POLYMERS COATINGS

TECHNOLOGY *and* APPLICATIONS

Edited by Inamuddin, Rajender Boddula, Mohd Imran Ahamed, & Abdullah M. Asiri

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Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

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Preface

Polymer coatings are thin polymer films that are applied to flat surfaces or irregular objects. Protective and decorative layers can be served by these coatings. They can be used as functional coatings with corrosion inhibitors or for decorative purposes like in paints. Polymeric coatings are known to be made of organic materials. However, they may contain metallic or ceramic grains to enhance endurance, properties or appearance. Polymeric coatings can be obtained using natural and synthetic rubber, urethane, polyvinyl chloride, acrylic, epoxy, silicone, phenolic resins or nitrocellulose, etc. There is a wide range of fabrication methods to design and construct polymer-coated materials. Compared to conventional coatings, they offer efficient and cost-effective coatings, facile fabrication methods with excellent properties such as corrosion, wear, and heat resistance, higher mechanical strength, and additional benefits, including good chemical and blocking resistance, and excellent scratch/abrasion resistance. Besides which, high gloss to matt looks, soft-touch effect, no color chage after UV exposure, excellent adhesion on metal and plastics, short drying time, fast hardness development, and easy formulation are other advantages of these coatings. Polymer coatings have various applications in the field of painting, storage media, semiconductors, optical devices, fluorescent devices, etc., and interest in them has increased due to their applications in areas such as electronics, defense, aeronautical and automotive industries.

This edition of *Polymer Coatings: Technology and Applications* explores the cutting-edge technology of polymer coatings. It discusses fundamentals, fabrication strategies, characterization techniques, and allied applications in fields such as corrosion, food, pharmaceutical, biomedical systems and electronics. It also discusses a few new innovative self-healing, antimicrobial and superhydrophobic polymer coatings. Subsequently, current industrial applications and possible potential activities are also discussed. This book is an invaluable reference guide for engineers, professionals, students and faculty members working in areas such as coatings, polymer chemistry, and materials science and engineering. Based on thematic topics, this edition contains the following eighteen chapters:

Chapter 1 provides an up-to-date account of fabrication methods for polymer coatings from the basic science to the latest innovations. The techniques which are described and discussed include blade coating, dip coating, spray coating, thermal spray coating, pulsed laser deposition, plasma polymerization, flow coating, spin coating, sol-gel and grafting.

Chapter 2 includes the different fabrication methods of organic/inorganic coating, namely, sol-gel method, cold spray technique, chemical vapor deposition, physical vapor deposition, thermal spray coating, electroplating deposition and electroless deposition. The classification of different coating methods for various organic/inorganic matrices and nanofillers are reported in detail.

Chapter 3 describes various eco-friendly dry powder coating techniques explored in the formulation and development of dry powder inhalers. Additionally, the chapter also includes a segment detailing the process analytical technology techniques, force controlling agents, implications in inhaler device coating and use of computational fluid dynamics in coating technology.

Chapter 4 first introduces the growth of bioinspired superhydrophobic coatings. Then, several theoretical backgrounds are discussed briefly. Afterwards, various methods are considered relating to the importance of creating chemical and physical textures on the surface. Additionally, the development of superhydrophobic and self-cleaning coatings with added nanoparticles are also presented.

Chapter 5 first investigates the nature (substrate-substance) and applications of superhydrophobic coatings. Afterwards, superhydrophobic coating applications are divided into three major categories of restrictive attributes, self-cleaning and smart attributes. All applications of hydrophobic coatings which have been examined in several studies are discussed.

Chapter 6 provides a brief overview of adsorptive polymer coatings, their techniques and a comprehensive comparison. Moreover, adsorptive polymer coating applications in various fields are also discussed. Furthermore, a future perspective of existing challenges provides a better direction and understanding for overcoming these challenges in coming days.

Chapter 7 deals with the formulations and chemistry of polyurethane (PU) coatings, and also provides an insight into the development of PU over the conventional coatings. A detailed discussion of the advantages of PU coatings and their future scope in industry is also presented.

Chapter 8 emphasizes a unique type of polymer coatings based on electroactive material. Fabrication, essential characteristics, and potential applications of electroactive polymer coatings are discussed.

Chapter 9 deals with the importance of conducting polymer coatings in the field of corrosion resistance.

Chapter 10 discusses the main objectives, materials and techniques used for encapsulating food components or coating food surfaces such as fruits and vegetables, meat and meat products, eggs, cheese, nuts, and fried food. Biopolymers including polysaccharides, proteins, and waxes are the main ingredients used for this purpose.

Chapter 11 discusses the scope of biopolymers as edible coating in food products. The chapter emphasizes the various types of raw materials used for preparing edible coating. The role of edible packaging in microbial spoilage, mechanical damage, and consumer acceptance of food is discussed along with its advantages and limitations and selection criteria as edible coating for different varieties of food products.

Chapter 12 addresses the wider aspects of pharmaceutical coatings using different types of polymers and their applications in the development and manufacturing of conventional and modified release drug delivery systems. A historical perspective on pharmaceutical coatings along with their physical attributes and characterization are also discussed, which will guide researchers and pharmaceutical manufacturers to their appropriate selection.

Chapter 13 summarizes the critical characteristics of self-healing polymeric coatings. Progress in existing self-healing coating methods and realistic frameworks of polymeric coatings are presented. Surface self-regeneration and anti-corrosive protective layer fractures are discussed. Issues related to the transition from laboratories to valid industrial application of these self-healing technologies are addressed.

Chapter 14 describes various methods that have revolutionized the role of this fascinating strategy in biological science especially in biomedical applications, notably infectious therapy, drug delivery system for therapeutic agent and protective layer for implants and biomedical devices. The major focus is given to some key applications which are trendsetting for surface functionalization of implants and biomedical materials.

Chapter 15 describes the role of polymers against various microorganisms such as bacteria, protozoans and fungi. These polymers mimic the action of antimicrobial peptides which are utilized by immune systems of such living organisms to kill the microorganism. The main purpose of antimicrobial coating is to combat antimicrobial resistance and infections.

Chapter 16 discusses in detail the various processes and techniques that are most commonly used for the coating of polymers which protect active pharmaceutical ingredient (API) against environmental hazards and bodily fluids, protecting the body from adverse effects of API and modifying the release of API.

Chapter 17 discusses the different conducting polymer coatings used over metal surfaces for corrosion protection along with the role of conducting polymers and various coating techniques. Additionally, this chapter summarizes the performance improvement and bulk modifications of conducting polymers and extensive studies on the protective coating of conductive polymer materials are discussed.

Chapter 18 presents extensive research studies reported by worldwide scientists and specialists in the area of polymer coatings for industrial applications. New and emerging industrial applications are discussed, including microsystems, oil and gas industries, electronics, biomedical systems, pipeline, automotive industries, micro bit storage systems, anti-corrosion and antibacterial coatings.

Chapter 19 discusses recent advancements in the usage of polymers for coating of different dosage forms such as tablets, capsules, implants, nanoparticles, and liposomes. Additionally, mechanisms of polymeric film formation and applications of polymer coatings in the different areas of biomedicine are clearly explained as are the application of different polymers in various coating functions.

Editors
Inamuddin
Rajender Boddula
Mohd Imran Ahamed
Abdullah M. Asiri
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Fabrication Methods for Polymer Coatings

Hüsnügül Yilmaz Atay

İzmir Katip Çelebi University, Department of Material Science and Engineering, Çiğli İzmir, Turkey

Abstract

Polymer coatings mean the top layer applied on any substance for purposes like protection and decoration. It is possible to apply to synthetic materials as well as metals and ceramics. They are resistant to high temperatures, such as up to about 280°C. The polymeric coating process comprises applying a polymeric material onto a supporting substrate and coating the substrate surface. Polymeric coatings can be obtained using natural and synthetic rubber, urethane, polyvinyl chloride, acrylic, epoxy, silicone, phenolic resins or nitrocellulose, etc. There are a wide range of fabrication methods to design and construct polymer-coated materials. In this chapter, the techniques are described and discussed including blade coating, spray coating, thermal spray coating, pulsed laser deposition, plasma polymerization, flow coating, spin coating, sol–gel, dip coating, and grafting. The key point is provided to highlight current methods and recent advances in polymer coating fabrication techniques.

Keywords: Polymer coatings, fabrication methods, blade coating, spray coating, thermal spray coating, pulsed laser deposition, plasma polymerization, flow coating, spin coating, sol–gel, dip coating, and grafting

1.1 Introduction

Polymer coatings are thin polymer films that are applied to flat surfaces or irregular objectives. Protective and decorative layers can be served by these coatings [1]. They can be functional coatings such as adhesives or photographic films. They can be used as corrosion inhibitors or for decorative purposes like paints. Moreover, for modifying the surfaces, they can be utilized such as paper coatings or hydrophobic coatings.

Email: hgulyilmaz@gmail.com

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Polymeric coatings are known to be made of organic materials. However, they may contain metallic or ceramic grains to enhance endurance, property, or appearance [2]. They offer various properties and additional benefits, for instance, very good chemical resistance, very good blocking resistance, and excellent scratch and abrasion resistance. Besides, high gloss to matt looks, soft touch effect, noncoloring after UV exposure, excellent adhesion on metal and plastics, short drying time, fast hardness development, and easy formulation are other acquirements of those coatings [3].

In general, polymer coatings are architected to manufacture a film of a kind of polymer. The process should be as fast as possible. The thickness is typically 1–100 m. The type of coating method varies according to the thickness of the desired covering, the rheology of the running, and the velocity of the web [2].

1.1.1 Starting Liquid Types

Before passing through to the coating methods, it is better to explain starting liquid types to obtain an impermeable and indiscrete polymer coating deposit. Three different types of starting liquids can be used to achieve this output. These are indicated as: polymer solutions, monomer liquids, and polymer latexes [2].

1.1.1.1 Polymer Solutions

It is necessary to decrease the viscosity of the polymer to make it a stickable fluid. For this purpose, the polymer is decomposed in a dissolvent. The fluidity property of the solution is regulated by varying the amount of solvent in the solution. The resulting fluid is covered onto the substrate. The dissolvent should then be removed by a drying operation. The glass transition temperature of the dispersion rises with removal of the solvent. If the drying temperature is smaller than the glass transition temperature, the coating passes to the solid phase. However, when the drying temperature is higher than room temperature, it is seen that solidification or hardening continues during the cooling of the coating. On the other hand, some of the polymers can crystallize when the dissolvent is removed. While some are cooling, they form semi-crystalline final polymer coatings [2].

Generally, most polymers are insoluble in water and organic solvents are used for dissolution. The solvent is selected in terms of both its ability to dissolve the polymer and its influence on the drying step. Due to the need to add different additives and reduce the cost, it may be necessary to use more than one volatile solvent [2].

The use of coatings produced with polymer solution is favored as they can be applied to a wide variety of polymers at the processing site specifications and formulated according to adjustable properties to produce evaluated properties in the last product. The quantity of polymeric material soluble in a solvent is relatively small. The drying requirement therefore appears as a function of the unit thickness of the coating. On the other hand, there are environmental and safety concerns due to complications related to solvent use. Solvent recycling is another important problem. It is also another disadvantage that flammable solvents need to be captured by expensive driers [2].

1.1.1.2 Liquid Monomers

Many monomers have fluid properties at room temperature. Therefore, there is no need to decrease their flow resistance at the coating process temperature. Also, they can be covered directly without adding any dissolvent. Oligomeric precursors can be said to be in this category. Without the need for a drying operation, the monomer liquids are allowed to solidify by serial curing reactions. Meanwhile, the molecular weight of the covering material rises in the period from progression of curing to the formation of a solid polymer layer. Hardening reactions are initiated by exposing them to energetic sources, for instance, ultraviolet light or electron beams [2].

The most widely used and popular coating material is epoxy in the field. They are not monomers, yet they are formed by a chemical reaction of oligomeric resins with its hardeners. The liquids can also be produced with dissolvent to enhance interoperability. Acrylates as liquid monomers are widely used for ultraviolet curing [2].

Monomer fluids do not require much drying step because they contain very little solvent. Therefore, they are quite attractive ways for coatings. The final coating properties (e.g., density of crosslinking) can be managed at the curing stage using parameters such as temperature, ultraviolet density, or the resin chemistry. Nevertheless, in some cases, the materials used in functional polymer solution coatings may be less expensive than monomers and initiating agents. Besides, due to the high degree of crosslinking, the final product can sometimes be brittle [2].

1.1.1.3 Polymer Latex

A latex can be defined as the dissipation of polymeric grains in water. In the case of lower water solubility of the polymeric materials having functional properties, the latex paths supply an environmentally suitable solution for forming enduring covering. Grains varying in size from ~ 10 nm to 1 umm can be manufactured from various polymeric chemicals by emulsion polymerization. It is easy to use, especially because they are synthesized in dispersion form and can be stabilized in the process. For some special applications, latex may also be formulated with other phases, such as ceramic grains [2].

The drying of the latex suspensions appears to be slightly different from the drying of the hard colloidal grains. This process is known as "film formation" depicted in Figure 1.1. Because water is removed, the grains go into the "consolidation" step and become more concentrated in suspension. When the drop time is over, surface tension, capillary, and van der Waals forces begin to pull the grains toward each other. Those forces must be powerful sufficiently to allow the grains to flatten at the grain–grain contact points. Consequently, the pores between the particles become smaller. This stage is called "compression." The final stage is the "union" stage. Here, the polymer chains boil the particles together and transcend the boundaries between the grains. With that process, a finalized covering is formed that lacks gaps that were once between the individual particles [2].

Water is a liquid medium that can be used in latex coatings. Thus, monomer and solvent may be an eco-friendly alternative to other coatings used.

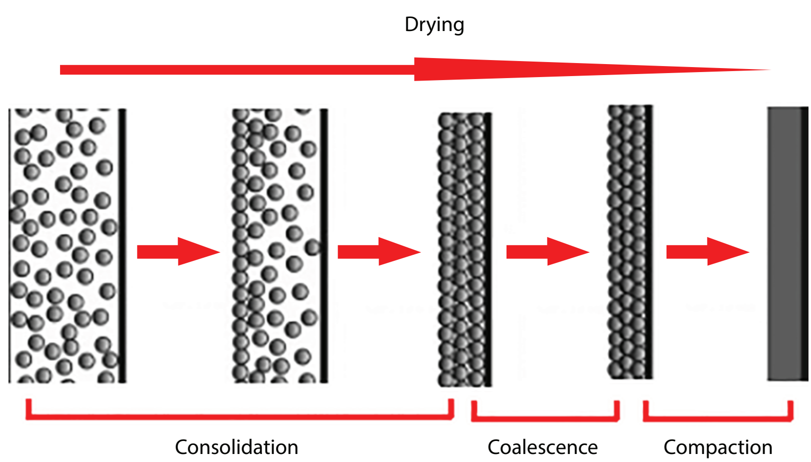

Figure 1.1 Latex film formation stages [2].

Various coatings, such as paints and varnishes, seem to start as latex dispersions. On the other hand, it is pricey to transport and purchase latexes as raw material on a commercial scale. Besides, drying of water is an operation that requires more energy [2–4].

1.1.2 Polymer Coating Methods

Coatings made of polymeric materials can provide many different surfaces: metallic, ceramic, or synthetic materials, using a number of different techniques [5]. They must adhere well to the substrate. They should also not be readily susceptible to moisture, salt, heat, or different kind of chemicals. Generally, the following properties are required for a good coating film [3]:

- Water-based resins. Low- or zero-volatile organic compounds (VOC)
- Very good stain and chemical resistance
- Very good blocking resistance
- Excellent scratch and abrasion resistance
- High gloss to matt looks
- Soft touch effect
- Nonyellowing after UV exposure
- Excellent adhesion on metal and plastics
- Carbodiimides for 2K systems

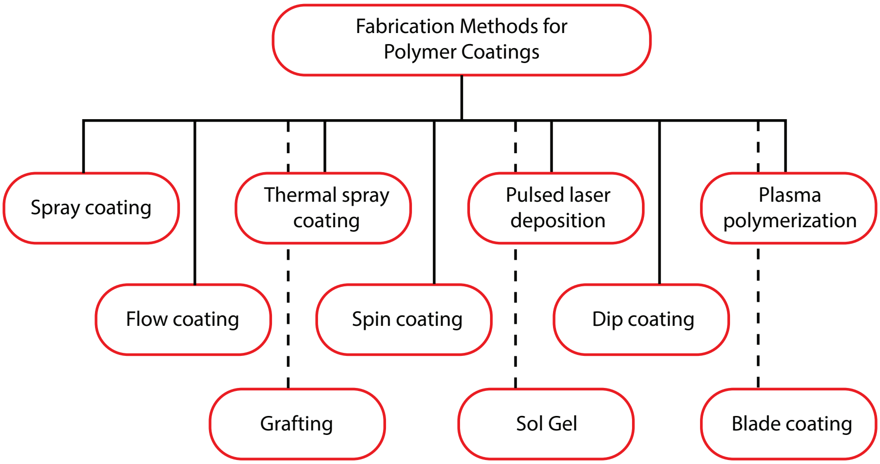

Figure 1.2 Fabrication techniques for polymer coatings.

- Short drying time, hence fast hardness development
- Easy formulation

Applied coating methods can affect the product quality, and thus the coating methods are important to obtain desired properties. Different fabrication methods are demonstrated in Figure 1.2.

1.1.2.1 Blade Coating

The blade coating can be defined as a process in which a certain amount of covering material is applied to the underside and the excess is removed by a measuring blade to obtain the desired coating thickness [6, 7]. This coating method has several advantages for obtaining a good coating film. Homogeneity of the coating area, small amount of material waste, prevention of intermediate layer melting, roll-to-roll production compliance, and economic use of the material [8–10]. In this method, fast drying process will prevent the slowing of the manufacturing process by solvent annealing [10]. Control of the thickness can be adjusted by controlling manufacturing conditions such as sol concentration, blade gap, and blade covering velocity [8].

1.1.2.2 Spray Coating

Spray coating technique is a process method in which the printing material (ink) is constrained through a nozzle and thereby forming a thin aerosol [11]. In this process, the performance of polymer solar cells seems to be limited by certain disadvantages, for instance, isolated droplets, non-uniform surfaces, and holes at some points. Regarding the process parameters, the flow rate, the pressure, the substrate temperature, the density of the mixing dissolution, the spraying time, the distance between the sample, and the air brush can be listed [6].

1.1.2.2.1 Nozzle-to-Substrate Distance

The distance between the nozzle and the surface is considered to be one of the process parameters, since it has a big effect on the morphology of the deposited part in the spray coating. Many studies were performed to examine and achieve the best distance of the nozzle and surface for the active coating. Vak *et al.* [12] found three areas between the air brush nozzle and the substrates, which were "wet," "intermediate," and "dry." They then concluded that the perfect linear control distance was in the "intermediate-region." This result is described as the spray time function.