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Yuri Estrin · Yves Bréchet ·
John Dunlop · Peter Fratzl
Editors

Architectured Materials in Nature and Engineering

Archimats

Springer

Editors
Yuri Estrin
Department of Materials Science
and Engineering
Monash University
Clayton, VIC, Australia

John Dunlop
Department of Chemistry and Physics
of Materials
University of Salzburg
Salzburg, Austria

Yves Bréchet
SIMAP
Institut Polytechnique de Grenoble
Saint-Martin d'Hères, France

Peter Fratzl
Department of Biomaterials
Max Planck Institute of Colloids
and Interfaces
Potsdam, Germany

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Preface

Over the last decade, the notion of 'architectured materials' has been steadily making its way into the mainstream materials science and engineering. This development came about due to the recognition that design of materials with new properties and functionalities can no longer rely only on traditional approaches based on manipulating a material's composition and microstructure. Following the pioneering views of M. F. Ashby, the inner architecture of the material at a length scale intermediate between the microstructural scale and the specimen dimensions is now considered as a new 'degree of freedom' in materials design. By using this degree of freedom, especially in the context of hybrid materials where the geometry and mutual arrangement of the constituents become the main elements of the inner architecture, it becomes possible to 'fill the holes' in material property charts, thus attaining new functionalities not possible with traditional materials design.

The workshop on *Designing Non-Traditional Materials Based on Geometrical Principles* organised by Yuri Estrin, Mike Ashby, Yves Bréchet and Arcady Dyskin in Hanover, Germany, in June 2005 has been inspired by the idea of architectured materials. Hardly noticed by the broad materials community at the time, the workshop nonetheless has defined the area and outlined possible directions of research on architectured materials. It also helped forming a fraternity of scientists and engineers who see the development of architectured materials ('archimats') as their mission. A workshop organised at Collège de France in 2012 as a closing event for a year of courses by Yves Bréchet as the chair in 'Innovation and Technology' funded by the Bettencourt Foundation provided an opportunity to witness the major progress in this new field. A number of forthcoming symposia at TMS, MRS, IUTAM, THERMEC and probably many other meetings are a testimony to the growing acceptance of the concept of architectured materials by a broader community. Its adoption as a solution to engineering design problems is indeed entering the mainstream research activities. This research naturally involves competences not only from materials science, but also from mechanics, chemistry, mathematics and biology.

Naturally grown materials, such as wood, bone, silk or seashells are generally based on a small selection of base materials, proteins, polysaccharides and minerals. From an engineering viewpoint, these base materials seem rather poor in terms of their intrinsic physical properties. Their power, however, resides in their self-assembly capacities, usually controlled and enhanced by living cells, into architectured materials with remarkable properties. Nature generates a multitude of functions not primarily by varying the chemical composition but rather by a diversity of mesoscopic structures. For this reason, biological materials are ideal sources of inspiration for the development of architectured engineering materials.

The area of architectured materials—both bioinspired and engineered ones—has now reached a degree of maturity and popularity, and we feel it is timely to review the progress made and provide an outlook to possible future developments. In this book that comprises 14 chapters, the various aspects of architectured materials are presented by authors who are active in the field. Important archetypes of archimats, such as microtruss composites and topological interlocking materials, are presented in the chapters written by Abu Samk and Hibbard (Chap. 1) and Dyskin, Estrin and Pasternak (Chap. 2), respectively. Chapter 3 (by Pasternak and Dyskin) and Chap. 4 (by Dirrenberger, Forest and Jeulin) deal with auxetic materials. Archimat design methodology is discussed by Kromm and Wargnier (Chap. 5), while Chap. 6 written by Vermaak et al. addresses topology optimisation, with an emphasis on the interfaces in architectured materials and the role they play in property improvement. A further group of chapters concern the methods by which archimats can be manufactured. These include friction stir processing (Simar and Avettand-Fènoël, Chap. 7), severe plastic deformation (Bygelzimer, Kulagin and Estrin, Chap. 8) and additive manufacturing (Molotnikov, Simon and Estrin, Chap. 9). Architectured materials and mechanisms occurring in living organisms, which may inspire engineering design, are discussed by Politi, Bar-On and Fabritius (Chap. 10), Seidel et al. (Chap. 11), and Krijnen, Steinmann, Jaganatharaja and Casas (Chap. 12).

While many chapters in this book touch upon possible applications of archimats, two of them discuss practical applications quite specifically. These are the contributions by Yrieix (Chap. 13), devoted to building materials, and Fallacara, Barberio and Colella (Chap. 14), which describes the use of topological interlocking in stereotomy-based architectural design and construction. Analytical and computer-based techniques enter several chapters, the one by Dirrenberger, Forest and Jeulin (Chap. 4) being specifically devoted to homogenisation techniques as a means for mathematical modelling of the mechanical behaviour of architectured materials.

Taken together, the contributions presented provide a rather full picture of the history, current state and future prospects of research on architectured materials. The book offers an instructive and entertaining reading both to a specialist in this field and to a person who just enters it. It provides a useful compendium of the results obtained to date owing to an intensive study conducted by several research groups. It is hoped that this book will promote the materials design principles underlying engineering of architectured materials and boost efforts to implement them in novel materials and structures, in a field which is now accepted as a mainstream strategy yet is still very open to further developments and new ideas.

Clayton, Australia	Yuri Estrin
Saint-Martin d'Hères, France	Yves Bréchet
Salzburg, Austria	John Dunlop
Potsdam, Germany	Peter Fratzl

Contents

Contributors

Khaled Abu Samk Department of Materials Science and Engineering, University of Toronto, Toronto, ON, Canada

G. Allaire CMAP, Ecole Polytechnique, Palaiseau, France

Marie-Noëlle Avettand-Fènoël Université de Lille, Unité Matériaux Et Transformations, UMR CNRS 8207, Villeneuve d'Ascq, France

Maurizio Barberio Dipartimento di Scienze dell'Ingegneria e dell'Architettura, Politecnico di Bari, Bari, Italy

Benny Bar-On Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel

Yan Beygelzimer Donetsk Institute for Physics and Engineering named after A. A. Galkin, National Academy of Sciences of Ukraine, Kiev, Ukraine

Y. Bréchet SIMaP, CNRS, Université Grenoble, Grenoble, France

Jérôme Casas Institute de Recherche en Biologie de l'Insecte, Université de Tours, Tours, France

Micaela Colella Dipartimento di Scienze dell'Ingegneria e dell'Architettura, Politecnico di Bari, Bari, Italy

Mason N. Dean Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Justin Dirrenberger Laboratoire PIMM, Arts et Métiers-ParisTech, CNRS, Cnam, Paris, France

A. V. Dyskin Department of Civil, Environment and Mining Engineering, The University of Western Australia, Perth, WA, Australia

R. Estevez SIMaP, CNRS, Université Grenoble, Grenoble, France

Yuri Estrin Department of Materials Science and Engineering, Monash University, Clayton, Australia

Helge-Otto Fabritius Department Microstructure Physics and Alloy Design, Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany

Giuseppe Fallacara Dipartimento di Scienze dell'Ingegneria e dell'Architettura, Politecnico di Bari, Bari, Italy

A. Faure SIMaP, CNRS, Université Grenoble, Grenoble, France

Samuel Forest Centre des Matériaux, MINES-ParisTech, CNRS UMR 7633, Evry, France

Glenn D. Hibbard Department of Materials Science and Engineering, University of Toronto, Toronto, ON, Canada

Ram K. Jaganatharaja TechMed Centre, University of Twente, Enschede, The Netherlands

Aravind K. Jayasankar Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Dominique Jeulin Centre de Morphologie Mathématique, MINES-ParisTech, Fontainebleau, France

F. Jouve Laboratoire J. L. Lions (UMR 7598), University Paris Diderot, Paris, France

Gijs J. M. Krijnen TechMed Centre, University of Twente, Enschede, The Netherlands

F. X. Kromm Université de Bordeaux, Talence, France

Roman Kulagin Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany

G. Michailidis SIMaP, CNRS, Université Grenoble, Grenoble, France

Andrey Molotnikov Department of Materials Science and Engineering, Monash University, Clayton, Australia

G. Parry SIMaP, CNRS, Université Grenoble, Grenoble, France

E. Pasternak Department of Mechanical Engineering, The University of Western Australia, Perth, WA, Australia

Yael Politi Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Ronald Seidel Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Ron Shahar The Robert H. Smith Faculty of Agriculture, Food and Environmental Sciences, Koret School of Veterinary Medicine, The Hebrew University of Jerusalem, Rehovot, Israel

Aude Simar Institute of Mechanics, Materials and Civil Engineering (iMMC), Université catholique de Louvain, Louvain-la-Neuve, Belgium

George P. Simon Department of Materials Science and Engineering, Monash University, Clayton, Australia

Thomas Steinmann Institute de Recherche en Biologie de l'Insecte, Université de Tours, Tours, France

N. Vermaak Department of Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA, USA

H. Wargnier Université de Bordeaux, Talence, France

Bernard Yrieix Materials and Mechanics of Components, EDF Lab Les Renardières, EDF R&D, Moret-Sur-Loing, France