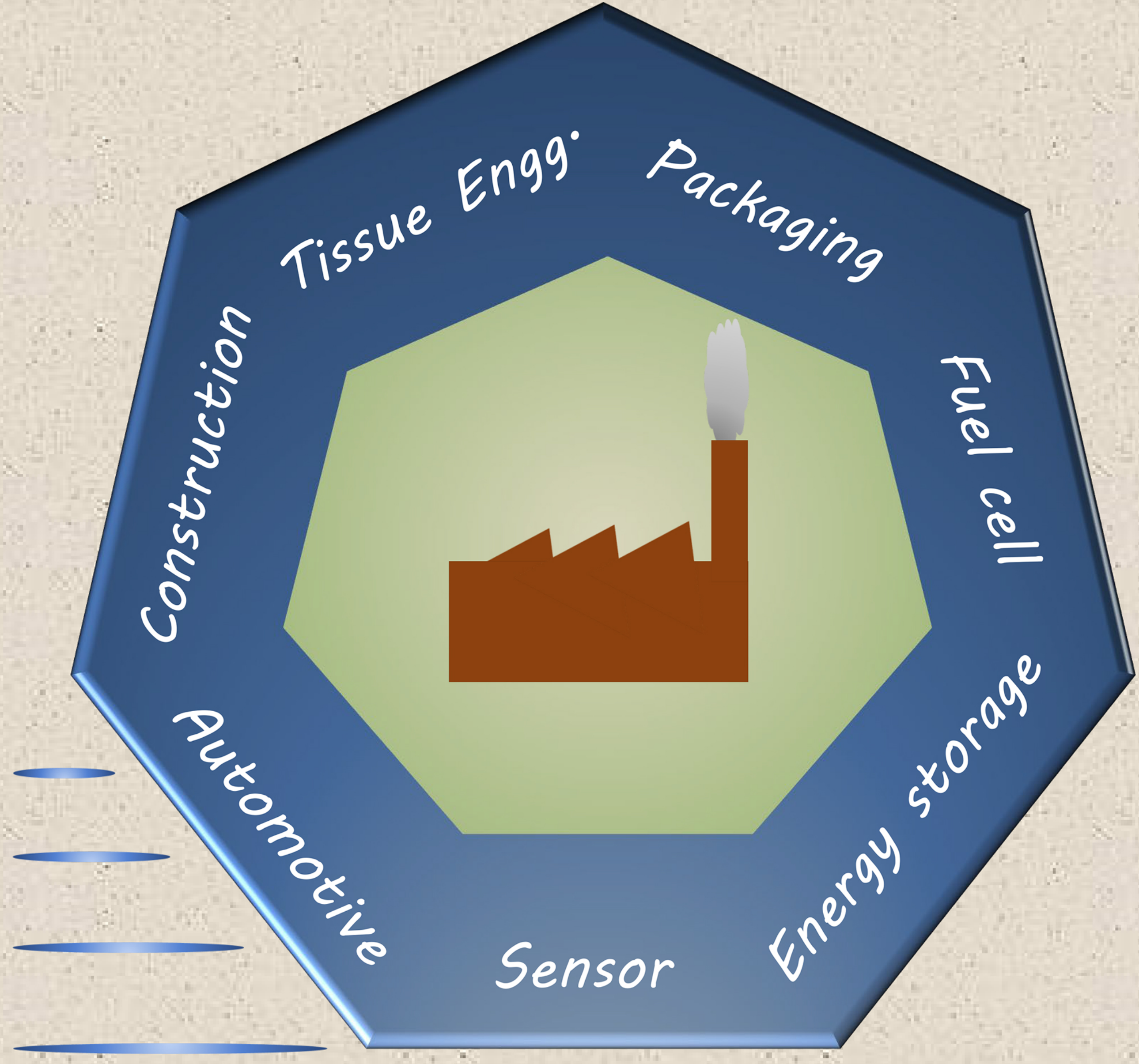
INDUSTRIAL APPLICATIONS OF POLYMER COMPOSITES



Editors:

Subhendu Bhandari
Prashant Gupta
Ayan Dey

Bentham Books

Frontiers in Polymer Science

(Volume 1)

Industrial Applications of Polymer Composites

Edited by

Subhendu Bhandari
Department of Plastic and Polymer Engineering
Maharashtra Institute of Technology
Aurangabad, India

Prashant Gupta
MIT-Center for Applied Materials Research and Technology
Department of Plastic and Polymer Engineering
Maharashtra Institute of Technology
Aurangabad, India

&

Ayan Dey
Indian Institute of Packaging
Mumbai
India

Frontiers in Polymer Science

(*Volume 1*)

Industrial Applications of Polymer Composites

Editors: Subhendu Bhandari, Prashant Gupta and Ayan Dey

ISBN (Online): 978-981-5124-81-1

ISBN (Print): 978-981-5124-82-8

ISBN (Paperback): 978-981-5124-83-5

Published by Bentham Science Publishers Pte. Ltd. Singapore.

First published in 2023.

BENTHAM SCIENCE PUBLISHERS LTD.

End User License Agreement (for non-institutional, personal use)

This is an agreement between you and Bentham Science Publishers Ltd. Please read this License Agreement carefully before using the ebook/echapter/ejournal (**"Work"**). Your use of the Work constitutes your agreement to the terms and conditions set forth in this License Agreement. If you do not agree to these terms and conditions then you should not use the Work.

Bentham Science Publishers agrees to grant you a non-exclusive, non-transferable limited license to use the Work subject to and in accordance with the following terms and conditions. This License Agreement is for non-library, personal use only. For a library / institutional / multi user license in respect of the Work, please contact: permission@benthamscience.net.

Usage Rules:

1. All rights reserved: The Work is the subject of copyright and Bentham Science Publishers either owns the Work (and the copyright in it) or is licensed to distribute the Work. You shall not copy, reproduce, modify, remove, delete, augment, add to, publish, transmit, sell, resell, create derivative works from, or in any way exploit the Work or make the Work available for others to do any of the same, in any form or by any means, in whole or in part, in each case without the prior written permission of Bentham Science Publishers, unless stated otherwise in this License Agreement.
2. You may download a copy of the Work on one occasion to one personal computer (including tablet, laptop, desktop, or other such devices). You may make one back-up copy of the Work to avoid losing it.
3. The unauthorised use or distribution of copyrighted or other proprietary content is illegal and could subject you to liability for substantial money damages. You will be liable for any damage resulting from your misuse of the Work or any violation of this License Agreement, including any infringement by you of copyrights or proprietary rights.

Disclaimer:

Bentham Science Publishers does not guarantee that the information in the Work is error-free, or warrant that it will meet your requirements or that access to the Work will be uninterrupted or error-free. The Work is provided "as is" without warranty of any kind, either express or implied or statutory, including, without limitation, implied warranties of merchantability and fitness for a particular purpose. The entire risk as to the results and performance of the Work is assumed by you. No responsibility is assumed by Bentham Science Publishers, its staff, editors and/or authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products instruction, advertisements or ideas contained in the Work.

Limitation of Liability:

In no event will Bentham Science Publishers, its staff, editors and/or authors, be liable for any damages, including, without limitation, special, incidental and/or consequential damages and/or damages for lost data and/or profits arising out of (whether directly or indirectly) the use or inability to use the Work. The entire liability of Bentham Science Publishers shall be limited to the amount actually paid by you for the Work.

General:

1. Any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims) will be governed by and construed in accordance with the laws of Singapore. Each party agrees that the courts of the state of Singapore shall have exclusive jurisdiction to settle any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims).
2. Your rights under this License Agreement will automatically terminate without notice and without the

Bentham Science Publishers Pte. Ltd.
80 Robinson Road #02-00
Singapore 068898
Singapore
Email: subscriptions@benthamscience.net

CONTENTS

PREFACE

A polymer composite is a three-dimensional combination of at least an organic or inorganic filler dispersed in a continuous or co-continuous phase of an individual polymer or a polymeric blend. The presence of polymers as well as fillers in different blends may be wisely utilized in different combinations to overcome the limitations of the individual components toward achieving the required characteristics of industrial products. The ability to achieve a set of desired characteristics such as mechanical, chemical, physical, electrical, electrochemical, biological, *etc.*, suiting the needs, processability, dimensional stability, thermal, cost, and so on has allowed polymeric composites to be used in a wide range of industrial applications such as construction, packaging, tissue engineering, energy storage, sensors, transportation, and so on. The consumption of polymer composites for industrial applications is ever-growing with time. With the advent of upgraded and new technologies related to the preparation of individual components and composites, different combinations of materials have attracted researchers from academia as well as industries. To meet the demand of consumers, new material development as well as finding new applications for the existing materials have become the major focus of industrial research. Several books were published on polymer composites in the last decade with a primary focus on materials, characterization, or any specific area of application. However, it is envisaged that a single book encompassing the knowledge related to polymer composites in different fields of application is unavailable in the market. In this book, the focus is on the recent developments in various major sectors where composite materials are very popular and significantly used. With the rich experience in polymer composites and nanocomposites of the editors, especially in application development, technical services, and new product development, we thought of bringing together authors having expertise in polymer composites in specific industrial domains. The outline of the book encompasses relevant knowledge from an application point of view and represents its diversities in a nutshell. Therefore, we feel the proposed book may attract a broad readership from industry as well as academia.

We thank all the contributors for their generous efforts and cooperation in providing chapters highlighting recent research and findings across the globe. We are thankful to all the authors of the studies cited in the present book. We also like to express our gratitude to the entire team of Bentham Science Publishers for their collaboration, prompt assistance, and patience during the publication of this book.

Subhendu Bhandari
Department of Plastic and Polymer Engineering
Maharashtra Institute of Technology
Aurangabad, India

Prashant Gupta
MIT-Center for Applied Materials Research and Technology
Department of Plastic and Polymer Engineering
Maharashtra Institute of Technology
Aurangabad, India

Ayan Dey
Indian Institute of Packaging
Mumbai
India

FOREWORD

This is a great pleasure for me to write a foreword for the book "Industrial Applications of Polymer Composites" which would definitely be a great addition to the library of documents concerning Polymer Science and Technology and more precisely the areas of polymer technology dealing with the applications of different polymer composites, the area of material science now under sharp investigation. Considering the growth of polymer technology to cater to the ever-increasing demand of society, polymer composites have appeared to us as God's blessings. The importance and scope of utilities of polymer composites cannot be overemphasized. The entire world of Material Science has been revolutionized since people could sense the widespread applicability and flexibility of polymer composites which now can be tailor-made. It can possibly be mentioned very concisely that the evolution of material science in the last three decades is the evolution of polymer composites.

The present book is a nice compilation of the scope of utilization of different types of polymer composites. The vision of the editors and the authors who are young and energetic academicians with very good exposure and practical experience in the different fields of construction, packaging, tissue engineering, batteries, microbial fuel cell, sensors and automotive appliances is really praiseworthy. Their tenacious endeavour in presenting the current scenario of the role of polymer composites in fabricating items of the different fields as mentioned above is quite inspiring and interesting. The field of construction has seen a sea change with the advent of polymer composites. The use of multi-layered laminar composites has enabled the civil engineer to substitute a substantial proportion of heavy concrete and thus help to reduce the total weight of the construction, an essential need of time. Many polymeric additives are now available to enhance the flow properties of concrete material. A highly durable, light weight construction is now readily available. The packaging industries have greatly benefitted from the use of polymer composites in a great way. The concept of multi-layered films, each film in its turn being a composite one has enabled the packaging scientists to control permittivity and diffusivity of the various harmful environmental gases and thus prolonging the shelf life of the contents. The synthesis of semi-permeable membrane, the most essential component of microbial fuel cells could not have reached so advanced stage so early without the polymer composites. The different gadgets and accessories meant for the automotive sector would not have been possible to be fabricated without the polymer composites. It is worthwhile mentioning here that the authors having expertise in the respective fields described in the book have tried their best to make the readers acclimatized with the products made up of polymer composites finding applications in different fields for their properties that cannot be challenged by other materials commonly available.

I presume the basic mission of the editors and authors has been successful. The readers would definitely be able to feel and sense the fragrance of the book on reading. I pray to the Almighty for its widespread success.

Debabrata Chakrabarty
Department of Polymer Science & Technology
University of Calcutta
Kolkata, India

List of Contributors

Amandeep Singh	Department of Polymer Science and Technology, University of Calcutta, Kolkata, India
Anusha Vempaty	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India
Arti Rushi	Maharashtra Institute of Technology, Aurangabad, India
Barun Kumar	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India
Bhagwan Ghanshamji Toksha	Maharashtra Institute of Technology, Aurangabad, India
Deepak Jadhav	Department of Agricultural Engineering, Maharashtra Institute of Technology, Aurangabad-431010, India
Dinesh Rathod	Department of Physics, JES, R. G. Bagadia Arts, S. B. Lakhotia Commerce, and R. Bezonji Science College, Jalna, India
Kalpana Sharma	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India
Kunal Datta	Deen Dayal Upadhayay KAUSHAL Kendra, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad (MS), India
Madhuri N. Mangulkar	Department of Civil Engineering, Marathwada Institute of Technology, Aurangabad, India
Naveen Veeramani	Center for Carbon Fiber and Prepregs, CSIR-National Aerospace Laboratories, Bangalore-560017, India
Nabakumar Pramanik	Department of Chemistry, National Institute of Technology, Arunachal Pradesh, Arunachal Pradesh-791113, India
Narayan Chandra Das	Rubber Technology Centre, Indian Institute of Technology, Kharagpur-721302, India
Prosenjit Ghosh	Center for Carbon Fiber and Prepregs, CSIR-National Aerospace Laboratories, Bangalore-560017, India
Rupesh Rohan	Indian Rubber Manufacturers Research Association (IRMRA), Sri City Trade Centre, Sri City, District: Chittoor, Andhara Pradesh, India
Sampad Ghosh	Department of Chemistry, Nalanda College of Engineering, Nalanda-803108, Bihar, India
Shweta Rai	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India
Soumya Pandit	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida-201306, India
Sovan Lal Banerjee	Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL, 60637, USA
Togam Ringu	Department of Chemistry, National Institute of Technology, Arunachal Pradesh, Arunachal Pradesh-791113, India

Tushar Kanti Das	Rubber Technology Centre, Indian Institute of Technology, Kharagpur-721302, India
Vaibhav Raj	Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India

CHAPTER 1

Polymer Composites for Construction Applications

Dinesh Rathod[1], **Madhuri N. Mangulkar**[2] and **Bhagwan Ghanshamji Toksha**[3,*]

[1] *Department of Physics, JES, R. G. Bagadia Arts, S. B. Lakhotia Commerce, and R. Bezonji Science College, Jalna, India*

[2] *Department of Civil Engineering, Marathwada Institute of Technology, Aurangabad, India*

[3] *Maharashtra Institute of Technology, Aurangabad, India*

Abstract: Polymer composite concrete (PCC) nowadays plays a major role in the construction industry. PCC is a valuable element in the development of sustainable construction materials. The polymers and classical concrete blends offer newer properties and applications. A polymeric action in the field of admixtures provides insight into the development of highly performing modified mineral concrete and mortars. The influence of various polymers on the properties of concrete is variable due to the polymeric chain reactions. The optimization of properties such as crack resistance, permeability, and durability with the addition of polymer is required. The present work reviews the types, performances, and applications of PCC to improve various properties of concrete in both fresh and hardened states as they have shown a strong potential from technical, economical, and design points of view.

Keywords: Concrete properties, Polymer composite concrete, Polymeric chain.

INTRODUCTION

In the history of mankind, the last two centuries have witnessed rapid advances in construction material technology enabling civil engineers to achieve structures with increased safety and functionality at the economy of scale which could have served the common needs of society [1-4]. The elongation of structural life span against environmental deterioration, sustaining natural calamities such as earthquakes, heavy traffic densities, blast impact from terror attacks, debris flow, and highly corrosive environments demands better quality of reinforced concrete for building structures. The activities encompass the upgradation of design codes and strength requirements. This leads to the exploration of reinforced concrete (RC) materials which could provide strengthening in structures to meet the adequate strength requirements and extend the service life [5-9].

---

[*] **Corresponding author Bhagwan Ghanshamji Toksha:** Maharashtra Institute of Technology, Aurangabad, India; E-mail: mittoksha@gmail.com

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

The use of polymer additives may be practiced either as a part of a concrete admixture recipe or as external support to already existing structures. The basic composition of concrete is a mixture of fine sand and liquid cement. This formulation is one of the most widely used items in the world after water which is used for construction of all building purposes [10]. The use of concrete is twice as the mixture of aluminium, wood, and plastic as well. As it is widely used globally, it is expected to generate about $600 billion in revenue in the upcoming 5-10 years [11]. Considering the massive use of concrete, there are some disadvantages as they contribute ca. 8% of greenhouse emissions [12-16]. The possible alternatives and related concerns with the usage of supplementary cementitious materials to address the issue of greenhouse gas emissions from the use of concrete were reviewed by Sabbier Miller *et al.* [17]. Other environmental concerns include large-scale illegal sand mining, as well as some effects on the surrounding environment, such as the changes in river surface leaf flow, the effects of urban heat on islands, and the effects of toxic factors on public health. There is a need for extensive research and development to control further damage to the environment still meeting human needs. One of the promising alternatives is to increase the production of secondary raw materials reducing the volume of conventional concrete with still maintaining the construction standards.

The second type of usage of polymer composite as external support includes repair, rehabilitation, and strengthening of structural elements such as beams/columns. The orthodox approaches to rehabilitation, and strengthening structures include the use of an external layer of metallic plate, textile fibre sheet, wire mesh, post tensioning, concrete or steel jacketing, and injection of epoxy [18-22]. The conditions and criteria for selecting one reinforced concrete over another are largely dependent on the type of structure, the degree of strengthening required, and the associated cost. The extent of strengthening and the cost at which it is achieved is a delicate balance to maintain. There are certain challenges with these conventional methods. The heavy weight of externally bonded steel plates requires mechanical fastening and ongoing maintenance to prevent corrosion [18]. The requirement of installation of steel anchorages, deviators, and protection of the steel strand and anchorages against corrosion are some of the downsides of external post-tensioning [24, 25]. These requirements add to the labour and cost of the solution. The need for section enlargement, erection of temporary formwork, and mechanical interlock achieved by the installation of steel dowel bars are un-desirous in concrete jacketing [21, 22]. Polymers and polymer composites were developed very fast compared to other civil engineering tools [23]. Advanced polymer composites have been used the primarily in the aerospace and marine industries, but have also been used in civil engineering for the last few years as they have some unique properties [24]. The scoring points for a particular reinforced concrete system will be fulfilling all design requirements, having the shortest installation time, and realization at the lowest cost including the initial material supply and installation, as well as future maintenance costs such as ongoing corrosion protection, regular inspection, and monitoring. There is a huge amount of polymeric materials available in the form of waste or recycled materials. The adaptation of circular economics modifying the current conventional economy of the construction industry is depicted in Fig (**1**). This model of inclusion of polymer materials is crucial for completing the cycle in a cost-effective way and addressing the environmental issues [25]. Polymer-based materials for reinforced concrete systems are one of the most promising solutions. Their characteristics being non-destructive, light weight, having high tensile strength, corrosion-resistance, lack of long-term maintenance requirements and cost-effectiveness increase their usability in reinforced concrete (RC) materials. Traditional approaches began to take shape in the early 20th century. Concrete-polymer composites including polymer-modified (or cement) mortar and concrete, polymer mortar and concrete, and polymer-impregnated mortar and concrete have been developed in the world for over the past 50 years. In 1965, the first sample of polymer-impregnated concrete (PIC) was discovered at Brookhaven National Laboratory [25]. After this, the whole world was drawn to it [26]. The implementation of polymer-based solutions for reinforced concrete needs to address the issues such as fire performance to provide the necessary fire endurance period without collapse [27]. The other limiting concern with the polymer-based solutions is the limits on the degree of strengthening that may be achieved. The use of fibre polymers in reinforced concrete will improve performances, compared to those realised through other existing techniques [28]. The comparison of stress-strain values of various materials used in concrete composites was recorded by Theodoros Rousakis *et al.* [29].

Polymer concrete is used in specialized construction projects where there is a need to resist several types of corrosion and is supported to have durability *i.e.*, to last longer. It can be used similar to ordinary concrete. Polymer concrete is applied for various construction purposes such as repairing corrosion-damaged concrete [31], pre-stressed concrete [32], nuclear power plants [33], electrical or industrial construction [34, 35], marine works [36], prefabricated structural components like acid tanks, manholes, drains, highway median barriers, waterproofing of structures, sewage works and desalination plants. Contemporary researchers are taking the help of advanced technological tools to explore the field of polymer concrete [37-40]. The use of artificial intelligence has also occupied space in enhancing the field of polymer concrete. The newer models are recently getting evolved for FRP- confined concrete [41]. The comparison between the hybrid models with the existing design relations of the ultimate strain and strain capacities has revealed that the hybrid models have superior abilities in terms of

CHAPTER 2

Polymer Composites as Packaging Materials

Amandeep Singh[1,§] and **Sovan Lal Banerjee**[2,*,§]

[1] *Department of Polymer Science and Technology, University of Calcutta, Kolkata, India*

[2] *Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL, 60637, USA*

Abstract: This chapter aims to obtain a better understanding of the role of polymer nanocomposites in different packaging applications such as food packaging, electronic packaging, and industrial packaging. Dispersion of nanoparticles (NPs) in the packaging materials improves the properties like mechanical strength and modulus, water resistance, gas permeability, *etc.* In addition, bioactive agents in the packaging materials impart interesting smart phenomena like antimicrobial, and antifouling properties. Generally, petroleum fuel-based thermoplastic polymers are conventionally used in primary and secondary packaging. Some of the widely used polymeric packaging materials consist of polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS). However, as the consequence of the harmful impacts of fossil fuel-based packaging materials on humans, animals, and the environment has become understandable, more and more emphasis has been shifted to biopolymers (cellulose, protein, marine prokaryotes, *etc.*) and their nanocomposites. Bio-based or bio-originated polymers or biopolymers are eco-friendly, non-hazardous to living beings as well as to the environment, biodegradable, abundant, and a better alternative to depletable fossil fuel-based materials. Biopolymer-based nanocomposites advocate all desirable aspects of a packaging material to be sustainable, reliable, and environmentally friendly. In addition, the nature-inspired active and intelligent/smart packaging materials are economical and their contribution to reviving the circular economy is prominent.

Keywords: Biopolymer, Nanocomposite, Polymer, Packaging.

INTRODUCTION

Nowadays, the implementation of nanotechnology in the packaging sector is widely accepted and considered a promising area of research due to its immensely interesting advantages such as gas barrier property, enhanced mechanical strength, increased bioavailability of nutrients, and special features such as antimicrobial,

---

[*] **Corresponding author Sovan Lal Banerjee:** Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL, 60637, USA; E-mail: sovanbanerjee1987@gmail.com

[§] Both the Authors equally contributed to this book chapter

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

antifouling, and conductive properties in the packaging materials [1 - 4]. Packaging materials play a significant role in different areas such as food [4], electronics [5], pharma [6], and several other industrial sectors. The contribution of the packaging industry to the overall economy of any nation is significant. For instance, the food packaging industry in the United States contributes approximately $561 billion, and about 15% of this amount goes to the food packaging segment itself. A packaging material provides a shield to the packaged stuff from mechanical hazards during transport or service delivery. Among diverse packaging materials such as glass, paper, metals *etc.*, polymers (thermoplastic, thermosetting, and elastomers) are chosen to be one of the best options as the packaging materials as they have good mechanical strength, manufacturing easiness, and are economical [7]. Petroleum-based polymers and their nanocomposites are being used in packaging for a long time. Polymer nanocomposites (PNCs) are materials where the required polymer/ blend of polymers are reinforced (generally, < 5 wt%) with desired nanoparticles (NPs) having aspect ratios (L/h) of > 300 to impart properties like mechanical strength, gas barrier properties, conductivity, bioactive properties (antimicrobial, antifouling), *etc.* [8]. For the gas barrier property, different kinds of clays *viz.* montmorillonite (MMT), kaolinite (K), layered double hydroxides (LDHs)] having silicate layers have been used, which actually enhance the diffusion path length for any gas/ gasses by forming a tortuous path inside the polymer matrix [9]. Composting with clay nanoparticles also enhances the water vapour resistance (WVR) property of the polymer nanocomposite [10]. As per the International Organization for Standardization [11], composite materials are defined as materials with multiple phases, where two or more materials of different chemical or physical properties are merged together to make a system with one continuous phase and another dispersed phase. Suppose in case of the polymer-clay nanocomposite material, polymer acts as a continuous phase whereas clay plays the role of the dispersed phase.

However, as the harmful effects of the packaging materials derived from fossil-fuel on human, animals, and environment are perspicuous, growing interests in the development of bio-based polymers and their nanocomposites have been observed nowadays [12 - 14]. The biodegradability, easy availability, and non-hazardous nature of the biopolymers to the living being undoubtedly highlight this category of polymer as a better alternative to depletable fossil fuel-based materials. More recently, to judge the environmental impact of biodegradable polymers and their nanocomposites, these have been used in the food industry [14, 15]. Suitable biopolymers for packaging such as cellulose, marine prokaryotes, starch, protein, poly-β-hydroxybutyrate (PHB), and polyhydroxy valerate (PHAs) are mixed with several additives to form the hybrids in order to develop various types of active and intelligent/smart packaging materials. Active food packaging not only supports the transportation of food materials by providing the safest milieu to protect the food, but such packaging also protects from harmful bacteria, contamination, and degradation due to the presence of specific additives in the packaging materials [16]. However, uses of the bio-based polymers are mostly limited to the food packaging industry because of their sustainability, reliability, and environment-friendly nature. But, in the electronic packaging sector, mostly thermosetting polymers are being used like phenolic, epoxy, silicone, and polyester [5]. These polymers serve as an adhesive material to glue a metal led frame to the semiconductor chip. Although, polymer-based electronic packaging material is a cheap alternative compared to the metal and ceramic-based packaging; however, much lower electrical and thermal conductivities are still the issues to be overcome [5]. Recently, the nature-inspired intelligent/smart packaging materials are also paving a new era to the packaging technology [17]. All these applications of the polymer-based nanocomposites in the packaging tors have been detailed in the following sections, which we believe, would be very interesting to the readers as well as to the researchers of this field.

Definition of Composites and Classifications of the Composite Materials

In polymer science, composite materials are defined as the systems consisting of two or more immiscible phases having different physical or chemical properties. There are different methods available to form the nanocomposites such as blending, compounding, filling, melting, mixing, and assembling. These are very well known terms in polymer composite area (Fig. **1**) and can be found elaborately in dedicated literature [18, 19].

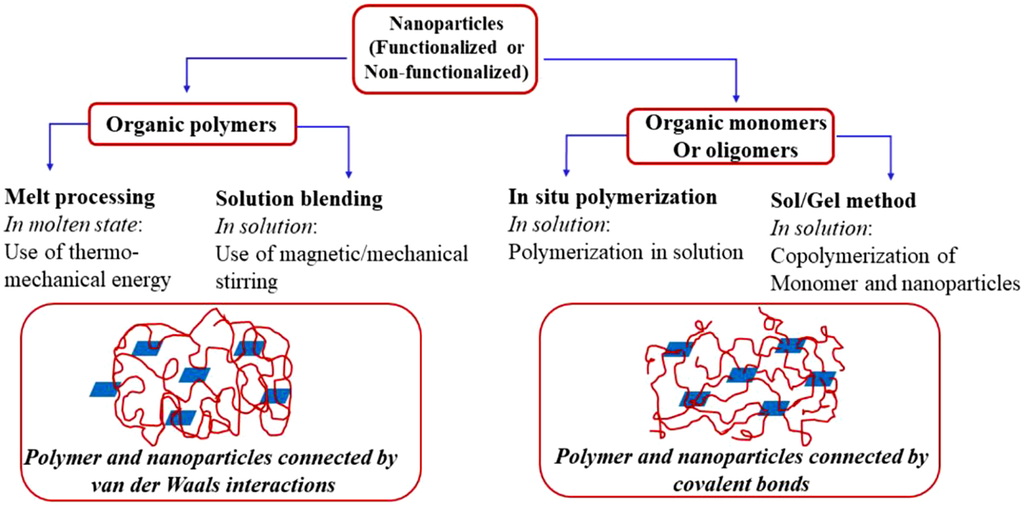


Fig. (1). Outline of polymer nanocomposite preparation techniques [19].

CHAPTER 3

Polymer Composites in Tissue Engineering

Togam Ringu[1], **Sampad Ghosh**[2] and **Nabakumar Pramanik**[1,*]

[1] *Department of Chemistry, National Institute of Technology, Arunachal Pradesh, Arunachal Pradesh-791113, India*

[2] *Department of Chemistry, Nalanda College of Engineering, Nalanda-803108, Bihar, India*

Abstract: A composite is a multiphase material made of layers of stacked phase *i.e.,* a matrix, an interface and a reinforced phase. The matrix phase is the main constituent of a composite. The interface binds the matrix and the reinforced phase, whereas, the latter provides strength to the material. Based on the matrix and the reinforced phase, it may be classified into various types such as fibers, particles, polymers, ceramics and metals. Polymer composite is a sub-type of composite having a polymer matrix and different reinforced materials. Due to its biocompatible nature, it is widely used in the field of biomedical applications. Many manufacturing methods are used in composites, but some of the commonly used manufacturing techniques include hand lay-up, reinforced reaction injection molding (RRIM), centrifugal casting, *etc*. High strength, and ductility with lightweight, cytocompatibility, and non-toxicity are some of the properties due to which composite materials are widely used in various industries such as automobile, aerospace, sports equipment, and tissue engineering. In tissue engineering (TE), a biomaterial called a scaffold, is developed that evolves into a functional tissue. Enhanced cell proliferation, cell adhesion and cell viability are observed with the composite-developed scaffold. Scaffold is fabricated using two types of composites; natural and synthetic composites. The applications of polymer composites at the bioengineering level are of great interest nowadays. This chapter intends to study various physicochemical properties of polymer composites including their bioengineering/tissue engineering applications elaborately. The study investigating the physicochemical properties and bioengineering/tissue engineering applications of polymer composites may bestow valuable insight into the potential of polymer composites in modern science.

Keywords: Cytocompatibility, Cell proliferation, Interface, Matrix, Multiphase, Polymer composites, Reinforcements, Scaffolds, Tissue engineering.

INTRODUCTION

In the field of material science, polymer composite materials have shown great development and growth over the past decades due to their diverse characteristics

---

[*] **Corresponding author Nabakumar Pramanik:** Department of Chemistry, National Institute of Technology, Arunachal Pradesh, Arunachal Pradesh-791113, India; E-mail: pramaniknaba@gmail.com

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

and applications. From being used in aerospace and electronics industries to biomedical applications, these are some of the transitions seen over the years in the development of polymer composites [1]. The dynamic transition in the usage of polymer composite is shown in Fig. (**1**). Polymer composite materials have replaced the conventional use of materials *e.g.,* metals in automobiles are being replaced by carbon fiber composites which are lighter in weight and have higher strength, and improved speed and fuel efficiency when compared to conventionally used materials in automobiles [2]. Polymers are easy to manufacture and process and are very cost-effective compared to the conventionally used other materials. A polymer composite is defined as a combination of a polymer with non-polymeric components such as metals, particles, ceramic, fiber, *etc*. All these components when mixed together, form a polymer composite [3]. Each and every attribute used in polymeric composites gives equal potential to improve the quality and properties of polymeric composites. The constituents of polymer composites are of three phases [3]:

Matrix Phase

This is the main constituent of a polymer composite. It is continuous in nature and surrounds the other phase *i.e.,* the dispersed phase. The materials used in the matrix phase are usually ductile or tough in nature. It also transfers stress to the fiber and maintains stability. It protects reinforcement from environmental factors such as chemicals and moisture, and also the surfaces of the fibers from mechanical degradation. Examples of the matrix phases are polymer matrix, ceramic matrix, metal matrix, *etc*.

Reinforced Phase

A material that gives strength to the composite is known as a reinforced material. Reinforced materials are usually strong with low density. It can also provide thermal and electrical conductivity apart from structural properties. Examples of reinforced phases are fiber, particles, graphite, *etc*.

Interface

Interface is a layer that separates matrix and reinforcement, and binds or holds the two phases together through bonding or adhesion.

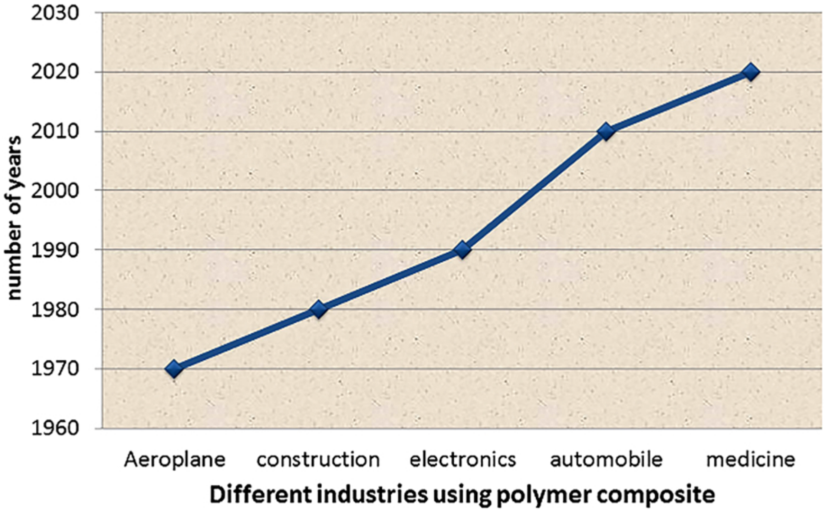


Fig. (1). Graphical representation of usage of polymer composite over the years.

Mixing or a combination of matrix and reinforced material is used in various *in-situ* and *ex-situ* methods. Mixing of these two phases creates a bond between them such as a mechanical bond or a chemical bond in which the matrix and the reinforced material are bound naturally or by using coupling agents to enhance their interactions with each other. Some of the commonly known coupling agents are silanes and titanates. In mechanical bonding, the roughness of the surface of fiber causes interlocking between the fiber and the matrix which causes mechanical bonding between them. Another method of bonding is reaction bonding; it happens when molecules of the fiber and matrix diffuse into each other at the interface. Thus, an interfacial layer is formed which is known as an interphase, and this helps in bonding between the two phases. Many new fabrications or modifications have been made in the concept of polymer composite in which it is modified or functionalized with certain components, which enhance the properties of the composite and reduce the cost of the product. Likewise, nowadays instead of conventional fibers, natural fibers are used as reinforcing materials which reduce the cost, improve the high specific properties, and have low density compared to conventional fiber materials [4]. Also, the usage of natural fibers leads to the manufacturing of biodegradable and non-abrasive attributes, unlike other reinforced fibers. Some of the common physicochemical properties of the composite materials are discussed in Table **1** referred to as [3].

CHAPTER 4

Polymer Composites for Energy Storage Application

Rupesh Rohan[1,*]

[1] *Indian Rubber Manufacturers Research Association (IRMRA), Sri City Trade Centre, Sri City, District: Chittoor, Andhara Pradesh, India*

Abstract: The chapter discusses the role and application of polymers (polymers and composites) in energy storage devices. Lithium-ion batteries and supercapacitors are the two main energy storage intermittents. The chapter underscores the utilization of polymers in various roles in these devices and their effect on performance, in addition to related future aspects and expectations.

Keywords: Energy, Electrolyte, Lithium ion battery, Polymer, Supercapacitor.

INTRODUCTION

In the past two- or three decades, energy demand increased tremendously because of the rising population and their unlimited demands. Energy is needed in every form to provide the basic needs of population. The demand of energy keeps on increasing exponentially, so there is an urgent need to search for a sustainable energy resource because traditional means will not going to fulfil the rising demands [1]. Combustion of natural gas, oil and coal contributes to fulfil around 80% of the energy demand and with the rigorous use, even fossil fuels are also in depletion. Though fossil fuels are renewable but they take a high amount of time so alternate sources of energy such as solar energy through UV rays, tidal energy through water *etc*, wind energy and biofuels are in high demand [2]. But the major drawback with these sources is that they are not reliable because of their intermittent nature. To overcome this drawback, an energy storage device comes as the most reliable method, where the energy stored is used supplied when required. These devices ensure adequate supply of energy timely, and hence are very much reliable. The amount of energy supply depends on the size of energy storage device; large energy storage devices provide energy for many hours even in remote areas whereas small energystorage devices are portable but can supply

---

[*] **Corresponding author Rupesh Rohan:** Indian Rubber Manufacturers Research Association (IRMRA), Sri City Trade Centre, Sri City, District: Chittoor, Andhara Pradesh, India; E-mail: rupeshrohan21@gmail.com

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

energy only for limited time period. Large energy storage devices can supply high amount of energy in a short period of time to several places such as where defence installation is done [3].

Natural and synthetic polymers possess a wide range of properties due to which they become the backbone of our daily life. Polymer-based batteries that are used to store energy have gained popularity since decades. These are advantageous as compared to metal originated batteries because of inherent properties of polymer such as light weight and flexibility, high breakdown strength, easy casting of electrodes made up of polymeric materials, vapor deposition, *etc.* These properties make polymers suitable for application in flexible and thinner devices. The electrochemical reaction involved in polymer-based batteries is simple; polymeric electrodes have a lower redox potential but energy density is high. Economically, a polymer can be synthesized at low cost and can also be extracted from bio-based materials. Polymers are used in both energy harvesting and energy storage devices [4].

Along with these advantages, many challenges are associated with polymer-based batteries. Polymers are soluble in electrodes which lead to a threat to battery stability. The active member which travels between the electrodes gets dissolved, leading to reduced cyclability and self-discharge of the batteries [5]. Most of the polymers are of insulating nature, so they require conductive additives which reduce the batteries capacity overall [5].

To overcome the challenges exhibited by polymer batteries, and for extension of their use in energy storage devices, many researches were carried out and polymer composites were developed for that purpose.

Energy storage systems are of two types, electrochemical energy storage devices and non-electrochemical energy storage devices [2]. Fuel cells, batteries, supercapacitors are the types of electrochemical cells and they consist of electrolytes, electrodes and the current collector [6-14]. These components are made of conducting polymers, carbon-based nanomaterials, conducting materials and metal oxides. These materials solve the purpose but are not highly reliable, there are still many challenges with the commercialization of energy storage devices. Since the last decade, research is on-going on developing polymer nanocomposites as an ideal material for making these components. Polymers have high flexibility in designing, because of which they can be used to design different components of an energy storage device [15].

Nanocomposite materials are hybrid materials made up of two or more materials with extremely different chemical and physical properties that remain distinct and separate with a dimension less than 100 nm size range. Nanocomposite materials have two components. The matrix or bulk substance is of one type, while the inorganic nanofiller is the other [15]. The material is called a polymer nanocomposite when a polymer functions as the matrix, and an inorganic nanomaterial works as the nanofiller. Due to the synergic interaction between the polymer and the nanomaterial filler owing to their “nanoeffect," polymer nanocomposite materials have remarkable qualities when compared to polymer composites with micron-size fillers [16-27]. With only a small amount of nanomaterial as a filler, tremendous improvement in the properties of polymeric materials can be achieved. The properties and nature of the polymer employed as the matrix for polymeric nanocomposites (PNCs), as well as the nanofiller, have a significant impact on electric conductivity, processing ease, ionic conductivity, tensile strength, and chemical, thermal, and mechanical stability [16, 23, 26-34].

Polymer nanocomposites have unique physicochemical features that cannot be achieved by using separate components. Due to their intriguing potential for a variety of applications ranging from environmental to medical, polymer nanocomposites have sparked a lot of scientific attention. Sensing and actuation, clean-up, energy storage, electromagnetic (EM) absorption, transportation and safety, defence systems, information technology, and innovative catalysts, among other things. Polymer nanocomposites, in particular, have sparked a lot of attention as a potential solution to both of these problems [19, 24, 27, 31, 32, 35-37].

For the electrochemical application, two types of polymers are generally used:

i. Electric conducting polymers
ii. Ion conducting polymers

General tendency of a polymer is insulation, but for electrochemical application, polymers having electrical conductivity are in demand. Polyaniline (PANI), polythiopene (PTh), and polypyrrole (PPy) are the polymers having high value in electrochemical systems because they are composed of organic monomers having conjugating double bonds [38, 39]. Along with electrical conductivity, these polymers are also budget friendly, easily processable, light weight, and exhibit thermal as well as mechanical flexibility. Fillers are used in nano form to further enhance the properties of these polymeric materials, and they are called as the nano fillers. Metals, graphene, carbon nanotubes (CNT), carbon, ferromagnetic materials, layered silicates, titanium nanotubes *etc.* are used as the fillers [40]. Polymer nanocomposites have unique physicochemical features that can't be achieved by using single component. Polymer nanocomposites have piqued researchers’ interest due to their potential for a wide range of applications, including environmental sustainability, sensing, EM absorption, energy storage

CHAPTER 5

Polymer Composite Membrane for Microbial Fuel Cell Application

Kalpana Sharma[1], **Anusha Vempaty**[1], **Barun Kumar**[1], **Shweta Rai**[1], **Vaibhav Raj**[1], **Deepak Jadhav**[2] and **Soumya Pandit**[1,*]

[1] *Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India*

[2] *Department of Agricultural Engineering, Maharashtra Institute of Technology, Aurangabad-431010, India*

Abstract: Energy production is a demanded process in today's world. Some processes might generate pollutants and other undesirable particulates and toxic chemicals. One such eco-friendly and efficient method for generating electricity and energy can be through fuel cells with the utilization of microbes (bacteria). Such a method can be termed Microbial Fuel Cells (MFCs). It is a bio-electrochemical system. It uses bacteria and their biochemical processes for generating an electric current, along with oxygen which is a high-energy oxidant. MFCs imitate the bacterial interactions that are found in the nature. Being a cell, it requires electrodes, substrates, and electrolytic solutions. To improve the efficiency of the MFC, we need to separate the anode and cathode into two compartments and the respective reactions taking place. Membranes play a crucial role in achieving it. A membrane not only divides the anode from the cathode but also prevents the entry of oxygen into the anode chamber. The most important function of a membrane is to allow the selective transfer of ions across the two electrode chambers. Membranes can be diaphragms or separators. Porous membranes are commercially used ones usually made of different effective polymer materials. Other important membranes can be semi-permeable and ion-exchange membranes. This chapter mainly reviews the various membranes and the materials used in their structures that have the potential to increase the MFC performance. It also focuses on the different transport processes across the membranes, along with a brief of advances in this technology and future scope.

Keywords: Ion-exchange, Mass transfer, Materials, Membranes, Microbial fuel cell, Porous separators.

---

[*] **Corresponding author Soumya Pandit:** Department of Life Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida – 201306, India; E-mail: soumya.pandit@sharda.ac.in

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

INTRODUCTION

To meet the tremendous need for energy supply for the huge population, an environment-friendly and sustainable form of production is crucial. It should also be economically stable by simultaneously maintaining the ecological balance during storage and conversion [1]. A much familiar form of energy is fossil fuels – coal and petroleum. However, these compounds are non-renewable, and their combustion leads to pollution in the surroundings, ultimately causing global warming. Hence, a more ecological and sustainable alternative is required for efficient energy production [2].

A fuel cell is the most dependable decision with proficient energy change innovation which is responsible for the conversion of chemical energy into electrical energy through electrochemical responses specifically anodic oxidation and cathodic reduction responses [3]. These cells are spotless energy change gadgets, where the oxidant and reductant are constantly provided to generate power, unlike batteries that contain pre-stuffed chemical constituents. They can give long-haul arrangements as sustainable and effective energy transformation gadgets with the least or zero discharge of greenhouse gases [4]. Huge ecological advantages are normal on fuel cells, especially for the automobile sector and energy production for fixed and mobile applications.

A fuel cell is an electrochemical cell, which consistently changes the chemical energy of a fuel and an oxidant to electrical energy in a cathode-electrolyte framework, intended for constant nourishment of reactants at a high temperature of an electrocatalyst to catalyze the oxidation and reduction responses [5].

Microbial Fuel Cells (MFCs) are the bio-electrochemical systems that use bacteria for the production of electric current. The biochemical reactions are catalyzed by bacteria. When we see the general construction of an MFC, we find electrodes, wirings, a salt bridge, and a membrane. The membranes play a crucial role in the cell [6].

A membrane is usually any medium that is used to separate the electrodes and hence, to obtain two different compartments. The flow of substances through these compartments gets minimized when they encounter the membrane [7]. This is to check and keep a balance between different chemicals, ions, or substances across the cell [8]. Even in living beings, all the cells have cell membranes that separate the interior of all cells from the outside environment. Hence, we understand the importance of membranes [9].

The main characteristics of the membrane material are:

- Pore size
- Porosity
- Capacity of ion-exchange

Membranes can be of two types:

- Permeable – also called diaphragms. They allow the flow of liquid as a whole (less filtering of substances passing through) and hence, it is non-selective in the transportation of ions or molecules.
- Semipermeable –mostly depends on the size of the molecules that pass through as well as the charge possessed. It allows selective transport of certain species or substances (ions or molecules).

Porous separators or membranes are the most commonly used separators. Their structures have pores of the size around 1–50 μm (Fig. **1**) which prevents the mixing of gaseous products and solid particles. Throughout the cell, ionic motion carries a current that results in a voltage drop, ΔV, across the separator. It is expressed in terms of the effective specific resistance, ρ (Ω cm), of the electrolyte in the material:

$$\Delta V = IR = I(\rho L / A) = (I / A)L / \kappa \qquad \textbf{(1)}$$

or

$$\Delta V = j\rho L \qquad \textbf{(2)}$$

Here, R - resistance, j - current density (A cm^{-2}), κ - conductivity (S cm^{-1}), ρL - area-specific resistance

Ionic and material transport across the membrane is through diffusion. In some cases, a small net flow is essential to prevent the back transport of certain species (in opposite direction). Hence, we can say that the membranes separate the anode and the cathode and make two electrolyte compartments. The flow of electrolyte thus is from one compartment to the other through the membrane. The performance of the membrane depends on its ability to control the transport of substances through its structure.

CHAPTER 6

Polymer Composites for Sensor Applications

Arti Rushi[1], **Kunal Datta**[2] and **Bhagwan Ghanshamji Toksha**[1, *]

[1] *Maharashtra Institute of Technology, Aurangabad, India*

[2] *Deen Dayal Upadhayay KAUSHAL Kendra Dr. Babasaheb Ambedkar Marathwada University, Aurangabad (MS), India*

Abstract: Polymers play a major role in sensor research nowadays. Specifically, when the electrical modality of sensing is concentrated then conducting polymers is found to be highly useful. They have been explored for the development of sensors to cope with advanced modern-day requirements. There is a huge demand for sensors in detecting and assessing environmental dynamics, harmful working conditions, food poisoning, and water contaminations, and diagnostic purposes. The recent pandemic, the COVID-19 outburst all over the world, ascertained the urgency of research in the direction of designing and developing biosensors enabling distinction among the diseases and enabling medical professionals to take faster clinical decisions. The conventional approaches in environment pollutant detection techniques have no universally accepted code of conduct. Moreover, there are various experimental drawbacks of poor calibration, tedious sample preparation, blank determination, and lengthy time-consuming procedure. The composites involving conducting polymers and CNTs bring in unique multifunctional features. The motive of the present work is to review various latest developments in conducting polymer composite-based sensors.

Keywords: Composites, Multi-walled CNT, Polymers, Single-walled CNT, Sensors.

INTRODUCTION

Functional polymer composites are a class of material displaying rapid, reversible, repetitive, and measurable changes in response to any detectable change in the area of interest when employed in detection applications [1]. The characteristics of this class of materials enable the sensor-based devices to respond to an external chemical/physical stimulus. The modern era of bio and chemical sensors has enhanced the facilities significantly in the field of medical diagnosis and environmental probing [2-5]. The critical parameters which decide the performance of bio/chemical sensors are sensitivity to the desired stimuli at the

---

[*] **Corresponding author Bhagwan Ghanshamji Toksha:** Maharashtra Institute of Technology, Aurangabad, India; E-mail: bhagwantoksha@gmail.com

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

micro-scale selectively, biocompatibility, and quicker response time [6-8]. The aspects of pollution include soil, air and water pollution which may or may not detected visually and by taste. Air pollution target ammonia, CO, NO_2, H_2S and many other gases, while the soil and water pollution mainly target heavy metal ions such as chromium (Cr), cadmium (Cd), mercury (Hg), lead (Pb) and arsenic (As). Other than damaging the respiratory systems, these pollutants are also neurotoxic producing a series of toxicological reactions. These are also responsible for medical complications such as anaemia, seizures, coma or even fatality. The market based device requirements such as cost effectiveness, robustness, miniaturized size and workability in extreme conditions are also desirable to the functioning and eventual performances [9-12]. In the unavailability of all the required parameters for effective sensing applications, there is a possible solution of using a composite or blend of two or more materials. The choice of sensing materials for the monitoring device and the involved active microelectronics becomes the next critical step of the design of sensor. The class of conducting polymers materials is explored in sensor technologies owing to their versatility, ease in production, higher surface area, low cost, high sensitivity when exposed to a variety of target pollutants and simple signal detection in terms of change of electrical and optical responses [13-17]. The carbon allotropes have proven their high potential in sensing applications due to their outstanding properties, especially in nanoscale. The structure of conjugated conducting polymers is such that single and double bonds occur alternatively in their polymer chain, thus forming the delocalized electrons which act as charge carriers. The low conductivity of polymers under normal conditions can be improved by composite effect with an oxidizing or reducing agent to several folds in magnitude [18]. The composite recipes also lead to better sensing performance. Such an improvement could be related to highly porous microstructure and good antifouling activity achieved in composite phases [19]. The inclusion of carbon allotropes in composites with conducting polymer could lead to formation of conducting paths, high active surface area and unique 3D microstructure contributing towards better sensing performance [20-23]. The developments in the field of 3D printing of sensors having conducting polymers and CNT composite as building block brings newer possibilities of sensing functions and expands the application boundaries. The possibilities involve the fabrication of highly customizable sensors capable of detecting microbial activity [24]. The other possibility with 3D print sensors to respond and record magnetic and electric fields, heat, light, pH and humidity. The research carried out in this direction produced promising results exhibiting 3D printed conducting polymers and CNT composite better conductive and mechanical properties and a better performance as compared to other formulations. The sensor functionalities were also achieved with commercially available desktop 3D printer leading to achieving low-cost functional sensor devices [25]. The blend of carbon nanotubes and graphene nanoplatelet in the thermoplastic polyurethane (TPU) composites were reported to result in high-performance flexible strain sensors synthesized *via* Fused Filament Fabrication (FFF) 3D printing. The blend carbon nanotubes and graphene nanoplatelet were reported to produce synergetic effect demonstrating higher sensitivity, better stability, and higher accuracy [26].

POLYMER COMPOSITE

Polymers are the materials which are formed by repetition of smaller chemical units which results into long chain molecules. Polymers has been found naturally, most interestingly; they are the integral part of living organisms. Polymers are found in living species in the form of proteins, cellulose, and nucleic acids. Naturally occurring rubber, various resins are some another examples of polymers. Along with this, synthetic polymers such as polyethylene, polypropylene, polystyrene are also getting the high attraction from entire human race. It has been observed that, polymers developed at early stage are insulating in nature. The conducting properties of the polymers were discovered by A. G. MacDiarmid, Professor A. J. Heeger and Professor H. Shirakawa. For this discovery they are awarded with the Nobel Prize in chemistry in the year 2000. Some of the well-known conducting polymer structures are provided below (Fig. **1**):

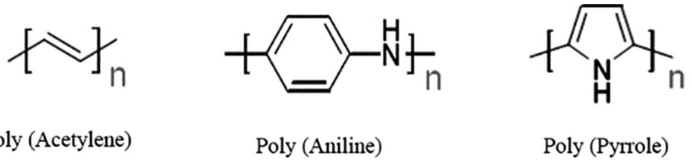


Fig. (1). Conducting polymer structures.

Modulation in the conducting properties of the conducting polymers provides an additional benefit for making their use in various electronics applications. Also, synthesizing the nanostructures of conducting polymers and making use of them are fascinating factors for the researchers. As far as sensor applications of conducting polymers are concerned, the nanostructures of conducting polymers are adopted in high extent [27]. Synthesis of composites is another approach that has been adopted to prepare polymer-based materials in the sensing field [28, 29]. It has been seen that polymers can be combined with the materials such as graphene [30], carbon nanotube [31] *etc.*, or the composites can also be formed by combining two different polymers [32]. Most of the sensors based on polymer composite, are fabricated with conducting polymers and carbon nanotubes.

Frontiers in Polymer Science, 2023, *Vol. 1*, 165-196

CHAPTER 7

Polymer Composites for Automotive Applications

Naveen Veeramani[1], **Prosenjit Ghosh**[1], **Tushar Kanti Das**[2] and **Narayan Chandra Das**[2,*]

[1] *Center for Carbon Fiber and Prepregs, CSIR-National Aerospace Laboratories, Bangalore-560017, India*

[2] *Rubber Technology Centre, Indian Institute of Technology Kharagpur, Kharagpur-721302, India*

Abstract: The last couple of decades have witnessed exceptional advancements in automotives; and the use of polymer composites (PCs) in making different automotive parts has emerged as an integral part of the advancement. Fiber-reinforced PCs offer weight benefits to automotives, thus enhancing fuel economy. Moreover, these composites can be engineered for versatile applications, *e.g.*, interior and exterior body parts. Ease of manufacturing is another advantage of PCs, although several major technical considerations still need to address before engineering these composites for wide-scale acceptance in various automotive applications, especially for exterior body parts. However, PCs are a new class of materials, and developing state-of-the-art manufacturing technology may enhance the comfort and security of modern vehicles. This chapter outlines the utility and recent advances in PCs for various automotive applications. In addition, quality assurance and the advantages of PCs are also given. The potential of PCs for future perspectives is also discussed.

Keywords: Automotive, Fuel economy, Polymer composites.

INTRODUCTION

Recent trends of fuel-saving and minimizing emissions during fabrication and transportation are fuelling interest in manufacturing low-cost, lightweight yet high-performance materials as a substitute for metals. Polymer composites (PCs) are alternative materials with excellent mechanical, processing, and thermal properties that have attracted much attention in replacing metallic components in automotive applications. Current automotive industries are welcoming these replacements [1]. PCs have shared almost 90% global market of composite-based manufacturing sectors. PCs exhibit variable properties depending on the reinforcement *i.e.* organic, inorganic, metallic and polymer matrix. Besides, the property of PCs can be further enhanced by selecting a proper composition, fabri-

---

[*] **Corresponding author Narayan Chandra Das:** Rubber Technology Centre, Indian Institute of Technology Kharagpur, Kharagpur-721302, India; E-mail: ncdas@rtc.iitkgp.ac.in

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

-cation methods, the density of the reinforcing materials, and its orientation in the polymer matrix [2]. So, PCs are gradually replacing the conventional materials used for the fabrication of various automobile parts. Potential research on PCs for automotive applications has been still ongoing to achieve the following benefits;

- Reduction in the weight of composites which enhance fuel economy and its performance.
- Better quality of the composites and reproducibility in fabrication techniques.
- Improve comforts during ride, *i.e.* reduction in noise and vibration.
- Lower investment cost.
- Acceptable style of vehicles depending on the demand of market.

Other areas are also there that require extensive research to improve the properties for various automotive applications [3].

The mechanical properties of PCs are not only the function of reinforcements but also of polymer matrices. This is because polymers are ductile and during breaking of PCs, reinforcements first get damaged on the application of stress, and then elastic deformation of the polymer supplies shear force to resist the applied stress. Such a transfer of load helps the PCs to combat the applied stress [4]. Besides, the orientation of reinforcement in the polymer matrix is a very important parameter and depending upon the final property requirements, the reinforcing materials are oriented in the polymer matrix. If the reinforcing materials are inclined to the applied stress direction, PCs exhibit the highest strength and modulus, while they show the lowest when directed at the transverse direction. Random distribution of reinforcing agents in the polymer matrix facilitates isotropic behavior of PCs, *i.e.* equal performance in all directions to the applied stress [5]. It is to mention here that most of the PCs used in automotive applications comprise randomly oriented reinforcing materials. These composites are fabricated either by compression molding or injection molding techniques. However, although in the longitudinal direction, reinforcing materials provide high mechanical strength, it is very difficult to construct the composites with reinforcing agents either in the longitudinal or transverse direction [6].

In automotive applications, both thermoplastic and thermosetting polymers are used to fabricate the respective PCs. Thermoplastic PCs are used mainly in making various interior and body parts of automobiles. Automotive industries use various thermoplastic polymers *e.g.*, polypropylene (PP), polycarbonate (PC), poly methyl methacrylate (PMMA), high density polyethylene (HDPE), acrylonitrile butadiene styrene (ABS) copolymer, plasticized polyvinyl chloride (p-PVC), polyethylene terephthalate (PET), polyamide-6 (PA-6), polyamide (PA-6,6) polybutylene terephthalate (PBT), *etc.* to make different components. These polymer resins are common in automotive parts making due to their low cost compared to other thermoplastics [1, 7]. On the other hand, general purpose thermoset polymers used in automotive industries are epoxy resin, polyester, vinyl ester, polyimide, polyurethane resin, phenolic resin, and amino resin. These composites are fabricated through sheet molding techniques where reinforcing materials are randomly oriented in the thermoset matrix. Another important method of fabrication of thermosetting composites is structural reaction injection molding, and this method is specifically predominant for polyimide and polyurethane resins [8, 9].

For manufacturing different parts of automotive industries, the primary reinforcing materials impregnated in the polymer matrix are carbon fiber, glass fiber, Kevlar fiber, natural fiber, various metals, and their alloys. Though other reinforcing agents are used for the fabrication of PCs, these are not widely used for automotive industries [10]. The main benefits of carbon fiber as reinforcement are very low density, high stiffness, and high strength to weight ratio. Though its cost is higher compared to other fibers, these can be compromised during the design and fabrication of PCs [11]. Glass fiber is another suitable reinforcing material used with the polymer matrix. There are various types of glass fibers available in the commercial market, such as E-glass, C-glass, R-glass, S-glass, and T-glass. Among these E and C glass fiber-based polymer composites are mostly used in automotive industries. E-glass fibers provide high electrical resistance, whereas C-glass fiber has good resistance to chemical attacks [12]. Depending upon the applications, different glass fibers are impregnated in polymers to fabricate composites. Though the cost of glass fiber is less than carbon fiber, it has a high density and low stiffness. For this reason, the glass fiber reinforced PCs are heavier and thicker than carbon fiber-based composites [13]. Besides, other reinforcing agents are also impregnated into the polymer matrix to manufacture different parts of automotive bodies, but these have less importance than either carbon or glass fibers. Because of these, research and development sections are gradually moving from metal or metal alloy-based PCs to other reinforcing material-based composites [14]. Fig (**1**) shows the usage of polymer composites in automotives to make various spare parts [15].

SUBJECT INDEX

Subhendu Bhandari, Prashant Gupta and Ayan Dey (Eds.)

Subhendu Bhandari

Dr. Subhendu Bhandari is an assistant professor in the Department of Plastic and Polymer Engineering at Maharashtra Institute of Technology, Aurangabad, Maharashtra since 2015. He earned Ph.D. in the field of nanostructured conducting polymer and its composites for supercapacitor application in the year 2015. His research interest includes conducting polymer, polymer nanocomposites, supercapacitor and fiber reinforced composites. He has a number of publications in the peer reviewed journals and books along with an Indian patent. He has also edited a book and authored a monograph. He is on the editorial board of two international journals. He is also a life member of The Indian Society for Technical Education, Asian Polymer Association and The Society for Polymer Science, India.

Prashant Gupta

Dr. Prashant Gupta has 10 years of academic research, teaching, and industrial R & D experience in application development, and technical services in polymer composites. He has a number of publications in peer-reviewed journals and books with international publishers. He is a professional trainer for courses oriented to the polymer industry and has offered his expertise in the form of technical presentations at different international and national conferences and events across the globe. He is a recognized content creator, coach, and reviewer in content development and assessment by Virtual Labs, Mumbai.

Ayan Dey

Dr. Ayan Dey did Ph.D. from Calcutta University, Kolkata in the year of 2018. He started his career as assistant professor at Maharashtra Institute of Technology, Aurangabad. He has contributed significantly as a research associate at Indian Institute of Packaging, Mumbai in the field of packaging. He has more than 4 years of post-Ph.D. experience in both the academic and industrial research in the field of polymer synthesis, smart materials, blends and composites, rheology for automotive, packaging and semiconductor industrial applications. He received different awards and has a number of publications to his credit.