Preface

Materials that are either manufactured or occur in nature and used both in industry and in our daily lives (metals, rocks, wood, soil, suspensions, and biological tissue) are very seldom homogeneous, and have complicated internal structures. Although the combination of two or more constituents to produce materials with controlled distinguish properties has been exploited since at least ancient civilization, modern composite materials were developed only a few decades ago and have found intensive application in contemporary life and in all branches of industry. Establishment of a link between the structure and properties in order to understand which kind of structure provides the necessary properties is an objective of "micromechanics," which exploits information about microtopology and properties of constituents of the heterogeneous medium for development of mathematical models predicting the macroproperties. The problem of micromechanical modeling of the mechanical properties of engineering materials is today a crucial part of the design process, and sample testing is usually performed only during the final stage for validation of the "virtual" design. An accuracy of the classical "trial and error" testing method of the new materials and constructions is no longer be affordable in modern industry and science.

Owing to wide applications of composite materials, their modeling has been developed very intensively over recent decades, as reflected in the numerous papers and books only partially presented in the reference section of this book. A variety of materials and approaches appearing in apparently different contexts and among different scientific disciplines (solid mechanics, geophysics, solid-state physics, hydromechanics, biomechanics, chemical technology, etc.) do not allow the opportunity to investigate adequately the whole field in a single book. In light of this, I was challenged with a natural question as to why it was necessary to write another book and what is the difference between this book and the ones published earlier. In parallel with this book, there are a few fundamental books combining readily applicable results useful for material scientists with a significant contribution to progress in theoretical research itself. However, a fundamental difference of this book is a systematic analysis of statistical distributions of local microfields rather than only effective properties based on the average field concentrator factors inside the phases.

The uniqueness of this book consists of the development and expressive representation of statistical methods quantitatively describing random structures which are most adopted for the subsequent evaluation of a wide variety of macroscopic transport, electromagnetic, and elastic properties of heterogeneous media. The popular methods in micromechanics are essentially one-particle ones that are invariant with respect to statistical second and higher order quantities examining the association of one particle relative to other particles. This book expressively reflects the explosive progress of modern micromechanics resulting from the development of image analyses and computer-simulation methods on one hand and improved materials processing on the other hand, since processing controls the prescribed microstructure. With the appearance of new experimental techniques, it is now possible to study the microtopology of disordered materials much more deeply to understand their properties. Modern techniques are also available to design materials with morphological properties that are suitable for planned applications. This progress in micromechanics is based on methods allowing for statistical mechanics of a multiparticle system considering n-point correlation functions and direct multiparticle interaction of inclusions, and the book presents a universally rigorous scheme for both analyses of microstructures and prediction of macroscopic properties which leaves room for correction of their individual elements if improved methods are utilized for the analysis of these individual elements. The book successfully combines advanced numerical methods for the analysis of a finite number of interacting inhomogeneities in either the bounded or unbounded domain with analytical methods.

It should be mentioned that there are two coupled classes of micromechanical problems for which averaging is critical. Averaging is usually suitable for predicting effective elastic properties. However, failure and elastoplastic deformations will depend on specific details of the local stress fields when fluctuation is important. In the framework of computational micromechanics in such a case, one must check the specific observable stress fields for many large system realizations of the microstructure with the use of an extremal statistical technique. A more effective approach used in analytical mechanics is the estimation of the statistical moments of the stress field at the interface between the matrix and inhomogeneities. The inherent characteristics of this interface are critical to understanding the failure mechanisms usually localized at the interface. In the framework of a unique scheme of the proposed multiparticle effective field method (MEFM), we attempted to analyze the wide class of statical and dynamical, local and nonlocal, linear and nonlinear micromechanical problems of composite materials with deterministic (periodic and nonperiodic), random (statistically homogeneous and inhomogeneous, so-called graded) and mixed (periodic structures with random imperfections) structures in bounded and unbounded domains, containing coated or uncoated inclusions of any shape and orientation and subjected to coupled or uncoupled, homogeneous or inhomogeneous external fields of different physical natures.

I do not pretend to cover the whole field of micromechanics in this book (restricted by my interests); there are many other topics in micromechanics, of much industrial and scientific importance, that are either treated schematically or only mentioned. In particular, the homogenization theory of periodic structures, the geometrically nonlinear problems, flow in porous media, viscoelasticity problems, and cross-property relations are not considered at all in this book while stochastic geometry, variation methods, propagation of waves in composites, and multiscale discrete modeling are not treated in depth they deserve and sometimes were only mentioned. Interested readers are referred to the references cited in the appropriate sections to achieve a deeper understanding of these topics. This book finalizes my research in micromechanics that began with the papers published in 1986. It was written piece by piece at different times and in different countries facing new challenging problems in micromechanics. The book is suitable as a reference for researchers in different disciplines (applied mathematicians; physicists; geophysicists; material scientists; and electrical, chemical, civil, and mechanical engineers) working in micromechanics of heterogeneous media and providing a rigorous interdisciplinary treatment through experimental investigation. The book is also appropriate as a textbook for an advanced graduate course.

I gratefully acknowledge the financial support for 30 years of research in micromechanics of heterogeneous materials by the National Research Council, and the Air Force Office of Scientific Research (AFOSR) of the United States, Austrian Society for the Promotion of Scientific Research, Max-Planck-Society of Germany, as well as by the Ministry of Higher Education, National Academy of Science, and the Ministry of Machine Construction of USSR and Russia. This book would not have been possible without this support. The excellent cooperation with the team at Springer is gratefully acknowledged; I owe special thanks to E. Tham, C. Simpson, and C. Womersly for their careful and patient editing of this book. Also, thank you Elsevier for allowing permission to use Figs. 3.1–3.3, 4.12, 4.13, 5.1–5.4, 8.1, 9.5, 9.6, 11.1–11.8, 12.2, 13.5–13.11, 14.1–14.4, 15.1–15.5, 15.8–15.11, Tables 11.1–11.5 originally published in [133], [134], [136], [137], [146], [168], [179], [182], [184], [190], [191], [633]; Birkhäuser Verlag AG for permission to use Figs. 4.10, 4.11, 10.1–10.6, 15.7, originally published in [145], [152]; SAGE Publication for permission to use Figs. 4.4, 4.6–4.10, 12.4–12.6, originally published in [166], [167]; ASME for allowing permission to use Figs. 12.11, 15.7, 16.10–16.14, originally published in [138], [187]; Begell House Inc. for permission to use Figs. 4.1–4.3, 12.3, 12.12, originally published in [144], [153], [195]; Springer Science and Business Media for allowing permission to use Figs. 12.1, 12.7–12.10, 15.6, 16.6, 16.7, 18.7–18.19 originally published in [131], [155], [185].

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I am aware of the fact that the book may contain controversial statements, too personal or one-sided arguments, inaccuracies, and typographical errors. Any the remarks and comments regarding the book will be fully appreciated (bury-ach@woh.rr.com).

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