Edited by Swapan Kumar Ghosh

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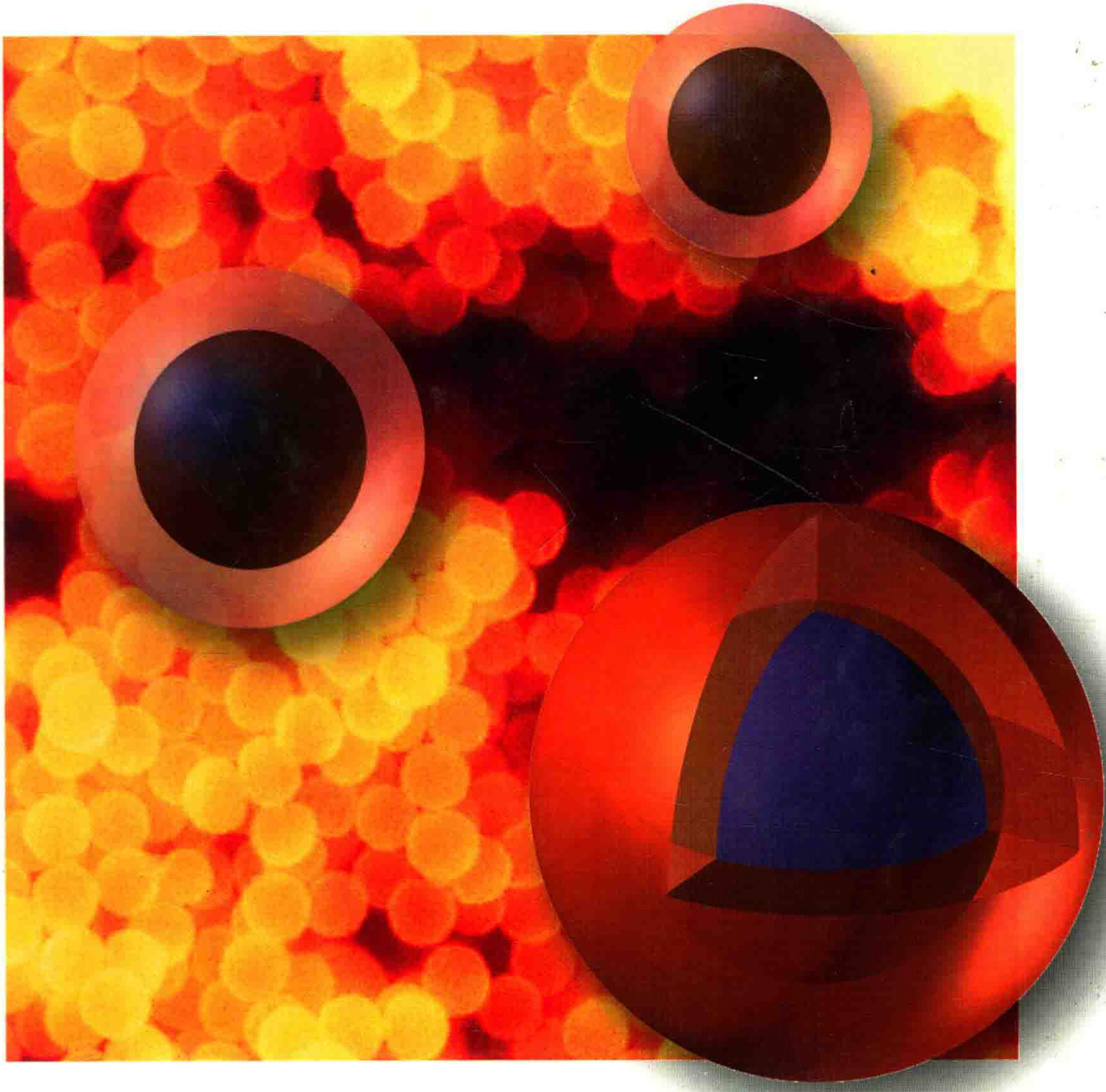
Functional Coatings

by Polymer Microencapsulation



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The Editor

Dr. Swapan Kumar Ghosh
Arcelor Research Industry Gent
OCAS N. V.
John Kennedylaan 3
9060 Zelzate
Belgien

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Preface

Over the past few decades, coating technology has been transformed into an extensive field of materials research. Today's industry demands additional requirements and functionalities from coatings, in addition to their basic protective and decorative values. Recent advances in polymer science and inorganic chemistry – especially at the nanoscale level – have further enhanced this growth. In this context, microencapsulation, a commercially successful technology which is used mainly in the paper and pharmaceutical industries, provides an additional input to the growing needs of functional coatings. This book aims to review the art of microencapsulation and to provide the readers with a comprehensive and in-depth understanding of the fundamental and applied research into microcapsules containing functional coatings.

The topics detailed in Chapter 1 provide an overview of the different microencapsulation techniques available, and the use of microcapsules in functional coatings. Chapters 2 to 5 describe the different aspects of encapsulating organic and inorganic particles, with the relevant properties and applications. Developments of this technology, based on conducting polymers, are outlined in Chapter 6, while Chapter 7 emphasizes the growth and applications of microencapsulation in the textile industry, highlighting especially the future prospects of smart coatings. Sol-gel technology and electrolytic co-deposition techniques, both of which have attracted much attention during the past few years in the development of functional coatings, are detailed in Chapters 8 and 9, respectively.

I would like to express my gratitude to the contributing authors in making this project a success, and to Dr. Martin Ottmar and Dr. Bettina Bems of Wiley-VCH for their assistance and encouragement in this venture. Finally, I would like to dedicate this book to my wife, Anjana, for her support, encouragement and assistance during its preparation.

Swapan Kumar Ghosh
Spring 2006

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List of Contributors

Elodie Bourgeat-Lami
Laboratoire de Chimie et Procédés de Polymérisation
CNRS/CPE
Bât. 308 F, BP 2077
43 Bd. du 11 Novembre 1918
69616 Villeurbanne Cedex
France

Christophe Déjugnat
Max Planck Institute of Colloids and Interfaces
Wissenschaftspark Golm
14424 Potsdam
Germany

Etienne Duguet
Institut de Chimie de la Matière Condensée de Bordeaux
CNRS/Université Bordeaux-1
87 Ave. du Docteur Albert Schweitzer
33608 Pessac Cedex
France

Swapan Kumar Ghosh
Arcelor Research Industry Gent
OCAS N.V.
John Kennedylaan 3
9060 Zelzate
Belgium

Serge Hoste
Department of Inorganic and Physical Chemistry
University of Gent
Krijgslaan 281
9000 Gent
Belgium

Katharina Landfester
Department of Organic Chemistry III
Macromolecular Chemistry and Organic Materials
University of Ulm
Albert-Einstein-Allee 11
89081 Ulm
Germany

Zhu Liqun
School of Material Science and Engineering
Beijing University of Aeronautics and Astronautics
P.O. Box 103
100083, Beijing
China

Dmitry G. Shchukin
Max Planck Institute of Colloids and Interfaces
Wissenschaftspark Golm
14424 Potsdam
Germany

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Parshuram G. Shukla
Polymer Science and Engineering
Division
National Chemical Laboratory
Dr. HomiBhaba Road
Pune 411 008
India

Gleb B. Sukhorukov
Max Planck Institute of Colloids and
Interfaces
Wissenschaftspark Golm
14424 Potsdam
Germany

and

IRC at Biomedical Materials
Queen Mary University of London
Mile End Road
London E1 4NS
United Kingdom

Isabel van Driessche
Department of Inorganic and Physical
Chemistry
University of Gent
Krijgslaan 281
9000 Gent
Belgium

Marc van Parys [AWAITING DE-
TAILS] Textile Institute – TO2C
Technical University Gent
Voskenslaan 362
9000 Gent
Belgium

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Functional Coatings and Microencapsulation: A General Perspective

Swapan Kumar Ghosh

1.1
An Overview of Coatings and Paints

Today, many objects that we come across in our daily lives, including the house in which we live and the materials we use (e.g., toothbrushes, pots and pans, refrigerators, televisions, computers, cars, furniture) all come under the "umbrella" of coated materials. Likewise, fields such as military applications – for example, vehicles, artilleries and invisible radars – and aerospace products such as aircraft, satellites and solar panels all involve the widespread use of coated materials. Clearly, the importance of coatings has increased hugely during the modern era of technology.

Coating is defined as a material (usually a liquid) which is applied onto a surface and appears as either a continuous or discontinuous film after drying. However, the process of application and the resultant dry film is also regarded as coating [1]. Drying of the liquid coating is mostly carried out by evaporative means or curing (cross-linking) by oxidative, thermal or ultraviolet light and other available methods. Paint can be defined as a dispersion that consists of binder(s), volatile components, pigments and additives (catalyst, driers, flow modifiers) [2]. The binder (polymer or resin) is the component that forms the continuous film, adheres to the substrate, and holds the pigments and fillers in the solid film. The volatile component is the solvent that is used for adjusting the viscosity of the formulation for easy application. Depending on their compositions, paints can be divided into three groups: solvent-borne, water-borne and solvent-free (100% solid). Solvent-borne paints consist of resin, additives and pigments that are dissolved or dispersed in organic solvents. Similarly, in water-borne paints the ingredients are dispersed in water. In solvent-free compositions, the paints do not contain any solvent or water and the ingredients are dispersed directly in the resin.

The properties of coating films are determined by the types of binders, pigments and miscellaneous additives used in the formulation. Moreover, types of substrates, substrate pretreatments, application methods and conditions of film formation

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play additional roles in determining the end properties of the coating. The terms "coating" and "paint" will be used synonymously in this book. In general, collectively or individually, paints, varnishes (transparent solutions) and lacquers (opaque or colored varnishes) are termed as coatings [3].

Coatings occur in both organic and inorganic forms. Inorganic coatings are mainly applied for protective purposes, while organic coatings are mostly used for decorative and functional applications [4]. Organic coatings can be classified as either architectural coatings (house, wall and ceiling coatings) or industrial coatings (appliances, furniture, automobiles, coil coatings) [3]. Although organic and inorganic coatings may be used individually for industrial applications, for specific requirements a combination of both systems – termed hybrid coating – is favored.

1.2 Classification of Coating Properties

Coatings are usually applied as multi-layered systems that are composed of primer and topcoat. However, in some cases – for example automotive coating systems – this may vary from four to six layers. Each coating layer is applied to perform certain specific functions, though its activities are influenced by the other layers in the system. The interactions among different layers and the interfacial phenomenon play an important role in the overall performance of the multi-coat systems [5]. Different properties of coatings are typically associated with specific parts of a coating system (Fig. 1.1) [6].

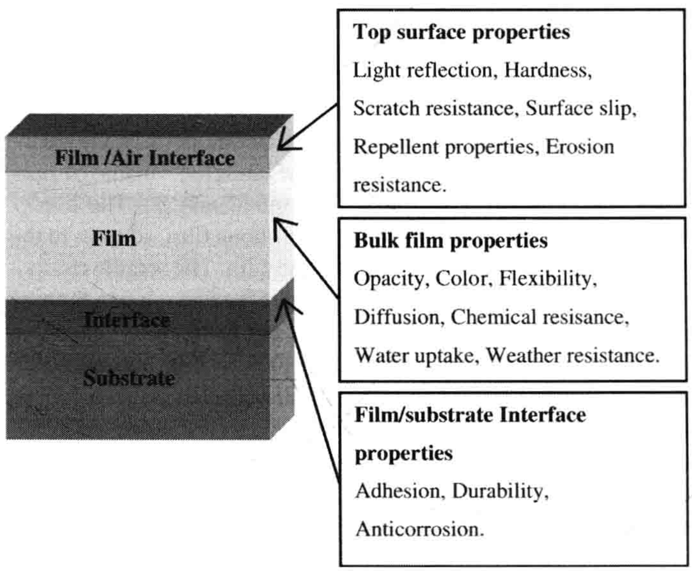

Figure 1.1 Topographical classification of coating properties.

1.3
What are Functional Coatings?

Coatings are mainly applied on surfaces for decorative, protective, or functional purposes, but in most cases it is a combination of these. The term "functional coatings" describes systems which possess, besides the classical properties of a coating (i.e., decoration and protection), an additional functionality [7]. This additional functionality may be diverse, and depend upon the actual application of a coated substrate. Typical examples of functional coatings are self-cleaning [8,9], easy-to-clean (anti-graffiti) [10], antifouling [11], soft feel [12] and antibacterial [13–15]. Although various mechanisms are involved, as well as numerous applications, there is a common feature that is of particular benefit and which satisfies some users' demands. Most coatings (whether inorganic, organic or ceramic) perform critical functions, but as these fields are extensive it is beyond the scope of this book to include all of them at this stage. Thus, the discussion here is limited to coatings with organic binders.

1.4
Types and Application of Functional Coatings

Apart from their special properties, functional coatings must often satisfy additional requirements; for example, nonstick cookware coatings must be resistant to scratching, abrasion and thermal effects. Typical expectations of functional coatings include:

- durability
- reproducibility
- easy application and cost effectiveness
- tailored surface morphology
- environmental friendliness

Functional coatings can be classified as several types depending on their functional characteristics (Fig. 1.2).

Functional coatings perform by means of physical, mechanical, thermal and chemical properties. Chemically active functional coatings perform their activities either at film–substrate interfaces (anticorrosive coatings), in the bulk of the film (fire-retardant or intumescent coatings), or at air–film interfaces (antibacterial, self-cleaning) [16].

Some applications of functional coatings are discussed in the following sections.

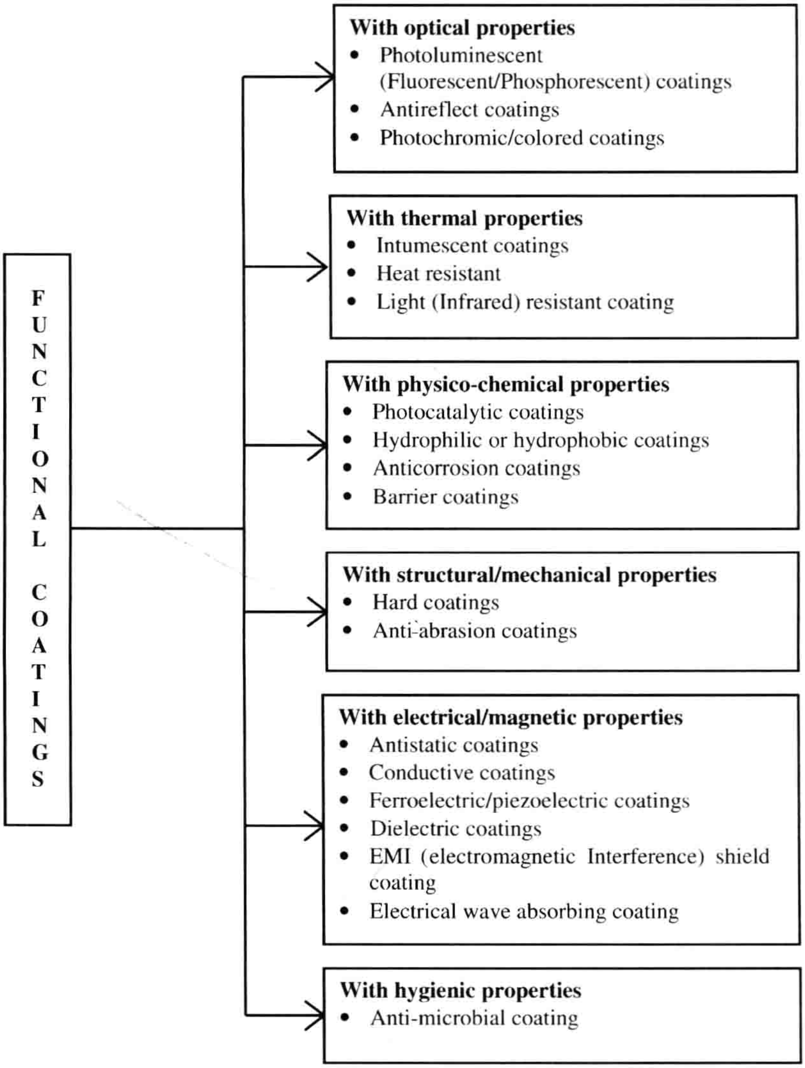

Figure 1.2 Types of functional coatings.

1.4.1 Anticorrosive Coatings

It is known that, when iron is exposed to a natural atmosphere, then rust is formed. Although the rusting of iron or steel is usually termed as corrosion, the latter is a general term which is used to define the destructive interaction of a material with its environment. Corrosion usually refers to metals, though nonmetallic substrates such as plastics, concrete or wood also deteriorate in the environment. Corrosion causes enormous industrial losses with a depletion of our natural resources. When two areas of a metallic component are exposed to different operational environments, or they differ in their surface structure or composition, an electrical potential is developed. Corrosion is in fact an electrochemical process where the electrical cell is composed of an anode (the corrosion site), an electrolyte (the corrosive medium), and a cathode (part of the metal which is active in the corrosion process but does not itself corrode) [17].

In general, organic coatings are applied onto metallic substrates in order to avoid the detrimental effect of corrosion. The anticorrosive performance of the coating depends upon several parameters, including: adhesion to metal, thickness, permeability, and the different properties of the coating. In most cases, the primer is mainly responsible for protecting the metallic substrate and adhering to other coating layers. In this context, surface preparation is essential in order to provide good adhesion of the primer to the metallic substrate [18]. The mechanisms by which organic coatings offer corrosion protection are summarized as follows.

- Sacrificial means: The use of a sacrificial anode such as zinc to protect steel is a longstanding and well-known industrial practice. The zinc layer on galvanized steel degrades when exposed to an adverse environment, and this protects the underneath surface. Using a similar approach, both inorganic and organic resin-based, zinc-rich coatings have been developed to protect a variety of metal substrates [19,20].
- Barrier effect: In general, polymeric coatings are applied to metallic substrates to provide a barrier against corrosive species. They are not purely impermeable. Moreover, defects or damages in the coating layer provide pathways by which the corrosive species may reach the metal surface, whereupon localized corrosion can occur. Pigments having lamellar or plate-like shapes (e.g., micaceous iron oxide and aluminum flakes) are introduced to polymeric coatings; this not only increases the length of the diffusion paths for the corrosive species but also decreases the permeability of the coating [21]. Other pigments such as stainless steel flakes, glass flakes and mica are also used for this purpose. The orientation of the pigments in the coating must be parallel to the surface, and they should be highly compatible with the matrix resin to provide a good barrier effect. Layered clay platelets such as montmorillonite may also be introduced into organic resin systems to increase the barrier effect towards oxygen and water molecules, thereby enhancing the anticorrosive performance of the coating (Fig. 1.3) [22].
- Inhibition: Traditionally, chromate- and lead-based pigments are the most common compounds used as corrosion inhibitors to formulate anticorrosive primers for metallic substrates. These substances are considered to be toxic and ecologically unsafe, and therefore the search for new alternative anticorrosive pigments is under way. Today, primers containing metallic phosphate, silicate, titanate or molybdate compounds are available commercially. These pigments form a protective oxide layer on the metallic substrates, and often also form anticorrosive complexes with the binder. To reduce the cost, a number of elements and compounds have been combined to develop an effective anticorrosive pigment, including aluminum zinc phosphate, calcium zinc molybdate, zinc molybdate