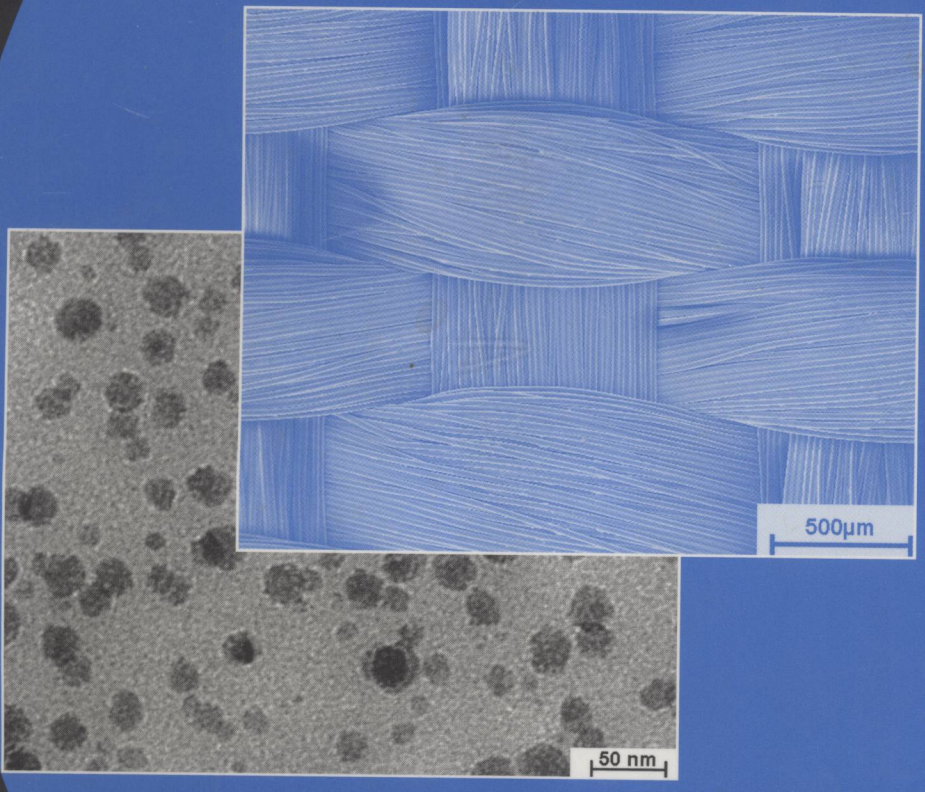
POLYMER COMPOSITES

From Nano- to Macro-Scale



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Preface

The use of polymer composites in various engineering applications has become state of the art. This multi-author volume provides a useful summary of updated knowledge on polymer composites in general, practically integrating experimental studies, theoretical analyses and computational modeling at different scales, *i.e.*, from nano- to macroscale. Detailed consideration is given to four major areas: structure and properties of polymer nanocomposites, characterization and modeling, processing and application of macrocomposites, and mechanical performance of macrocomposites.

The idea to organize this volume arose from a very impressive workshop – The First International Workshop on Polymers and Composites at IVW Kaiserslautern: Invited Humboldt-Fellows and Distinguished Scientists, which was held on May 22-24, 2003 at the University of Kaiserslautern, Germany. The contributing authors were invited to incorporate updated knowledge and developments into their individual chapters within a year after the workshop, which finally led to these excellent contributions. The success of this workshop was mainly sponsored by the German Alexander von Humboldt Foundation through a Sofja Kovalevskaja Award Program, financed by the Federal Ministry for Education and Research within the "Investment in the Future Program" of the German Government. In 2001, the Humboldt Foundation launched this new award program in order to offer outstanding young researchers throughout the world an opportunity to establish their own work-groups and to develop innovative research concepts virtually in Germany. One of the editors, Z. Zhang, was among the 29 award winners in total, who was supported to establish an independent research team between 2001 and 2005 at the Institute for Composite Materials (IVW), University of Kaiserslautern, hosted by K. Friedrich.

The importance of promoting better knowledge in the field of polymer composites is demonstrated by the contents of this volume, which contains 18 independent chapters. The first part of this volume deals with the topic of structure and properties of polymer nanocomposites. In Chapter 1, Schulte *et al.* review the state of the art of carbon nanotube-reinforced polymers. The opportunity to apply carbon nanotubes as a filler for polymers and the improvement of the mechanical and functional properties are discussed. The application of non-layered nano-particles in polymer modification is described by M. Q. Zhang *et al.* in Chapter 2. A grafting polymerization technique is applied to inorganic nanoparticles, which helps to provide the composites with balanced performance. Chapter 3, authored

by Haupert and Wetzel, focuses on the reinforcement of thermosetting polymers by the incorporation of micro- and nanoparticles. Homogeneously distributed inorganic nanoparticles possess the potential to improve the mechanical performance of epoxy at very low filler contents. Privalko *et al.* present some interesting results concerning the synthesis and structure-property relationships of polyimide reinforced with a sol-gel derived organosilicon nanophase in Chapter 4, which suggest a good potential of low dielectric permittivity materials of this nanocomposite. Chapter 5 by Varghese and Karger-Kocsis focuses on the layered silicate/rubber nanocomposites *via* latex and solution intercalations. The structure-property relationships are discussed based on the dispersion state of the clay and the aspect ratio of the silicate layers. In Chapter 6, Sreekala and Eger report the property improvements of an epoxy resin by nano-silica particle reinforcement. The incorporation of SiO_2 nanoparticles into a reactive epoxy resin *via* a sol-gel process generated a new class of nanocomposites with perfect nanoparticle dispersion.

Part II focuses on some special characterization methods and modeling in the field of polymer composites. Chapter 7 by Goda *et al.* deals with micro-scratch testing and finite element contact and debonding analysis of polymer composites. A finite element macro/micro contact model has been introduced with the displacement coupling technique in order to study wear and failure mechanisms in real fiber-reinforced composites. Chapter 8, authored by Lauke *et al.*, concentrates mainly on the determination of the interface strength of polymer-polymer joints by a curved interface tensile test. A new experimental method for the determination of the adhesion strength between two different materials is proposed and the stress concentration at the interface as a function of applied load is derived by the finite element method. In Chapter 9, Evstatiev *et al.* present the manufacturing and characterization of microfibrillar reinforced composites from different thermoplastic polymer blends. Various examples of the manufacturing and processing of this new type of polymer-polymer composites are given and their structure-property relationships are investigated. Z. Zhang and Friedrich review the state of the art of the tribological properties of micro- and nanoparticle reinforced polymer composites in Chapter 10. Nanoparticles have a significant influence on the wear performance of polymers and composites.

"Macrocomposites: Processing and Application" is the topic of the third part of this volume. In Chapter 11, Nunes *et al.* consider the production of thermoplastic towpregs and towpreg-based composites. A purposely built powder-coating equipment was used to make thermoplastic matrix towpregs and pre-consolidated tapes (prepregs) from continuous fibers and a polymer powder. The mechanical properties of the composites were determined in order to assess the efficiency of this new process. Chapter 12 by Mitschang and Ogale deals with the manufacturing of tailored reinforcements for liquid composite molding (LCM) processes. Stitching and sewing processes exhibit high potential to generate various

advanced fiber-reinforced polymer composites based on LCM. Ye *et al.* describe the deconsolidation and reconsolidation of thermoplastic composites during processing in Chapter 13. A mechanistic model for void growth during thermal deconsolidation, and a transient heat analysis are introduced. An indicative void-closure model and a squeezed creep flow model are further discussed regarding to these important issues during thermoplastic composite processing. In Chapter 14, long fiber-reinforced thermoplastic composites and their automotive applications are discussed by Harmia *et al.* Advantages in processing and excellent performance suggest the use of these composites in the automobile industry.

In the last part of this volume, the mechanical performance of macro-composites is considered. Chapter 15 deals with deformation mechanisms of knitted fabric composites. Duhovic and Bhattacharyya provide a general understanding of the sheet forming behavior of knitted fabric thermoplastic composites gained from tensile, dome-forming, cup-drawing and V-bending experiments. Numerical simulations are carried out as well. Chapter 16, entitled "Impact Damage in Composite Laminates", is authored by Suemasu. A theoretical study, Rayleigh-Ritz approximation and finite element analysis are performed to obtain solutions on various levels of simplification for the damage problem and to clarify the mechanism of the initiation and growth of the low-velocity impact damage. Discontinuous basalt fiber-reinforced hybrid composites are discussed by Czigány in Chapter 17. Basalt fibers produced by melt blowing with proper surface treatments are recommended as a suitable reinforcement for both thermoplastic and thermoset polymers. An accelerated testing methodology for durability of polymer composites is the topic of Chapter 18, authored by Nakada *et al.* A prediction method of the fatigue strength of polymer composites and structures is introduced, which is applied to various fiber-reinforced plastics (FRP) and FRP/metal joints.

Various groups of readers may find particular interests in this volume: those who are active or intend to become active in the research on some aspects of polymer composites (material scientists, physical chemists, and mechanical engineers); those who have encountered practical problems in using polymer composites and wish to learn more updated approaches to their solution (designers, engineers and technologists in industries dealing with polymer composites' selection, processing and application); and teachers and students at universities.

Finally, the editors would like to thank all the contributing authors for their excellent chapters. Special gratitude is due to Dr. Greg Franklin, Springer, who contributed strongly to the publication of this volume. We would like also to thank the team in Sofia, Bulgaria, who helped the editorial work.

Klaus Friedrich
Stoyko Fakirov
Zhong Zhang

Editors Biographies

Klaus Friedrich – born in 1945, graduated in Fabrication Technology and in Mechanical Engineering before receiving his Dr.-Ing. (PhD) degree in Materials Science in 1978 from the Ruhr-University Bochum (RUB) in Germany. In addition to his industrial experience as a design engineer and his function as "Chief-Engineer" at the Institute for Materials, RUB, he was associated in 1980 as a Visiting Assistant Professor with the Center for Composite Materials, University of Delaware, USA. After that, he worked for eight years as a Professor of Polymers and Composites at the Technical University Hamburg-Harburg. Since August 1990, K. Friedrich became Research Director for Materials Science at the Institut für Verbundwerkstoffe GmbH (Institute for Composite Materials), University of Kaiserslautern. His major research interests include the fatigue and fracture properties as well as the friction and wear behavior of fiber-reinforced polymeric materials. Recent works are concentrating on fundamental aspects in the manufacturing of high performance composites with thermoplastic matrices. Prof. Friedrich was included in the Advisory Committees of many international conferences, and is a Scientific Board Member of various international journals in the fields of materials science, composites and tribology. In addition, he acted as consultant to various industrial companies within Europe and the USA. Together with his co-workers and students, he has published more than 600 papers in refereed journals and conference proceedings. Further, he is the Editor of three books on *Friction and Wear of Polymer Composites*, *Application of Fracture Mechanics to Composite Materials*, and *Advances in Composites Tribology*, respectively. In 1995, he was appointed as an Honorary Visiting Professor of the Zhongshan University, Guangzhou, China, for his achievements in the field of polymer tribology. At the end of 1996, his research group was awarded the innovation prize of the State of Rhineland-Palatine for applied research in the field of manufacturing of thermoplastic composite components. Besides, Prof. Friedrich has a long established track record in successful grant application from the German Science Foundation (DFG) and other research supporting establishments in Germany and Europe. In March 2001, he received an Honorary Dr. degree (Dr.h.c.) from the Budapest University of Technology and Economics, Hungary, and in June 2004, he was awarded the title of an Honorary Guest Professor of the University of Science and Technology of China, Hefei, which is among the best universities in China.

Stoyko Fakirov – got his MS degree in Chemistry from the Sofia University, Bulgaria, in 1959 and his PhD degree on Structure of Amorphous Polymers (1965) under the guidance of Prof. V. A. Kargin from the Lomonossov State University in Moscow. He received his DSc degree in 1982. In 1972, he became Associate Professor and in 1987, Full Professor of Polymer Chemistry. He is a co-organizer of the polymer education at the Sofia University (with obligatory courses on polymers for all chemistry students), as well as a founder and Head of the Laboratory on Structure and Properties of Polymers at the same university. He acted also as a Vice-Rector of this university for 3 years. Worth mentioning awards are Humboldt Fellow (1971, 88) and Humboldt Research Award Recipient (2000), Fellow of the Ministries of Education of Egypt, India, Spain, Turkey and Portugal, of the Japan Society for Promotion of Science, of the US Information Agency, of NATO-Spain, Member of the Advisory Board of the Institute for Polymer Research Dresden, Member of the Editorial Boards of three international journals on polymers. He has published about 300 papers in international polymer journals, has 11 US patents and contributed to about 150 international polymer meetings as well as delivered more than 100 invited seminar talks worldwide on his areas of interest: structure-properties relationships in polymers and composites, reactions in solid and molten condensation polymers, chemical healing, microfibrillar- and microplate-reinforced composites, microhardness of polymers, gelatin- and starch-based biomaterials. In addition, he acted as author, co-author, editor, co-editor and always as a contributor to 11 books on polymers, as for example, *Transreactions in Condensation Polymers* (1999), *Handbook of Thermoplastic Polyesters* (2002), *Handbook of Condensation Thermoplastic Elastomers* (2004) (all three of Wiley-VCH, Weinheim), *Microhardness of Polymers* (2000), Cambridge University Press, London, *Structure Development during Polymer Processing* (2000) Kluwer, Dordrecht. He was a Visiting Professor at the Universities of Mainz (Germany), Delaware, Newark (USA), Bosphorus, Istanbul (Turkey), Minho (Portugal), Kaiserslautern (Germany), CSIC, Madrid (Spain), NJIT, Newark, NJ (USA), and currently – Auckland (New Zealand). Here, he is focusing on new application opportunities of the concept of microfibrillar-reinforced composites (as developed in joint projects with the University of Delaware and the Institute for Composite Materials of the University of Kaiserslautern). These applications include commodity materials (with improved barrier properties), biomedical materials (scaffolds for tissue engineering and carriers for controlled drug delivery), materials for microelectronics (conductive elements), manufacturing of nanofibrillar reinforced composites, as well as the development of composites based on geopolymers.

Zhong Zhang – born in 1968, is a Guest Professor and a group leader at the Institute for Composite Materials (IVW) of the University of Kaiserslautern, Germany. He obtained his BS, MS, and PhD degrees from the University of Science of Technology of China, Hefei, China in 1990, 1996, and 1999, respectively. His

main research area involves the processing-structure-property relationships of polymers and composites. His research activities were mainly sponsored by the National Natural Science Foundation of China when he worked at the Cryogenic Laboratory (Beijing), Chinese Academy of Sciences between 1990 and 1996. In 1997 and 1998, he joined some world leading institutions, *e.g.*, Karlsruhe Research Centre, Germany, and Rutherford Appleton Laboratory, England, concentrating on low-temperature properties of polymers and composites. Parts of these results on failure processes in resins were of importance to support the design of large (11 m diameter) superconducting magnets for the Atlas experiment at CERN. He started to work at the IVW as an Alexander von Humboldt research fellow in September 2000. In 2001, he obtained a distinguished award from the same foundation, the Sofja Kovalevskaja Award financed by the Federal Ministry for Education and Research within its "Investment in the Future Program", and especially created for young and highly talented scientists. Zhong Zhang was selected in a worldwide competition as the only one from China, and one of only two in the field of Engineering Science, among 29 Sofja Kovalevskaja Award winners in total. The foundation has granted him one million Euros to establish an independent research team at the IVW from 2001 to 2005. The objective of his research is to investigate the long-term behavior (*e.g.*, tribological, creep and fatigue properties) of short fiber/nanoparticle-reinforced polymer composites, finally leading to an accelerative use of these materials in various industrial applications. Artificial neural networks are also used in his project to predict the performance of these materials as a function of their compositions and testing conditions. Dr. Zhang gave more than 20 invited lectures at world leading institutions, and some keynote and plenary lectures at international meetings. So far, he published more than 80 scientific papers in refereed journals and international conference proceedings.

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