Industrial Applications for Intelligent Polymers and Coatings

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Editors

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Preface

This book is a comprehensive collaboration on intelligent polymers and coatings for industrial applications by world-class researchers and specialists. The authors cover the basic and fundamental aspects of intelligent polymers and coatings, challenges, potential mechanisms and properties, classification and composition, synthesis, characterization, and processing of intelligent polymers and smart coatings, bioactive and electroactive polymers and coatings, and stimuli responses of intelligent polymers and smart coatings. They include recent and emerging industrial applications in medical, smart textile design, oil and gas, electronic, aerospace, and automobile industries as well as other applications including micro-systems, sensors, and actuators, among others. The authors discuss the potential for future research in these areas for improvement and growth of marketable applications, current capability, and scale up of intelligent polymers and smart coatings in order to improve and spread their applications. This book serves as a valuable reference to industries, R&D managers and staff, scientists and engineers (chemical, mechanical, materials, etc.), chemists, academics, and other professionals in polymers and coatings, and manufacturers and designers dealing with intelligent polymers and coatings. It can also be a guide for science and engineering students in universities and research institutes.

Chapter 1 provides a critical discussion and an overview of the stimuli-responsive polymeric based nano-sized hosts and their applications in drug delivery. Furthermore, multi-responsive systems and their forthcoming development as well as the challenges associated with some stimuli-responsive polymeric based systems are discussed. Chapter 2 covers the stimuli responsiveness of smart polymeric coatings in various applications and their future outlooks within the coatings industry, as well as present practical applications and necessities of the stimuli-responsive smart polymeric coatings for industrial applications. Chapter 3 gives a critical review of diverse biomedical systems implementing electroactive polymers and coatings including pharmaceutical and medical industry and highlights their applications, advantages, and possible limitations. The chapter also introduces innovative approaches for enabling EAP and EAC-based systems to attain their full clinical

potential. Chapter 4 highlights some of the recent and novel findings in the development of piezospectroscopic particle reinforced polymers as smart stress and damage sensing coatings. The piezospectroscopic effect for alumina-based particulate composites is outlined and discussed in this chapter for current and future applications in the industry. Chapter 5 provides an overview of the methodologies reported to produce smart polymer surfaces depending on the external stimuli employed to vary reversibly the surface properties. The methodologies to prepare patterned surfaces as a function of their final resolution and some of the applications are highlighted in which smart polymer surfaces have been applied including wettability, biomedical purposes, sensoring, or smart adhesion. Chapter 6 addresses the smart textile transducer elements, textile platforms, application techniques, and construction methods. Multiple applications that have been inspired by the lightweight and compliant characteristics of smart textiles are further discussed in this chapter. Design principles and challenges associated with coating technologies as applied to textiles including surface treatment for strong adhesion, durability and environmental/mechanical constraints, and future trends are also introduced. Chapter 7 highlights new controlled living polymerization methods. Molecule-loading and types of morphologies of self-assembled supramolecular structures derived from smart polymers are also discussed. Chapter 8 discusses functions of bioactive and intelligent natural polymers in the optimization of drug delivery. It provides the contexts of natural bioactive and intelligent polymers and their unique applications in drug delivery that would ultimately benefit drug delivery systems in benchmarking new drug formulations. Chapter 9 looks at the current literature and patents pertaining to aptamer-based smart materials and the applicability of these materials for industrial applications. Aptamer-based smart materials bring together aptamer technology with material science, producing multifunctional, advanced materials with tunable properties that could be applied to many facets of industry. Chapter 10 presents the study of superhydrophobic and water-repellent polymer–nanoparticle composite films. The methods described in this chapter, where nanoparticles are embedded into inherently hydrophobic polymers to achieve the desired hierarchical micro/nanostructure on surface, are easy, low cost, and can be used to treat large surfaces implemented using various nanoparticles and polymers. Chapter 11 deals with the application of conducting polymers in solar water-splitting catalysis. Water splitting assisted by or driven by illumination with sunlight and involving conducting polymers and the properties of conducting polymers that make them favorable for this purpose are also discussed. Comparisons of these properties with those of conventional water-splitting materials are made, and a statement of research and achievements of solar hydrogen production through water splitting using conductive polymers is reported. Chapter 12 provides an in-depth review of the techniques that are typically employed in the preparation and characterization of smart and active biopolymers, films, and microparticles, their potential applications within the food industry, and the challenges that are associated with their use and development. Chapter 13 discusses the use of ATRP and click chemistry for polymerization of various clickable monomers using clickable ATRP initiators along with other post-polymerization modification strategies that can be used to construct macromolecules

with self-healing ability. Chapter 14 comprehensively aims to address a wide overview of polyurethane-based smart polymer and the chemistry behind the shape memory properties. This chapter also summarizes the recent studies on the exploration of SMPU using vegetable oils along with petroleum-based polyol and the potential applications of smart polyurethane. Chapter 15 discusses different polymorphisms of PVDF depending on the chain conformations of trans and gauche linkages. Various methods employed for the investigation of phase transition and strategies for the enhancement of the β-phase such as mechanical stretching, electrical polling, and addition of fillers are also summarized in this chapter. The evaluation components of the piezoelectric efficiency and applications of PVDF polymers are emphasized in the design of piezoelectric sensors, actuators, and energy harvesting devices. Chapter 16 discusses the different types of multifunctional materials used in biotechnology, resuming the opportunities and challenges that are implied by those systems with a focus on the multicomponent systems used for complex needs, with properties derived from interactions between the system constituents. The implementation of multifunctional materials in targeted delivery system that simultaneously perform diagnostics, targeted delivery, and efficient therapy is also summarized. Chapter 17 provides a short classification of the polymer nanocomposites, highlighting the importance of the shape, size, distribution, and origin of the nanofiller. A review of the investigation methods of the microstructure evaluation is performed. Synthesis for the mathematical models developed for their electrical, thermal, and dielectric properties is also presented. The current trends in obtaining intelligent polymer composites (thermo-sensitive, pH responsive, and other responsive stimuli) for various applications are also reviewed. Chapter 18 starts with a brief discussion of the relevant knowledge base, including microstructure of polymer nanocomposites, influence of nanomodification on properties of polymeric coatings, fabrication approaches, and the use of polymeric nanocoating as a carrier for corrosion inhibitors. It also provides a review of technological advances in the use of nanotechnology to produce high-performance polymeric coatings with outstanding corrosion resistance and other relevant properties as well as advanced characterization of nanocomposite coatings for corrosion protection. Chapter 19 introduces amphiphilic invertible polymers as novel smart macromolecules. The amphiphilic invertible polymer macromolecules possess an enhanced flexibility and rapidly respond to changes in an environmental polarity by changing their macromolecular conformation. Chapter 20 discusses functional materials used as reservoirs that enable the controlled delivery of corrosion inhibitors or healing agents and mainly focused on those primary stimuli that cause the release of inhibitive species from the reservoirs: mechanical damage, ion-exchange processes, and local pH changes. Chapter 21 highlights the recent advances and developments in the fabrication of ECPs-based textile supercapacitors, including different types of pure ECPs and their composites with other conducting materials for preparation of hybrid supercapacitors with superior performance for textile supercapacitor applications. Chapter 22 reviews recent advances in preparation and characterization of different self-healing coatings on steel. The main techniques for obtaining self-healing coatings and the challenges for future research are also briefly discussed.

Chapter 23 critically discusses silane resin coatings, their structure, characteristics, and applications. The concepts of the novel silane compound films, the rationale for the research and development, and the application possibilities in many industrial fields are also introduced in this chapter. Chapter 24 provides the principles and fundamentals of various types of smart coatings, materials, design, and processing methods, strategies to heal the mechanical damage, and the microencapsulation approaches to self-healing polymer development. Chapter 25 presents recent results describing sol-gel hybrid optical coating sensors to demonstrate their state-of-the-art industrial applications for gases, pH, solvents, and ionic species monitoring. Chapter 26 is focused on sensory polymers for detecting explosives and chemical warfare agents. Chemical warfare agents, conjugated or conductive polymers, molecularly imprinted polymers, and sensor arrays based on a set of polymers are discussed. The chapter concludes that polymer chemosensors are the best choice when designing and developing chemosensory materials for explosive sensing. Chapter 27 describes the synergistic combination of smart polymeric microencapsulation technology for industrial applications such as coatings and paints, construction, textile industry, food and beverage industry, pharmaceutical formulations, biomedical applications, aerospace, and automobile applications. Chapter 28 provides an overview of the approaches to the destructive and nondestructive characterization of adhesion, from the traditional methods to less common intelligent techniques. The main challenges, strengths, and weaknesses related to the evaluation of adhesion are also communicated in this chapter. Chapter 29 reviews waterborne coatings based on reactive polymer nanoparticles and the first attempts to use smart polymer nanoparticles where the crosslinking is triggered by a stimulus which occurs after the desired extent of interdiffusion. Different types of crosslinking that have the potential to be used in smart waterborne coatings, involving functional groups such as alcoxisilanes, carboxylic acids, carbodiimide, aziridine, isocyanates, and polyols, are also discussed. Chapter 30 introduces a new class of smart UV-curable coatings. Smart coatings such as self-cleaning, self-healing, anti-fog, antibacterial, and synthesizing routes for smart coatings and different types of smart UV-curable coatings for various engineering applications are also discussed. Chapter 31 discusses the use of innovative multifunctional composite silane-zeolite coatings. The method proposed in this chapter is based on the deposition, using a hybrid silane binder, of the adsorbent material based on aluminum zeolite. The characterization of the composite materials in order to evaluate its industrial applicability is also discussed. Chapter 32 gives the approaches for conducting the intercalation of poly [oligo (ethylene glycol)-oxalate] (POEGO) into lithium hectorite. It also discusses the preparation of different nanocomposite materials by varying the molar ratio of the polymer to the lithium hectorite and their characterization using powder XRD, TGA, DSC, and ATR along with the use of AC impedance spectroscopy to measure the ionic resistance of the nanocomposites when complexed with lithium triflate.

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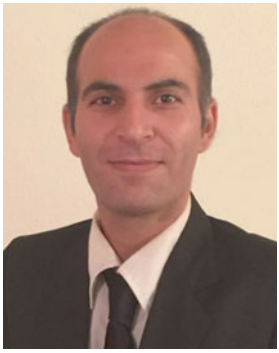

Majid Hosseini has earned both his Ph.D. and M.S. degrees in Chemical Engineering from *The University of Akron* in Ohio, United States. He has also completed his Bachelors degree in Chemical Engineering at *Sharif University of Technology* in Tehran, Iran. Dr. Hosseini's research interests, expertise, and experiences are very diverse, ranging from intelligent polymers and coatings to micro/encapsulation, nanoparticles for biomedical applications, industrial biotechnology, renewable energies, bioprocess engineering and developement, and biofuels. Dr. Hosseini has been actively engaged in various fields of polymers, bio/nanotechnology, sustainability, biofuels, and related technology development both in industry and academia. He is a persistent reviewer of leading international journals, has published high caliber research articles, and coinvented US and international patent application technologies. Dr. Hosseini has been a member of several professional bodies in the USA including *The New York Academy of Sciences, American Institute of Chemical Engineers (AICHE), AICHE-Institute for Sustainability, AICHE-SBE (Society of Biological Engineering), New Design Institute for Emergency Relief Systems (DIERS), International Society for Pharmaceutical Engineering (ISPE), AICHE-Pharmaceutical Discovery, Development and Manufacturing Forum, and The National Society of Collegiate Scholars.*

Abdel Salam Hamdy Makhlouf Dr. Makhlouf is RGV STAR Professor in the Department of Manufacturing & Industrial Engineering, UTRGV. He is the Founder of Surface Engineering Laboratory and a leading faculty of the Rapid Response Manufacturing Center.

Prof. Makhlouf is a multiple-award winner for his academic excellence: He received several prestigious awards in Germany (Humboldt Research Award for Experienced Scientists at Max Planck Institute); USA (Fulbright Visiting Scholar, NSF Fellow, and Dept. of Energy Fellow); Belgium (Belgian Federal Science Research Fellowship); Arab League (Arab Youth Excellence Award in Innovation 2013); Jordan (Abdul Hameed Shoman Award in Engineering Science 2012); Egypt (National Prize of Egypt in Advanced Science and Technology 2006, Egyptian Prize of Excellence in Surface Technology and Corrosion 2006, and Egyptian Prize of Excellence and Innovation in Materials Science and their Applications 2009); and Palestine (An-Najah Prize for Research 2014). Makhlouf's biography was selected to be included in *Who's Who in the World*® 2015, 2007, and 2006.

Prof. Makhlouf was able to make breakthroughs in several highly important areas of materials science and engineering. His publication list (+170) includes studies and review papers authored in journals from top publishers. He is the editor of 11 books and 20 book chapters. One of his articles has been ranked the second among the Top 25 Hottest Articles in Materials Science, Elsevier, 2006. He has made significant contributions to the field of materials science and manufacturing engineering, all of which place him among the top scientists working in his field. In fact, when performing a Google Scholar database search using the keywords "silica conversion coatings aluminum"; "corrosion aluminum composites"; "corrosion niobium stainless steels"; "smart coatings materials protection"; "Electroless Ni–P alloy coatings"; "self-healing coatings magnesium"; or "nano-particle aluminum coating", his articles on these subjects appear among the top 1st–7th out of >100,000 scholarly articles on these highly specialized research topics. Thus, his publications are among the most important and influential articles. Dr. Makhlouf's book "Handbook of Nanoelectrochemistry: Electrochemical Synthesis Methods, Properties, and Characterization Techniques", published by Springer, 2016 has been featured in the website of the International Society of Electrochemistry.

Prof. Makhlouf has gained invaluable experience by working in coatings and corrosion laboratories in USA, Italy, and Germany and by collaborating on a multitude of international projects with American, French, Romanian, Saudi, and Korean institutions among others. His career has spanned appointments and invitations to work with other scientists in the top 1 % of material engineering across the globe, and he has been called upon exhaustively to report his expert opinion on scientific panels, conference keynote addresses, and to government and industry committees. He is a Consultant for Innosquared GmbH, and for Covestro, Germany. He has organized and served as a head speaker at numerous highly prestigious international symposiums and conferences over 30 times. His work as a professor has also brought him acclaim, with numerous appointments at outstanding institutions and universities in the USA, Germany, Italy, Egypt, and Asia and a record of having supervised and graduated 11 PhD and Master's students and 5 postdoctoral fellows.

Prof. Makhlouf is a persistent journal reviewer, advisor, and judge of the work of his peers. He is a referee for over 30 international journals of a high caliber and a continued board member of over 22 journals. He is also an experienced Editor with board titles at journals published by Springer and Elsevier, an Expert Evaluator for the EU's FP7, with an estimated budget of over €50.521 billion, expert for the German Ministry of Education and Research, reviewer for the German Academic Exchange Service, and expert for the German Aerospace Center. He is a reviewer/panelist for the NSF programs: MME, MEP, and CREST; with an estimated budget of over $7.6 billion. He is a reviewer for the US Fulbright Commission, the Qatar National Research Fund, and the Kuwait Foundation for the Advancement of Sciences.