



# Fillers and Reinforcements for Advanced Nanocomposites

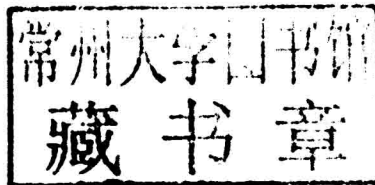
Edited by Yu Dong, Rehan Umer  
and Alan Kin-Tak Lau

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*Edited by*

***Yu Dong, Rehan Umer  
and Alan Kin-Tak Lau***



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# List of contributors

- H.P.S. Abdul Khalil** School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia
- M.H. Abdul Kudus** Universiti Sains Malaysia, Pulau Pinang, Malaysia
- M.A.S. AlMaadeed** Qatar University, Doha, Qatar
- V. Anandakrishnan** National Institute of Technology, Tiruchirappalli, Tamil Nadu, India
- S. Banerjee** University of Southern Queensland, Toowoomba, Australia
- A.K. Basak** Adelaide Microscopy, University of Adelaide, Adelaide, SA, Australia
- D. Bhattacharyya** The University of Auckland, Auckland, New Zealand
- L. Cao** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- C.L. Chiang** Hung-Kuang University, Taichung, Taiwan
- H. Chu** Center for Composite Materials and Structures, Science Park of Harbin Institute of Technology, Harbin, People's Republic of China
- R. Das** The University of Auckland, Auckland, New Zealand
- I. Davies** Curtin University, Perth, WA, Australia
- Y. Dong** Curtin University, Perth, WA, Australia
- J. Du** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- S. Feng** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- S.-Y. Fu** Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, China
- P. Guo** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- H.J. Haroosh** Curtin University, Perth, WA, Australia
- A. Hassan** Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
- M. Haq** Composite Vehicle Research Center, Michigan State University, East Lansing, MI, USA

- M.P. Ho** The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China
- Z. Hu** Yanshan University, Qinhuangdao, People's Republic of China
- M.N. Islam** Curtin University, Bentley, WA, Australia
- Z. Jia** Chengde Petroleum College, Chengde, People's Republic of China
- A. Khomenko** Composite Vehicle Research Center, Michigan State University, East Lansing, MI, USA
- N.H. Kim** Chonbuk National University, Jeonju, Jeonbuk
- E.G. Koricho** Composite Vehicle Research Center, Michigan State University, East Lansing, MI, USA
- T. Kuila** CSIR-Central Mechanical Engineering Research Institute, Durgapur, West Bengal, India
- A.K.-T. Lau** The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China
- J.H. Lee** Chonbuk National University, Jeonju, Jeonbuk
- J. Leng** Center for Composite Materials and Structures, Science Park of Harbin Institute of Technology, Harbin, People's Republic of China
- Y.-Q. Li** Khalifa University of Science, Technology and Research, Abu Dhabi, UAE
- K. Liao** Khalifa University of Science, Technology and Research, Abu Dhabi, UAE
- D.Y. Liu** Institute of Metal Research, Chinese Academy of Sciences, Shenyang, China
- Y. Liu** Department of Aerospace Science and Mechanics, Harbin Institute of Technology, Harbin, People's Republic of China
- J. Ma** Yanshan University, Qinhuangdao, People's Republic of China
- H. Md Akil** Universiti Sains Malaysia, Pulau Pinang, Malaysia
- S.S. Md Saleh** Universiti Sains Malaysia, Pulau Pinang, Malaysia; Universiti Malaysia Perlis, Perlis, Malaysia
- M.K. Mohamad Haafiz** School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia; Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
- M. Mrlik** Qatar University, Doha, Qatar
- A.N. Nakagaito** The University of Tokushima, Tokushima, Japan
- N.H. Noor Mohamed** Graduate School of Advanced Technology and Science, The University of Tokushima, Tokushima, Japan
- A. Pramanik** Curtin University, Bentley, WA, Australia

- X. Qi** Yanshan University, Qinhuangdao, People's Republic of China
- S. Rao** Khalifa University of Science, Technology and Research, Abu Dhabi, UAE;  
The University of Auckland, Auckland, New Zealand
- H. Salam** Curtin University, Perth, WA, Australia
- F.U.A. Shaikh** Curtin University, Perth, WA, Australia
- Md. Sohrab Hossain** School of Industrial Technology, Universiti Sains Malaysia,  
Penang, Malaysia
- G.X. Sui** Institute of Metal Research, Chinese Academy of Sciences, Shenyang,  
China
- S.W.M. Supit** Curtin University, Perth, WA, Australia
- H. Takagi** The University of Tokushima, Tokushima, Japan
- Y. Tang** Flinders University, Adelaide, SA, Australia
- R. Umer** Khalifa University of Science, Technology and Research, Abu Dhabi,  
UAE
- J. Upadhyay** The University of Auckland, Auckland, New Zealand
- J. Wang** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- R. Wu** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- S. Xu** Xinjiang University, Urumqi, Xinjiang, People's Republic of China
- J.M. Yang** Hung-Kuang University, Taichung, Taiwan
- Y. Yang** Yanshan University, Qinhuangdao, People's Republic of China
- L. Ye** University of Sydney, Sydney, NSW, Australia
- C. Zhang** Xinjiang University, Urumqi, Xinjiang, People's Republic of China;  
The University of Auckland, Auckland, New Zealand
- Q. Zhang** Yanshan University, Qinhuangdao, People's Republic of China
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# Preface

The successful development of advanced nanocomposites depends primarily on the sophisticated use of well-dispersed fillers and reinforcements such as nanocelluloses, nanotubes, nanoplatelets, nanofibers, etc., which can lead to enormous applications in structural design, energy harvesting, drug delivery, electronics, wear/thermal shields, and marine environmental protection. Such nanofillers can enhance the mechanical, electrical, thermal, barrier, optical, tribological, and flame-retardant properties of corresponding nanocomposites when they are homogeneously dispersed into continuous matrices to provide high aspect ratios and large surface area-to-volume ratios.

*Fillers and Reinforcements for Advanced Nanocomposites* is not limited to the dominant field in polymer nanocomposites. It also covers the wider range of advanced composite topics such as nanoparticle-reinforced metal matrix composites, concrete-based nanocomposites, and bionanocomposites with the use of natural renewable and biodegradable reinforcements. From the perspective of fillers and reinforcements, relatively new nanofillers such as halloysite nanotubes (HNTs), bamboo nanosilica, and carbon nanopapers (CNPs) are introduced in addition to popular carbon nanotubes (CNTs), nanoclays, graphene oxides (GOs), and nanosilica. Despite the general route of nanocomposite fabrication using in situ polymerization, solution casting, and melt compounding, this book also highlights the development of electrospinning technique to generate ultra-thin nanocomposite fibers as potential fillers and reinforcements.

This book comprises 21 review and research chapters that are categorized into five focused parts, including Part One, “Nanocelluloses” (Chapters 1–3); Part Two, “Nanotubes” (Chapters 4 and 5); Part Three, “Nanoplatelets” (Chapters 6–10); Part Four, “Nanoparticles” (Chapters 11–14); and Part Five, “Filler Applications” (Chapters 15–21).

In Part One, Chapter 1 introduces the fundamentals of nanocellulose and conducting polyaniline and further investigates the synthesis and properties of electrically conductive nanocellulose-based composite films. The effects of concentration of aqueous nanocellulose suspension on the structure and properties of composites are also discussed. Chapter 2 studies polylactic acid (PLA) reinforced with microcrystalline cellulose (MCC) and cellulose nanowhiskers (CNWs) extracted from the oil palm empty fruit bunch. The addition of MCC and CNWs into PLA is found to increase the thermal stability and Young’s modulus of composites. The incorporation of CNWs at the low filler loading can significantly increase the tensile strength of composites, which is contrary to MCC at the similar loading with the decrease of tensile strength. Chapter 3 reviews cellulose nanofiber-based composites with the focus of

natural reinforcements such as cellulose and chitin. Nanofiber properties and relevant extraction processes, composite fabrication, and nanofiber dispersibility in polymer matrices are explicitly covered.

In Part Two, Chapter 4 describes a general fabrication-characterization route of electrospinning PLA:poly( $\epsilon$ -caprolactone) (PCL)/HNT composite fibers. The effects of HNTs with or without the modifier 3-aminopropyltriethoxysilane on fiber diameter, morphological structure, thermal properties, crystalline structures, and degree of crystallinity, as well as the intermolecular interaction of electrospun nanocomposite fibers, are thoroughly studied to provide the appropriate guidance to the controlled drug release associated with fibrous structures. Chapter 5 deals with the synthesis and characterization of CNT hybrid fillers via chemical vapor deposition (CVD) technique for polymer nanocomposites. Optimized synthesis parameters are presented and comparative studies are also conducted between chemical hybrid-filled and physical hybrid-filled polymer nanocomposites in terms of their typical applications.

In Part Three, Chapter 6 provides a critical review on the development of bio-based polymer/clay nanocomposites, including general fabrication techniques and optimization of mixture homogeneity in solutions. In particular, the impacts of interactions between biopolymer matrices and clays on the structural, mechanical, and thermal properties as well as the biodegradability of currently available bio-based polymer nanocomposites are evaluated, along with the summary of future trends for such bio-nanocomposites. Chapter 7 elaborates on the recent research progress in graphene-based polymer nanocomposites, which consists of the graphene synthesis method, its surface modification, and fabrication techniques as well as applications of graphene-reinforced nanocomposites. Chapter 8 works on the production of multifunctional nanocomposite films using reduced GO and poly(methyl methacrylate) (PMMA) via electrospinning and compression molding. With exceptional electrical conductivity and gas barrier properties, such nanocomposite films are proven to be highly suitable for applications in food and beverage packaging and chemical processing plants. Chapter 9 studies the effect of exfoliated GO on the processing characteristics of glass composites by the resin-infusion process. The rheological behavior and cure kinetics of GO as well as the flexural properties of composites are determined to assess the influence of GO content on important resin-infusion processing parameters. Chapter 10 concentrates on the synthesis of epoxy/graphene nanosheet oxide (GNO) composites in which a flame retardant with silicon and phosphorus is grafted onto GNOs. Such nanocomposites are detected to exhibit much greater flame retardancy than neat epoxy, which is ascribed to the synergistic effect among silicon, phosphorous, and GNOs.

In Part Four, Chapter 11 offers the effectiveness of calcium carbonate nanoparticles on the improvements of compressive strength and durability of high-volume fly ash concrete. These resulting properties are further correlated with relevant microstructure and crystalline phases by means of X-ray diffraction, mercury intrusion porosimetry, differential thermal analysis, and thermal gravimetric analysis. Chapter 12 reviews current research and relevant techniques for the manufacture and application of amorphous carbon and its nanocomposites. Various applications for the textile, plastic, and healthcare industries, as well as in the fields of gas and water filtering, electrical applications, and food packaging, are also discussed based on the superior and unique properties of

these materials. Chapter 13 introduces the preparation and properties of silica/polyimide nanocomposite films by sol-gel and in situ polymerization processes. The effect of coupling agent, preparation process, and nanofiller content on the structural, mechanical, and thermal properties of composite films is investigated, which confirms that the incorporation of silica nanofillers can enhance the overall material performance of polyimide. Chapter 14 reviews the recent trends on nanoparticle-reinforced metal matrix composites and related critical issues. The main challenge is stated to retain the nanosize of reinforced particles in metal matrices after material processing in order to improve fracture toughness, creep resistance, thermal shock resistance, wear resistance, and dimensional stability at high temperatures for nanocomposites.

In Part Five, Chapter 15 offers the fabrication strategies of CNPs as a promising candidate material for device areas and engineering, which consists of CVD and solution-based deposition. Widespread applications are also briefly illustrated, such as transistor, transparent electrode, flexible display, flame retardancy, de-icing, and lightning strike protection, on the basis of the electrical, optical, and mechanical properties of CNPs. Chapter 16 addresses various principles of energy-harvesting techniques, selected fillers and polymer matrices, and processing possibilities as crucial parameters for energy storage. Moreover, mechanical and thermal properties of advanced nanocomposites in relation to energy-harvesting performance are evaluated. Chapter 17 summarizes the fracture toughness of epoxy resin modified with silica nanoparticles in terms of particle size and concentration effects to establish the structure-property relationship in a nanosilica-reinforced epoxy composite system. Chapter 18 investigates the effect of micro- and nanofillers as reinforcements and curing cycle on curing-induced shrinkage of epoxy resins. Such study lays a solid foundation for measuring shrinkage-induced effects on strengths of resins and resulting micro- and nanocomposites. Chapter 19 assesses the impact behavior of glass fiber-reinforced polymer composites with various concentrations of nanoclays and hollow glass microspheres. It is found that energy adsorption mechanics and damage extent vary depending on loading conditions and filler concentration, which facilitates the understanding of these novel nano-/micromodified composites to allow for designing lightweight structural components in a wide range of applications. Chapter 20 describes the latest research achievements of the contributors' group on the tribological performance of polytetrafluoroethylene nanocomposites reinforced with nanoserpentine powders and lamellar nanostructure-expanded graphite. The addition of these nanofillers appears to effectively decrease the friction coefficient of the friction pair and the radial wear rate, which further expands the service life of spherical plain bearings in unlubricating tribosystems. Chapter 21 comprehensively reviews three new classes of nanocomposite hydrogels (i.e., polymer/zero-dimensional inorganic gels, polymer/one-dimensional inorganic gels, and polymer/two-dimensional inorganic gels) with detailed preparation methods and developments. Perspectives for future directions, challenges, and possible avenues for the further enhancement of nanocomposite gel properties are finally mentioned.

This book gathers a wide spectrum of fillers and reinforcements to be used for the fabrication and synthesis of advanced nanocomposites, which cannot be achieved without the dedication and excellent work from chapter contributors. Furthermore, it



presents multidisciplinary work in relation to material engineering, polymer chemistry and physics, material processing, organic synthesis, and industrial design and applications. It also demonstrates systematic approaches and investigations from processing material characterization to properties of advanced nanocomposites to establish their important nexus as the essential guideline for end-user applications. This book is expected to become a very useful reference and technical book for composite material research and development sectors, university academics, postgraduate students at the master's and PhD levels, and industrialists for material commercialization.

We would like to show our sincere gratitude to all chapter contributors for their persistence and professionalism to timely complete this important edited book after rigorous scholarly peer review and numerous modifications for each of contributed chapters. We are also deeply indebted to Steven Mathews and Gwen Jones from Woodhead Publishing, Ltd. (an imprint of Elsevier, Ltd.) for their countless publishing management, communication, and coordination efforts at every stage of this work.

We appreciate any comments and feedback from peers and industries to improve the overall quality of this book. We anticipate that the book contents can shed light on the prospect of effective utilization of fillers and reinforcements for advanced nanocomposites.

*Yu Dong, Rehan Umer, and Alan Kin-Tak Lau  
Perth, Abu Dhabi, and Hong Kong*