

Engineering Materials

Vadim V. Silberschmidt  
Valery P. Matveenko *Editors*

# Mechanics of Advanced Materials

Analysis of Properties and Performance



 Springer

Vadim V. Silberschmidt · Valery P. Matveenko  
Editors

# Mechanics of Advanced Materials

Analysis of Properties and Performance

 Springer



*Editors*

Vadim V. Silberschmidt  
Wolfson School of Mechanical and  
Manufacturing Engineering  
Loughborough University  
Loughborough, Leicestershire  
UK

Valery P. Matveenko  
Institute of Continuous Media Mechanics  
Russian Academy of Sciences  
Perm  
Russia

ISSN 1612-1317

Engineering Materials

ISBN 978-3-319-17117-3

DOI 10.1007/978-3-319-17118-0

ISSN 1868-1212 (electronic)

ISBN 978-3-319-17118-0 (eBook)

Library of Congress Control Number: 2015935404

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media  
([www.springer.com](http://www.springer.com))

# Preface

In the last two decades, Mechanics of Materials as a discipline has experienced a type of revival. The main reason for this has been a continuing introduction of new materials (or even their classes) with extraordinary microstructures, properties and performance. Carbon nanotubes, quantum dots, bulk metallic glasses and graphene are some of the examples. This revival process was additionally enhanced by an application-related drive to expose these—as well as previously known and used—materials to harsher conditions: high strains, strain rates, loads and temperatures as well as combinations of various loading and environmental factors. Recent developments in aerospace, energy, automotive and defence industries as well as in microelectronics were possible thanks to extended usability envelopes for various components and structures.

Another important factor was the introduction of technologies allowing the production of materials and even final parts with precise control of their microstructural features, and, hence, properties and performances. A typical example is additive manufacturing—more known as *3d printing*—that can reproduce detailed microstructural patterns, developed by researchers in *silico*; it currently also has a capability to use multiple materials, gradual changes in properties—and with continuously improving spatial resolution.

This progress affected significantly Mechanics of Materials that its broadly used classical formulations does not fully meet the new challenges. This volume presents some of the current developments and trends in this field covering experimental, theoretical and numerical approaches and results. The examined materials include established ones such as metals and alloys (including, *i. a.*, pure indium), or polymeric fibrous networks as well as new types of materials: bulk metallic glasses, smart materials and metamaterials with a negative Poisson's ratio. Properties and deformation behaviours of composites with various types of constituents are also discussed.

Among the theoretical matters presented are the use of a phase-field formalism and its finite-element realisation for analysis of crack initiation and propagation in brittle materials; a statistical scheme for mechanics of composites with random reinforcement employing correlation functions of the second and higher orders and



a variational formulation for quasi-harmonic vibrations of an electro-viscoelastic smart material consisting of elastic, viscoelastic and piezoelectric elements. All these theoretical schemes are also accompanied by examples of their numerical implementations for various case studies. Some dedicated numerical approaches and algorithms are also offered in other parts of the volume.

A wide range of experimental methods are discussed: tests at small scale (nanoindentation and micropillar compression); creep at various temperatures; wedge indentation etc. These tests were performed on specimens of various shapes and dimensions, for different stress/strain states and microstructures.

Thus, this volume would be of interest to researchers and engineers working on links between microstructures of advanced materials and their mechanical properties and performance.

Loughborough, UK  
Perm, Russia

Vadim V. Silberschmidt  
Valery P. Matveenko

# Contents

<b>Finite Element Modelling of 2D Brittle Fracture: The Phase-Field Approach . . . . .</b>	<b>1</b>
H.A.F.A. Santos and V.V. Silberschmidt	
<b>Crystalline Deformation in the Small Scale . . . . .</b>	<b>23</b>
Murat Demiral, Anish Roy and Vadim V. Silberschmidt	
<b>Methods of Stochastic Mechanics for Characterization of Deformation in Randomly Reinforced Composite Materials. . . . .</b>	<b>43</b>
Mikhail A. Tashkinov	
<b>Optimization of the Damping Properties of Electro-Viscoelastic Objects with External Electric Circuits. . . . .</b>	<b>79</b>
V.P. Matveenکو, M.A. Yurlov and N.A. Yurlova	
<b>Bulk Metallic Glasses: Mechanical Properties and Performance. . . . .</b>	<b>101</b>
V. Nekouie, G. Abeygunawardane-Arachchige, A. Roy and V.V. Silberschmidt	
<b>Constitutive Properties of Pure Indium in Wide Temperature Range. . . . .</b>	<b>135</b>
Xiaojin Cheng, Changqing Liu and Vadim V. Silberschmidt	
<b>Metamaterials with Negative Poisson's Ratio: A Review of Mechanical Properties and Deformation Mechanisms . . . . .</b>	<b>155</b>
Xiaonan Hou and Vadim V. Silberschmidt	
<b>Deformation and Damage of Thermally Bonded Nonwoven Networks. . . . .</b>	<b>181</b>
Farukh Farukh, Emrah Demirci, Memiş Acar, Behnam Pourdeyhimi and Vadim V. Silberschmidt	

Engineering Materials

Vadim V. Silberschmidt · Valery P. Matveenko *Editors*

## Mechanics of Advanced Materials

Analysis of Properties and Performance

The last decades have seen a large extension of types of materials employed in various applications. In many cases these materials demonstrate mechanical properties and performance that vary significantly from those of their traditional counterparts. Such uniqueness is sought – or even specially manufactured – to meet increased requirements on modern components and structures related to their specific use. As a result, mechanical behaviors of these materials under different loading and environmental conditions are outside the boundaries of traditional mechanics of materials, presupposing development of new characterization techniques, theoretical descriptions and numerical tools. The book presents interesting examples of recent developments in this area. Among the studied materials are bulk metallic glasses, metamaterials, special composites, piezoelectric smart structures, nonwovens, etc.

Engineering

ISBN 978-3-319-17117-3



9 783319 171173

► [springer.com](http://springer.com)

