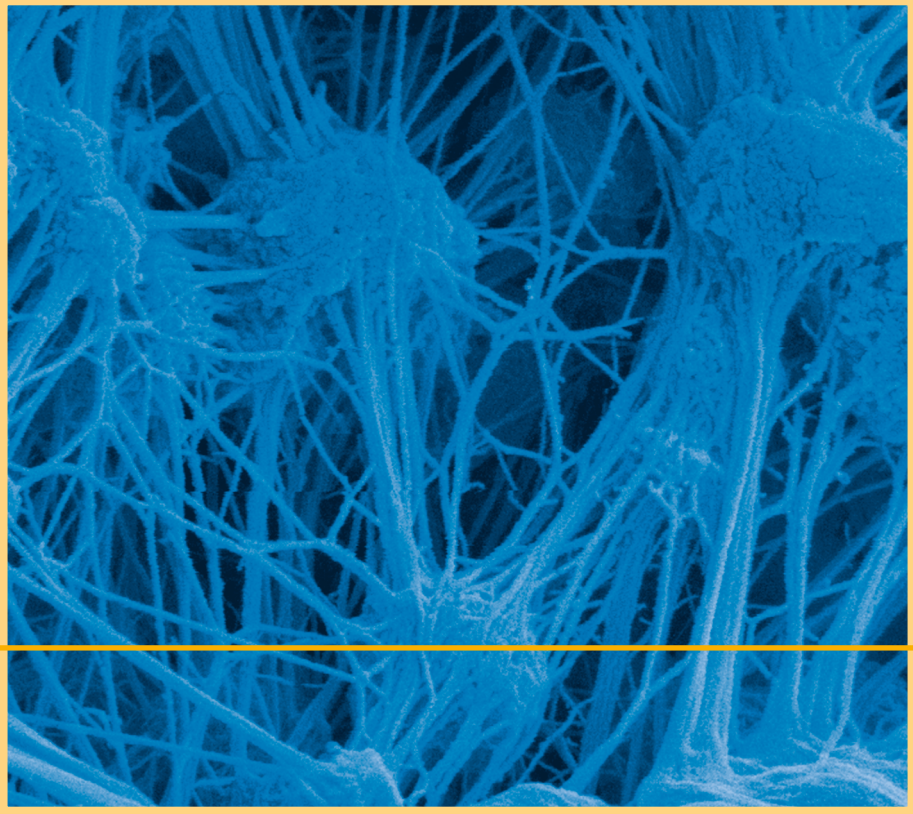
Goerg H. Michler

Atlas of Polymer Structures

Morphology, Deformation and Fracture Structures



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The Author:

Prof. Dr. habil. Goerg H. Michler, Martin-Luther-Universität Halle-Wittenberg, Institut für Physik, 06099 Halle (Saale), Germany

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Preface

Polymers are important materials in many fields of daily life, from household, medicine, agriculture, and automotive industry products, up to microelectronics and space research. The morphology of polymers provides and controls the physical, chemical, and other properties of technical relevance. Therefore, analysis and control of the morphology of polymers is a crucial precondition to material development, to improve properties in general and to better fit specific properties to defined applications.

In the last few decades, the amount of interest in polymeric systems has gradually shifted from the micron-scale to the nanometer-scale region. As a consequence of the trend toward producing more nanostructured polymers and miniaturizing components (microsystems), a better understanding of the hierarchical structure of polymers is needed. In general, knowledge of the property-determining structures and microprocesses or mechanisms is a necessary precondition for exploiting the full potential of polymeric materials and is key in successfully developing new polymers and improving the properties of polymers already in use. This Atlas will help scientists and engineers to understand the morphology of polymers and, therefore, to understand their properties better.

The detailed investigation of the complex hierarchical structures of many polymers requires the use of specialized techniques. Electron microscopy and atomic force microscopy have both developed into powerful tools in the field of polymer science. By using different techniques, morphological details can be detected at length scales from the visible (0.1 mm) down to the atomic level (about 0.1 nm). Additionally, the influence of several parameters, such as temperature, environment, and mechanical stresses, can be investigated together with the morphology of the material. In particular, under mechanical loading, the influence of the local morphology on the mechanical effects that occur at the nano- and microscopic level can be examined. Therefore, electron microscopy and atomic force microscopy directly contribute to a better understanding of structure-property correlations in polymers.

This book reviews the research results of academia and industry with a comprehensive overview of the morphology of all groups of polymers. The different levels of morphology, that is, the hierarchical structure of polymers, are illustrated with micrographs from all of the different microscopic techniques with magnifications from the millimeter down to the subnanometer scale. In addition, changes in morphology during and after mechanical loading up to fracture structures are presented together with illustrations of the nano/micromechanical and failure mechanisms. The reader will find a compact and understandable description and illustration of the structural or morphological variety of polymers with a focus on the morphological details, which are relevant for the application properties of the polymers. The micrographs and explanations allow correlations between the morphology and properties of the polymers and help readers to better understand the ultimate properties. The aim of this book is to give guidelines for polymer researchers, chemists, chemical engineers, and material scientists in institutions and industry for understanding the principles of morphology formation and for improving

properties, in particular mechanical properties. Finally, the book will also be helpful for students of polymer physics, chemistry, and engineering, as well as for those researchers interested in the microscopic and nanoscopic world of polymers.

After an introductory chapter in Part I of the Atlas, with an overview of the molecular and supermolecular structures (morphology) and the mechanical behavior of polymers, Chapter 2 offers a summary of the main techniques and methods used to investigate the nanostructure and morphology as well as the nano- and micromechanical processes and mechanisms. It describes briefly the wide variety of preparation methods and the different microscopic techniques of electron microscopy and atomic force microscopy used in morphological investigations, accompanied by representative micrographs. In particular, contrast formation in the different microscopes is discussed to help the reader to interpret the micrographs of the many polymers. Chapter 3 discusses several factors of sample preparation as well as investigation technique that can influence the appearance of micrographs or lead to false interpretations.

The subsequent nine chapters of Part II form the main part of the Atlas, with the presentation of micrographs of the different groups of polymers, including amorphous and crystalline polymers, block copolymers, blends and rubber-toughened polymers, particle- and fiber-reinforced composites, biopolymers and biomedical polymers, nanofibers, and special polymer forms. Each of these chapters starts in the first section with a general overview of the particular polymer group; the following sections show in detail representative micrographs from different microscopic techniques with short descriptions, illustrating the characteristic features and also the variety of structures and morphologies of the polymers and showing the influence of the preparation method. In addition to the legend for each micrograph, in some cases micrographs are grouped and compared in one figure with extended information. In all cases, a clear identification of magnification with a scale bar and, if necessary, the direction of mechanical loading are indicated. Next to the typical morphologies, examples of deformation and fracture structures together with the relevant deformation mechanisms and the most commonly occurring defects and failures are highlighted as well. Each chapter closes with a list of relevant references.

In Part III are some tables to help the reader quickly find the figures of the different polymers illustrated in Part II and find micrographs with characteristic morphological details and characteristic deformation and fracture structures. In addition, some morphological terms have a culinary or natural background.

This book presents lots of illustrating micrographs that result from all of the direct imaging methods of optical, electron, and atomic force microscopy. It contains knowledge and experiences developed over more than four decades in different working groups in academia, universities, applied research institutes, and the polymer industry. For many of the microscopic investigations and micrographs I thank my former coworkers in Halle, Schkopau, and Merseburg, Germany, in particular DI (FH) Irene Naumann, DI (FH) Helga Steinbach, Dr. Katerina Morawietz, Ingeburg Schülke, DI (FH) Sylvia Goerlitz, Cornelia Becker (†), Dipl.-Phys. Werner Lebek, Dipl.-Phys. Volker Seydewitz, DI Stefanie Scholtyssek, Dr. Reinhold Godehardt, Dr. Ashraf Sh. Asran, Dr. Sven Henning (now Fraunhofer Institute of Materials Mechanics in Halle), Dr. Rameshwar Adhikari (now Kathmandu, Nepal),

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Many examples of polymers with representative micrographs together with a description of the nano- and micromechanical properties are from the first publication in this field by G. H. Michler, "Kunststoff-Mikromechanik: Morphology, Deformations- und Bruchmechanismen," Hanser, 1992, and from the book "Nano- and Micromechanics of Polymers: Structure Modification and Improvement of Properties," Hanser, 2012, together with my friend Francisco Jose Baltá-Calleja, Madrid, whom I also thank for improvements of the manuscript. For helpful discussions over many years, I thank Prof. Dr. Dr. h.c. Hans-Henning Kausch, Lausanne, Switzerland, and Prof. Dr. Wolfgang Grellmann, Merseburg, Germany.

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