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Architectured Multifunctional Materials

MATERIALS RESEARCH SOCIETY
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Architectured Multifunctional Materials

Symposium held April 14–16, San Francisco, California, U.S.A.

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MULTIFUNCTIONAL MATERIALS

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PREFACE

Multifunctional requirements are becoming the rule in terms of design. Weight saving, safety and energy management are societal requirements that cannot be ignored, and an efficient use of matter requires that several functions can be obtained in the same component. While the last decades have been driven by the development of new materials, or by the appropriate choice of materials for a given application, this new and demanding engineering approach triggers the development of "tailored materials."

Very often, contradictory requirements cannot be met by single materials. The development of new "materials," in a more general sense, able to combine otherwise contradictory properties, cannot be achieved by classical "alloy design" or "combinatorial polymer chemistry." Various innovative strategies are possible: either combining different materials (such as multilayers), or playing with material architectures (such as foams or truss lattices), or developing microstructural gradients. These strategies open a whole new range of materials and properties, where structural requirements and functional properties can be combined. They also reveal new challenges such as implementing new processes, developing appropriate constitutive equations, engineering interfaces, developing and modeling bio-inspired hierarchical structures, and promoting design methods to deal systematically with optimizing this new class of materials. These strategies are especially suited for a "materials by design" approach where material combinations, microstructural gradients and multiscale architectures are optimized to meet a complex set of requirements, possibly leading to a combination of properties that is otherwise impossible to reach. This is a whole new field of research and engineering that is opened by these new strategies.

Symposium LL, "Architectured Multifunctional Materials," held April 14–16 at the 2009 MRS Spring Meeting in San Francisco, California, the first of its kind on this very general topic, was an attempt to bring together physicists, chemists, materials scientists and mechanicians dealing with a wide variety of fields of application. It is hopeless, in such a wide and rapidly evolving field, to aim at an exhaustive description. More to the point is to highlight the spirit of the new approach so that other researchers can bring in their own competences, their own creativity. Both functional and structural properties are on the agenda, materials are metals, polymers and ceramics, processing routes are from all the possible states of matter, solid, liquid, gaseous. Architectures under consideration span all scales of condensed matter, from the nanoscale to the millimeter. The common point is the impossibility to fulfill the required properties with a single unstructured material; the spirit is to design the material for the requirement. Seventy contributions were presented at the symposium, a selection of 29 proceedings papers in this volume give a glance at the variety of approaches, and at the future developments.

The organization of the proceedings reflects this variety. The first section gathers contributions on the basic concepts, materials combinations, optimized geometries, and hierarchical structures, with an insight in the possibility to seek inspiration from natural materials. The "ancestors" of architectured materials, namely fibrous and cellular structures will illustrate the concepts. A third group of papers deal with the new processes involved and required by complex materials and architecture combinations. Architectured materials are somewhere between microstructure and structure: a whole range of possibilities is open at the "millimeter scale" where geometry can be more easily controlled; this will be the leitmotiv of the "toward structures" section. Finally, the last group of papers illustrate the driving force behind these new strategies in materials developments: looking for "multifunctional materials."

There is one contribution missing from this volume, that by Professor Tony Evans on "Geometrical Aspects of Architectured Materials Design." Sadly, Professor Evans died during the preparation of this volume and was unable to contribute the written version of his paper. He was a man of great dedication and courage and we would like to dedicate this volume to his memory. A small tribute to a man who was an inspiration and mentor to many researchers and who was indeed one of the pioneers in this emerging area of materials research.

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June 2009

INTRODUCTION

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"*Architecture: the Art and Science of structural design*." It is a definition that works well here. When the population of Cro-Magnon man first exceeded the capacity of caves and other natural habitats, the need to build structures was forced upon them, and architecture, one of mankind's oldest creative activities, was born. It provided shelter, protection from predators and, later, storage for grain and security for livestock. It was, in a word, *multifunctional*.

Today, three million years later, we have multifunctional architectured *materials*. The papers in this volume echo the long-past history in more than one way. There is the Art – the ingenuity in devising processing paths for controlling the scale and connectivity of foam-like cellular structures, for welding tiny hollow sphere into close-packed arrays and for binding fibers into brush-like bundles. There is Art, too, in the elegant microscopic and tomographic images by which they are characterized. And there is the Science – the physical testing, the physical modeling and the digital simulation that allow properties of micro-architectured structures to be understood and predicted.

Architectured materials had, of course, evolved millions of years before *homo sapiens* appeared on earth. The multilevel structures of wood, bone, coral and shell exploit the advantages offered by cellular microstructure, composite reinforcement and sandwich design. They provide inspiration (even, sometimes, templates) for the design of architectured materials of today. The external or internal skeleton of animals has to provide stiffness and strength, yet it must also allow articulation if the creature is to move. Nature solves this problem by creating what, in contemporary terminology, are called tensegrity structures: rigid interlocking vertebra or scales-like segments, pulled together at joints by tendon and muscle to allow relative motion. The key feature, preventing dislocation, is the topological interlock of the joints. This has inspired a new set of architectured structures of a different kind, made up of discrete small but interlocking blocks, held together by surrounding tensile "ligaments" that promise to expand the use of brittle ceramics in load bearing structures.

Multifunctionality is a much misused word, easy to claim – even the most ordinary material can, after all, be used in more than one way – and can, or could, perform more than one function. To justify the claim of "multifunctionality" beyond the ordinary, an architectured material must either allow two properties that are usually coupled to be decoupled, allowing independent optimization of each, or it must perform useful functions in more than one realm, simultaneously providing mechanical, thermal, electrical or optical functions that are beyond the scope of simple homogeneous materials. The papers of this volume provide examples of both. They include materials with uniquely-tunable values of stiffness, strength and thermal expansion, and materials with independently adjustable strength, weight and acoustic damping. But despite the long history of its antecedents, this is a field in its infancy, and this symposium a report of work in progress, exciting work; with the promise of more excitement to come.

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