Biological Materials Science and Engineering: Biological Materials, Biomaterials, and Biomimetics

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This second issue of *JOM* dedicated to biological materials science in 2008 complements the March issue admirably. We remind the reader that the 'bio' field has three prominent components: biological materials—natural materials; biomaterials—synthetic materials used in a biological environment; and biomimetics—bioinspired materials and structures.

In the March issue, the importance of biological materials within the framework of materials science and engineering (MSE) was emphasized; it was pointed out that this is not a passing fad but a structural evolution. Figure 1 is a brief historical overview (presented counterclockwise, starting at the top left-hand corner) showing how metallurgy gave rise to materials science and engineering, which expanded from primarily structural materials to functional materials, leading now to biological materials that serve as inspiration for complex hierarchical systems of the future. The chart contains the following four components:

- Traditional metallurgy as practiced through the first part of the 20th century can be represented by the metallurgical triangle, which has extraction as the top vertex, with processing and properties as complementary components.
- The structure-properties-performance triangle created by Morris Cohen in the 1970s emphasized the connection among these three elements and presented MSE in a new light, with a distinctive approach. Metals, ceramics, polymers, and their composites were embraced in a unified manner as pioneered by M. Fine. The structure-property paradigm is still at the heart of MSE research.
- In the 1990s, the tetrahedron proposed by G. Thomas, which is featured on the cover of *Acta Materialia*, emphasized the growing importance of functional materials, a departure from an earlier focus on structural materials.
- The biological materials pentahedron created by E. Arzt in 2005 contains features that are unique to natural materials and that we hope to incorporate, through biomimetics, into synthetic systems. The pentahedron emphasizes the unique aspects of the field through its five vertices: synthesis in aqueous environment at ambient pressure and temperature, multifunctionality, hierarchical structure, self-assembly, and evolution/environmental effects. These aspects are indicative of the inherent complexity required to fully understand and exploit (through biomimetic design and processing) biological systems.

Figure 2 shows the evolution of activities in this field within TMS, starting with the founding of the Biomateri-

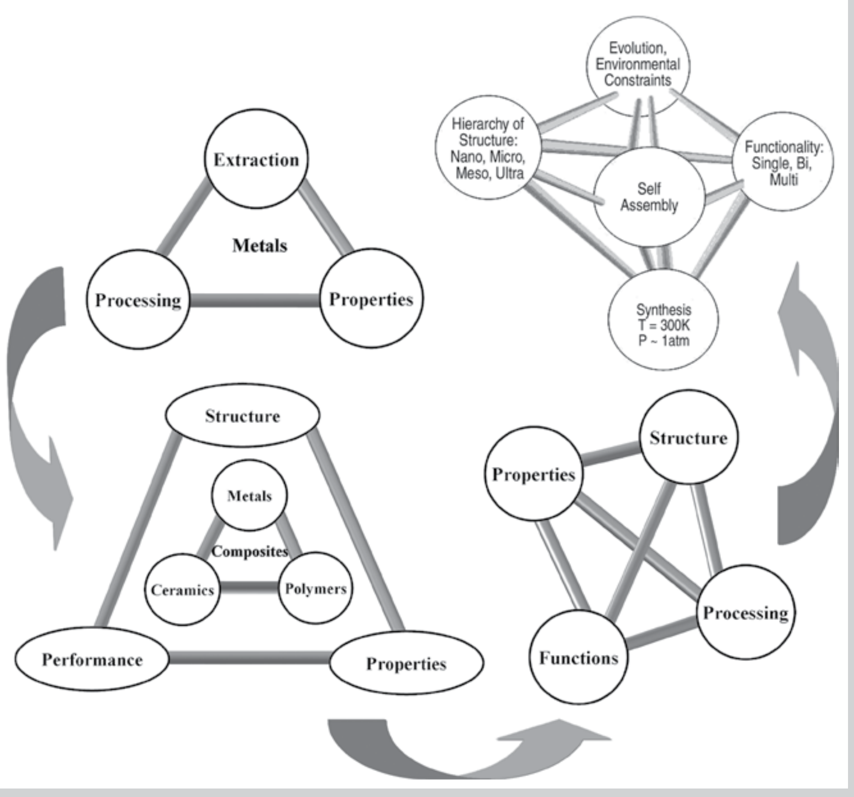

Figure 1. The evolution of materials science and engineering, starting with traditional metallurgy, proceeding through the Cohen structure-properties-performance triangle, then evolving to the Thomas tetrahedron emphasizing the current functional aspects, and culminating with the Arzt pentahedron on biological materials.

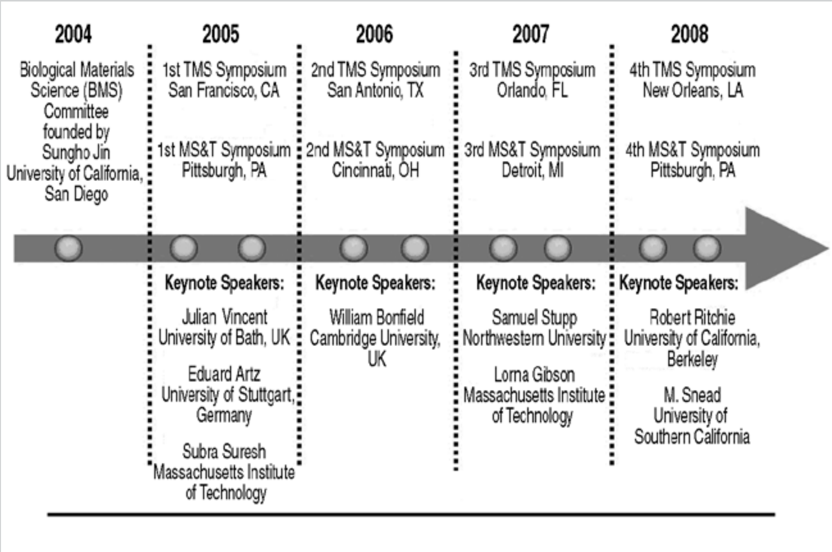

Figure 2. The evolution of TMS activities in biological materials science and engineering.

als Committee through the initiative of S. Jin in 2004. Four symposia at the TMS annual meetings have followed from 2005 to 2008, complemented by symposia at the fall meetings. The roster of keynote speakers has been outstanding with the global leaders listed in Figure 2 contributing significantly to the success of the symposia. Biological materials science and engineering is already solidly established within TMS, with symposia planned for 2009 and beyond. One of the highlights of the 2008 symposium was the well-attended lecture given by D. Brant (director, Biomaterials Program, Division of Materials Research, National Science Foundation [NSF]) on funding opportunities. The symposium was also generously supported by the NSF Biomaterials Program.

Reiterating the themes of the March issue and reinforcing them, we present a collection of excellent papers that evolved from keynote (R.O. Ritchie's contribution) and invited (C.T. Lim and A. Tomsia) lectures given at the third and fourth TMS symposia on biological materials science, as well as additional contributed talks.

The articles in this issue cover the three areas of biological materials, biomaterials, and biomimetics.

P.-Y. Chen and co-workers demonstrate that a hierarchy of structures is essential to the fascinating mechanical properties of a number of 'hard' biological materials: shells, crab exoskeletons, deer antlers, and feathers.

K. Koester, J. Ager, and R. Ritchie present a broad overview of their research into the effects of aging (a problem that affects us all) on bone and teeth using classical fracture mechanics techniques to discern the microstructural origins of the changes. They show that although toughness does not decrease greatly with age, the resistance to crack growth does.

R. Kulin, F. Jiang, and K. Vecchio demonstrate that bone is more brittle under rapid (such as impact) loading than in slow loading. In slow loading microcracks and crack branching take place, whereas in fast loading the crack path is less tortuous.

Y. Zhang and C.T. Lim describe biomimetic, electrospun nanofibers which are applied as tissue scaffolds in regenerative medicine.

O. Franke, M. Göken, and A. Hodge present a new technique to determine the viscoelastic properties of cartilage-nanoindentation with a sinusoidally varying load, so that the measurements of load and displacement (being out of phase) reveal the loss and storage moduli that define the viscoelastic response.

E. Munch and coworkers fabricate porous hydroxyapatite scaffolds for bone growth using two techniques: robotic-assisted deposition and freeze-casting. The freeze casting process mimics the formation of nacre in abalone and is thus a biomimetic process.

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