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Architected Materials in Nature and Engineering

Archimats

 Springer

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Preface

Over the last decade, the notion of ‘architected 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 architected 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 architected materials. It also helped forming a fraternity of scientists and engineers who see the development of architected 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 architected 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 architected 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 architected engineering materials.

The area of architected 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 architected 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 architected 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). Architected 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 architected materials.

Taken together, the contributions presented provide a rather full picture of the history, current state and future prospects of research on architected 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 architected 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.

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