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Book Review: *Random Heterogeneous Materials*

Random Heterogeneous Materials. Salvatore Torquato, Springer-Verlag, New York, 2002, 701 pages.

Understanding the microstructure and effective properties of heterogeneous materials has been a very active research field for several decades. With the advent of powerful computers, development of new theoretical approaches, and invention of new instruments, we are now able to not only obtain precise data on various properties of heterogeneous materials, but also develop realistic models that can provide accurate predictions for their effective properties. However, amazingly enough, despite their significance, there was, for a long time, no modern book that dealt with heterogeneous materials. *Random Heterogeneous Materials*, written by one of the leading contributors to this highly important research field, will go a long way to fill this large gap. This is a book of very high quality that covers several important topics in the physics and mechanics of inhomogeneous materials, describes many recent results, and is very well written. Since the author has been at the forefront of this research field, he has deep insight into many of the theoretical developments of the past two decades, and as a result has produced a book with many insightful comments. This book will be an invaluable reference for advanced graduate courses in heterogeneous materials in the disciplines of mechanics, physics, and applied mathematics.

The book describes in great details many theoretical developments and computer simulation studies of characterization of microstructure of disordered materials, and estimation and prediction of four of their main properties, namely, the effective conductivity tensor, effective elastic properties, the fluid permeability, and the mean survival time or the trapping constant for reactions in such materials. This set of problems also reflects the important contributions that Salvatore Torquato has made to the field of heterogeneous materials. The author treats these four problems in "parallel," i.e., every chapter of the book that discusses estimation of these properties begins with general theoretical developments, after which the analysis and the theoretical developments are applied to the problem of estimating these four main properties. In this way, the similarities and differences between the four different problems become highly

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transparent. All the theoretical developments presented in the book are, in my opinion, as rigorous as possible. Most of the theoretical developments and computer simulations that are described and discussed in the book use what I refer to as the *continuum models* of disordered materials, which consist mainly of dispersion of inclusions of various shapes (e.g., spherical, ellipsoidal, etc.) in a background matrix. Discrete or lattice models, which have been popular with physicists and even many engineers, are not described extensively, although many results that are described in the book are also applicable to the lattice model. The book does not discuss nonlinear properties, either in the form of a nonlinear constitutive relation between the flux and the potential gradient, or such nonlinear properties as mechanical fracture and electrical and dielectric breakdown. Time- or frequency-dependent properties are also not discussed. Covering all these aspects would, of course, have made the book much longer, and therefore the author has wisely avoided this. The book also contains an extensive, and more than adequate, list of references.

The book is divided into two main parts. After an introductory chapter, Part I describes characterization of microstructure of materials. Roughly half of the book is devoted to this aspect of disordered materials. Part II describes the relation between the microstructure and the four effective properties of disordered materials that the book covers.

Chapter 1 is an excellent introduction. Chapter 2 describes the microstructural descriptors, such as the various correlation functions and the pore size distribution. Chapter 3 presents statistical mechanical treatment of many-particle systems, and describes important topics such as the Ornstein–Zernike formulation and equilibrium hard-sphere systems. Chapter 4 describes how one can characterize the microstructure of materials by developing a unified approach that consists of the various correlation functions that are mostly derived from a single function, namely, the canonical correlation function H_n. The next two chapters describe in great details these correlation function and descriptors for two important classes of models of hetereogeneous materials, namely, the monodisperse and polydisperse spheres. Chapters 7 and 8 extend these results to models of anisotropic, and cellular materials, respectively. The next two chapters describe percolation and clustering and the important role that they play in describing the effective properties of multiphase materials. Image analysis and methods of reconstruction of models of materials based on some information have become important tools of studying disordered materials, and Chapter 12 describes these methods and also the computer simulation techniques in considerable detail.

Part II begins with Chapter 13 that describes the four main problems and properties that are to be studied in the remaining chapters, and the relationship between them. The next several chapters describe various methods of estimating the effective conductivity, elastic moduli, the fluid permeability and the trapping constant, including variational approach (Chapter 14); exact results for certain models of disordered materials (Chapter 16), such as laminates and periodic arrays of spheres; solutions to single-inclusion problems (Chapter 17); various mean-field and effective-medium approximations (Chapter 18); cluster expansions (Chapter 19); exact contrast expansions (Chapter 20) by which the effective properties of two-phase materials are estimated by expansions in the difference between the properties of the two phases, and rigorous upper and lower bounds to the effective properties (Chapters 21 and 22), a field to which Torquato has made very important contributions. In the last chapter, the important subject of relations that link the various properties, such as the link between the effective conductivity and the elastic moduli, and the link between the permeability and the survival time, is discussed. Other important topics, such as duality and phase-interchange relations, are also described.

I have recently finished writing a two-volume book(1) on the same subject that is being published by the same publisher. Thus, it may be useful to compare my book to Torquato's book. Although there is some overlap between the two books, they actually complement one another extremely nicely. Some of the topics covered are similar and some are not, but most importantly, the depth of coverage are quite different. As described above, Torquato spends the entire first half of his book on rigorous discussion of microstructure characterization, whereas my book, while covering the same materials, only summarizes the most important results in two chapters. While Torquato focuses exclusively on the prediction of the four properties, mentioned above, in the linear regime, my book covers these properties at almost the same level of depth, but also covers properties that Torquato's book either does not consider at all, or spends a small amount of space on, including nonlinear properties and fracture and breakdown, properties of the discrete models, and atomistic modeling. Therefore, in my opinion, these books complement each other extremely well.

Salvatore Torquato has done a great service to the community by writing this outstanding book. In my opinion, every serious researcher and advanced graduate student who is interested in heterogeneous materials should have a copy of this book.

REFERENCE

1. M. Sahimi, *Heterogeneous Materials, Volumes I and II* (Springer-Verlag, New York), in press.

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