BOOK REVIEW

Numerical Simulation of the Heat Conductivity of Randomly Inhomogeneous Two-Dimensional Composite Materials

Authors: Alexander Pysarenko, Ph.D. and Igor Zaginaylo, Ph.D.
Department of Physics, Odessa State Academy of Civil Engineering and Architecture, Odessa, Ukraine

A. What is this Book About

The book "Numerical Simulation of the Heat Conductivity of Randomly Inhomogeneous Two-Dimensional Composite Material" by Alexander Pysarenko and Igor Zaginaylo is an attempt to describe the thermal conductivity of composites in conjunction with their internal structure.

The authors consider materials with irregular structures and describe the features of the formation of preferred thermal transport paths through such materials. The total volume of the book is 176 pages. It contains 6 chapters (134 pages), a bibliography of 315 titles and an index of terms (4 pages).

The first part of the book, namely, Chapter 1 (Introduction), Chapter 2 (Models for Thermal Conductivity Composites) and Chapter 3 (Numerical Methods in Heat Conduction), provides a very detailed overview of the models describing the thermal conductivity of composites and modern numerical methods for calculation of heat transport through them. The second part of the book includes Chapter 4 (Research Method), Chapter 5 (Thermal Conductivity of Two-Component 2D Composites) and Chapter 6 (Statistics of Heat Fluxes Intensity Distribution). This part presents an approach to the description of the heat transport through the composite material, developed by the authors. The approach is based on a statistical analysis of local heat fluxes density calculated during the numerical experiments.

The following is a summary of each chapter.

- Chapter 1: <u>Introduction</u>. This short chapter introduces the reader to a set of tasks for which it is important to correctly predict the characteristics of thermal transport through composite materials. The authors focus their attention on two-dimensional two-component composites with random placement of filler particles as systems of minimal complexity in which it is possible to study the features of thermal transport, assuming that these features will be manifested in composites of the most diverse internal structure.
- Chapter 2: <u>Models for Thermal Conductivity of Composites</u>. In the first subsection, the authors consider traditional homogenization models, in which, under various assumptions, the dependence of the effective thermal conductivity of the material on the volume fraction of the filler and on the shape of these particles is calculated without taking into account other features of the internal structure. The second subsection describes an approach that takes into account the internal structure of the material using representative volume elements.
- Chapter 3: <u>Numerical Methods in Heat Conduction</u>. This chapter focuses on numerical methods, which directly take into account the internal structure of the material. The chapter contains three subsections. The first subsection mentions classical mesh methods for the numerical solution of the heat equation, namely, the finite difference method and the finite element method. The second subsection describes the statistical approach to solving the heat equation, implemented by the Monte Carlo method. This approach is based on replacing the solution of the heat conduction problem by solving the problem of a random walk of a particle, or by solving the problem of diffusion of particles. The third section describes multi-scale methods that are used to solve the problem of thermal conductivity in materials with a complex multi-scale internal structure.
- Chapter 4: <u>Research Method</u>. In this chapter, the authors describe their method, which they represent as the Non-Random-Walk Monte Carlo Method. The authors use the classical finite difference method to solve the heat equation. However, the simulation of the material structure is performed using a random number generator. The structure generation algorithm contains

certain rules called location parameters. All implementations of a random structure with the same placement parameters are considered equivalent. Solutions of the heat equation for various realizations of an equivalent random structure were processed statistically. Thus, this method can be attributed to the mesh- and statistical Monte-Carlo methods. The Visualization in Heat Conduction Analysis subsection is of particular interest. In this section, the authors show the importance of visualizing the spatial distribution of the density of the local heat flux vector in the material. Analysis of these visualizations allows the authors to determine several characteristic states of the composite matrix depending on the intensity of local heat fluxes. It should be noted that the authors in their work limited themselves to the case of the placement of heat insulating inclusions in a thermally conducting matrix.

- Chapter 5: Thermal Conductivity of Two-Component 2D Composites. In this chapter, the authors analyze the statistical distributions of solutions of the heat equation for equivalent random structures of the material. Based on the results of their numerical experiments, the authors derived formulas for the dependence of the effective thermal conductivity on the concentration of inclusions and on the placement parameter characterizing the packing density of the filler particles, which the authors call the minimum allowable distance between inclusions. It is shown that materials with random placement of inclusions have different effective thermal conductivity in different directions. To describe this difference, the notion of thermal conductivity effective anisotropy is introduced. The nature of thermal conductivity effective anisotropy is purely statistical. A measure of thermal conductivity effective anisotropy is the dispersion of the distribution of the effective thermal conductivity of a material.
- Chapter 6: Statistics of Local Heat Fluxes Intensity Distribution. This chapter introduces the statistical distributions of the density vector of local heat fluxes (LHF). These distributions have a multimode structure, and the number of modes varies from 2 to 4. Analysis of the distribution and visualization of the local heat flux vector density in different material implementations showed that certain modes of the statistical distribution of the local heat flux density are associated with certain characteristic areas of the material matrix defined in Chapter 4: so-called dark matrix, induced channels, etc. In the subsection Effect of LHF Flow Angles on Thermal Conductivity, the authors introduce a characteristic of the tortuosity of the thermal transport path in the composite. The authors call this characteristic the weighted average angle of LHF deviation from the temperature macro-gradient direction (WAA LHF). The existence of a statistically significant anti-correlation between WAA LHF and the effective thermal conductivity of the material is shown. Based on the results of their numerical experiments, the authors derived a formula for the dependence of WAA LHF on the concentration of inclusions in the composite.

B. What Attracted Me to this Book?

Any composite material is an evolving system. Material all its life is exposed to various physical and chemical factors leading to changes in its structure: the appearance of defects, the degradation of some bonds, etc. Heat transport through such an evolving material also evolves: heat fluxes do not flow in a continuous front, but in streams, using the most advantageous elements of the structure, including her defects. The approach proposed by the authors for determining the effective thermal conductivity of a material through the calculation of local heat fluxes, analysis of their statistical distribution and distribution over the volume of the material (visualization of density maps and directions of local fluxes) allows one to approach the description of thermal transport through evolving systems if changes in the internal structure of the material can be expressed in the language of formalized statistical parameters of the placement of elements of this structure. I think this is an important advantage of the book.

I suppose, however, that the authors do not develop some of their own ideas, for example, the discovered domain boundaries in the matrix were left without proper attention (Chapter 4, Figure 6, P.72), the idea of thermal lenses was not developed (Chapter 4, Figure 11, P. 78). Apparently, the authors decided to leave this to their readers. In addition, the detected correlation between the effective thermal conductivity of the composite sample and its WAA LHF (Chapter 6, Figure 60, P.127) suggests that the coefficients of approximation of the thermal conductivity concentration dependence in the formula (101) (Chapter 5, P.90) may be dependent from WAA LHF. However, the presence of ideas that can be developed is also the merit of this book.

C. Who Should Read this Book?

The book actually contains two parts - in the first part, the well-known models, concepts and approaches to the calculation of the heat-conducting properties of composite materials are summarized, and in the second part, the results of the authors' numerical experiments with their original approach are described. The analysis of heat transport in composite materials using the statistics of local heat fluxes is a promising and productive approach that was developed by the authors of this book.

Finally I believe that the readers, students and even experienced researchers of composite materials may benefit strongly from this book.

Professor Valery Vyrovoy
Odessa State Academy of Civil Engineering and Architecture
Ukraine