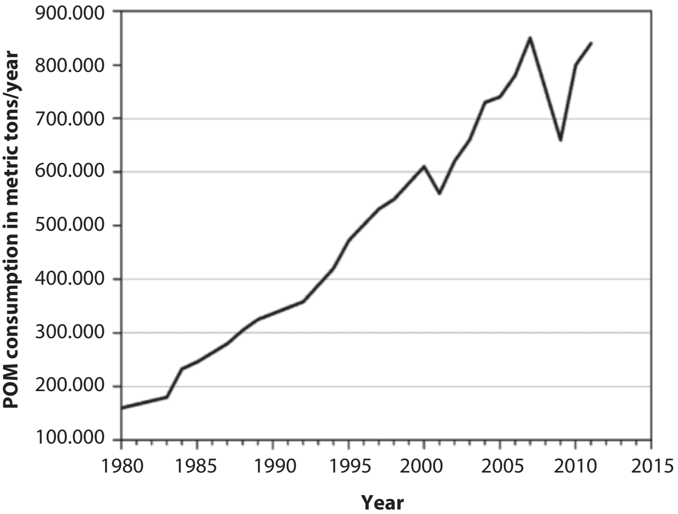


Figure 1.4 Worldwide consumption of POM resins over the last 30 years based on data from refs. [63,74,82–95].

2001 a drop in the demand in POM resins from 610.000 t/a to 560.000 t/a resulted because of difficulties in the automotive industry [86]. Further, the economic crisis of 2008 followed by its global economic slow down in 2009 is reflected in the consumption of POM resins during this period. Nonetheless, since 2010 the demand for POM has again increased as the global economy is recovering, and specifically in China an extraordinary rise in consumption in plastics can be noticed in comparison to other countries.

The major consumer of POM is the automotive industry followed by the electronic industry and consumer goods: automotive industry 27%, electronics 21%, consumer goods 16%, industrial applications 11%, fluid handling 7%, home appliance 4%, other 14% on a worldwide scale, but a clear difference in the repartition of the several applications can be seen in the three main regions involved in the major consumption of POM (Fig. 1.5) in 2009.

In Europe about 38% of the processed POM belongs to the automotive sector [63, 95–97]. Here the whole product range of POM is currently used, e.g., basic grades, fiber reinforced grades, mineral filler containing grades, impact modified grades, UV resistant grades, easy flowing grades for thin-walled parts, low-friction and low-wear grades, fuel resistant grades, low odor grades, etc.

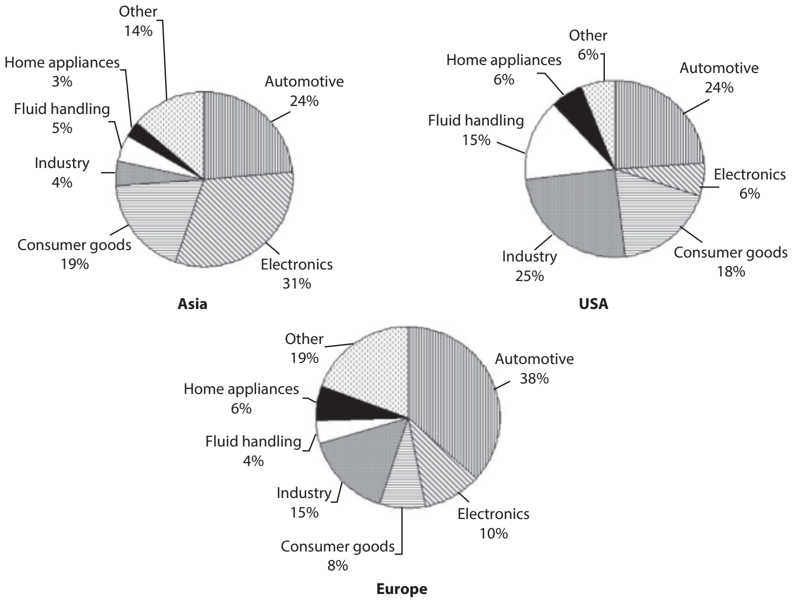


Figure 1.5 Consumption of the POM resins by regions based on data from [63].

Typical applications are in component parts for safety belt buckles, loudspeaker grills, fuel systems, snap fits, gears for the movement of wing mirrors, fan wheels, etc.

A special POM grade enables the manufacture of indoor components having a metallic appearance. This grade can be used for door pulls or other components that usually require a laborious procedure to obtain an aesthetic and robust metallic finishing [63].

To meet the market demand in POM the production capacities of the different manufacturers are constantly expanded and new manufacturing sites are constructed. In 2006, Ticona GmbH settled with the Frankfurt Airport to relocate their production facility in Kelsterbach, as it was an obstacle to the expansion of the airport. Hence, Ticona had to move its manufacturing plant to the Höchst Industrial Park. On this occasion, in 2011 a production plant was installed with an increased capacity of 40% (to 140.000 t/a) in view of the increasing demand for polyacetals [98].

Other manufacturers enlarged their production capacities specifically in Asia to respond to the increasing demand in automotive parts made of POM in this part of the world. In particular between 1998 and 2001 the production capacities have been expanded. This is particularly true for the Asian region that nowadays holds a capacity share beyond 50% of the world production capacity in POM resins [86] (Fig. 1.6). The production of polyplastics in Japan is currently at 100.000 t/a, in Kuanam (Malaysia) it will be raised by 90.000 t/a. Further, the company owns production facilities with a capacity of 20.000 t/a in Taiwan and 30.000 t/a in Malaysia. The joint venture with PTM Engineering Plastics in Nantong (China) gave access to an additional production capacity of 60.000 t/a. Mitsubishi Gas Chemical enlarges the production capacity up to a scale of 80.000 t/a to 100.000 t/a in its production sites in China and Thailand [74].

For the future it is expected that the growing purchasing power in Brazil, Russia, India and China (BRIC countries) will lead eventually to an increased consumption in automotive parts as well as consumer goods and home appliances, the major applications of POM resins. Hence, the shift in the division of markets from Europe and USA towards Asia will be more pronounced. As a result the enlargement of production capacities for POM resins in the Asian region will continue in order to meet the demands in this part of the world [74].

In the past the enlargement of the product range in POM resins has been the focus of the manufacturer. Nowadays, the current products are optimized in view of their properties. Nevertheless, new products have been presented to the market. Ticona has developed a POM resin that can be detected by ultraviolet (UV) light. The purpose of MT (medical