REINFORCEMENT OF POLYMER NANO-COMPOSITES

Reinforced rubber allows the production of passenger car tires with improved rolling resistance and wet grip. This book provides in-depth coverage of the physics behind elastomer reinforcement, with a particular focus on the modification of polymer properties using active fillers such as carbon black and silica. The authors build a firm theoretical base through a detailed discussion of the physics of polymer chains and matrices before moving on to describe reinforcing fillers and their applications in the improvement of the mechanical properties of high-performance rubber materials. Reinforcement is explored on all relevant length scales, from molecular to macroscopic, using a variety of methods ranging from statistical physics and computer simulations to experimental techniques. Presenting numerous technological applications of reinforcement in rubber such as tire tread compounds, this book is ideal for academic researchers and professionals working in polymer science.

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REINFORCEMENT OF POLYMER NANO-COMPOSITES

Theory, Experiments and Applications

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Preface

Why a new book about the science of an apparently old material? This question can be easily posed, when reading the title of this book. Indeed, filled rubbers are well known and well used in daily life. However, it is less known that recipes and the corresponding processing cycles of carbon black or silica filled rubber are extremely complex, which leads to a complex structure of the material in a wide range of length scales. Rubbers are classes of relatively soft materials without which modern technology would be unthinkable, similar to the case of metals, fibres, plastics, glass, etc. No matter where these rubber materials find their application, especially in tires and in a great variety of industrial and consumer products, e.g. motor mounts, fuel hoses, heavy conveyor belts, profiles, etc., the applications make high demands on rubber materials. The requirements are manifold, e.g. high elastic behavior even at large deformation, tailored damping properties during periodic deformations, great toughness under static or dynamic stresses, high abrasion resistance, impermeability to air and water, in many cases a high resistance to swelling in solvents, little damage, and long life.

Their importance for applied sciences and engineering is unquestionable, so why not collect the ideas and facts about these materials in a book? Aren't there many theories and facts around which many could form the basis for a review book? This would be, however, too simple, at least for us and for the completely different backgrounds of the three authors. Providing such a book is probably useless and not very exciting. Moreover, most of the theories that are around seem to suffer from too much phenomenology, too much diversity, and too much empiric reasoning.

Rubbers are far more than boring materials, at least from a theorist's point of view, at least from an experimentalist's point of view, at least from an engineer's point of view. Last but not least, from the materials point of view, simply because the function and the wide-ranging properties of the material depend on large variety of lengths and time scales. Filled elastomers are a typical example, where multiscale science plays a major role in the structure–property relationship. Imagine a car driver who needs to brake suddenly to stop at a very short distance. Can he, at the same time, imagine that this macroscopic, highly nonlinear process can be drawn back to certain and well-desired physical properties of the nanoscale polymer layer formed around the filler particles that are embedded within the rubber matrix? Can the car driver imagine the role of the filler network formed by the aggregated filler particles that form a random (cluster–cluster) percolating network? Or, how is the wet grip of the tire related to certain time and length scales within the tread rubber material that is excited periodically during sliding over a rough, even fractal, road surface?

The present book cannot give all the answers to all the questions, but we try here to develop a picture for filled elastomers, which joins basic theoretical ideas with practical applications. The basic ansatz here is therefore different. Starting from theories, we try to understand many, so far, empirical laws to provide more physical insight. We try to join different ideas together by using solid models. These, very often fundamental starting points will nevertheless lead to new ideas, new pictures, and new models. This is, what we, the three authors have done over the past 10 years in our common research starting from our three individual backgrounds. Thus the book has a very personal point of view. It is based on our own reach and based on the different attitudes of all three of us. It joins basic polymer physics, sometimes hard core theory, with experiments and at various places questions located in applications and engineering. This book is an attempt to provide more physical insight into the properties of materials, and therefore we try to relate most of the macroscopic features, which define the properties, to elementary physical pictures and models. To do so, we need a large variety of theoretical and experimental approaches, since a broad spectrum of lengths and time scales need to be taken into account. For us it was sometimes exciting to realize how purely theoretical results from simple models, e.g. universal exponents for frequency dependence of relaxing localized chains, transport themselves into measurable quantities, e.g. the relaxation time spectrum ruling the frequency dependence of the modulus, in certain time scales. Perhaps the reader can share our excitement here and there in this book.

Therefore, this book is indeed a kind of review book, but of our own work and from our own points of views. This remark needs to be understood as an apology to many other authors who will not find themselves quoted here, but also as an invitation to follow different ideas and different viewpoints about a classical material. If the reader is following this invitation, he can then perhaps agree with us. Filled elastomers are indeed classical materials, but they offer still many open questions and many possibilities for fundamental studies. On the other hand, cognition of our studies has been used by the authors to develop and to design certain kinds of future rubber materials based on concepts of rubber nanocomposite technologies.

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In particular, this can serve as a tool for developing a new tire generation with improved rolling resistance, wet traction and wear properties, and in this way, break through the magic triangle of tire technology. However, this will not form part of this book.

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