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Exploring Material Property Space Using Bioinspiration and Architecture

Francois Barthelat
McGill University, francois.barthelat@mcgill.ca

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Exploring material property space using bioinspiration and architecture

Francois Barthelat[1]
(1) McGill University (Montreal, Canada), francois.barthelat@mcgill.ca

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Architectured materials are high-information materials with controlled structures at intermediate length scales between microstructure and whole component [1, 2], and manipulating material architecture is a powerful approach to generate new combinations of properties that expand material property space [3]. We have recently focused on dense architectured materials, made of hard and stiff building blocks joined by weaker and more deformable interfaces. These interfaces can deflect and guide cracks into toughening configurations, or channel large nonlinear deformations. These general principles lead to building blocks which can slide, rotate, separate or interlock collectively, providing a wealth of tunable mechanisms, precise structural properties and functionalities [4]. Interestingly, nature is well ahead of us at making and using architectured materials. Bone, teeth and mollusc shells rely on stiff mineral building blocks and on weak proteinaceous interfaces [5, 6] to generate unusual and useful combinations of stiffness, strength and toughness [7]. Other natural architectured materials such as scaled skins and fish fins combine hard and soft to create flexible armors and exoskeletons [8], or to achieve morphing capabilities [9]. Here I will discuss how we are exploring material architecture and bioinspiration to design, fabricate and test new materials and structures based on very hard and very soft materials (Fig. 1): nacre-like ceramics and glasses [10], sutured interfaces [11], laminated glasses augmented with bioinspired cross plies, topologically interlocked structures from platonic solids [12], flexible protective skins covered with hard elements of tunable shape and arrangements [13]. To explore this vast design space we use finite elements models, discrete element models, 3D printing, 3D laser engraving and a variety of mechanical tests. Our materials display a rich array of mechanisms which can be finely tuned to achieve desired sets of properties. They can also be fabricated in large volumes with relatively simple methods, making them suitable for rapid implementation in various engineering applications.

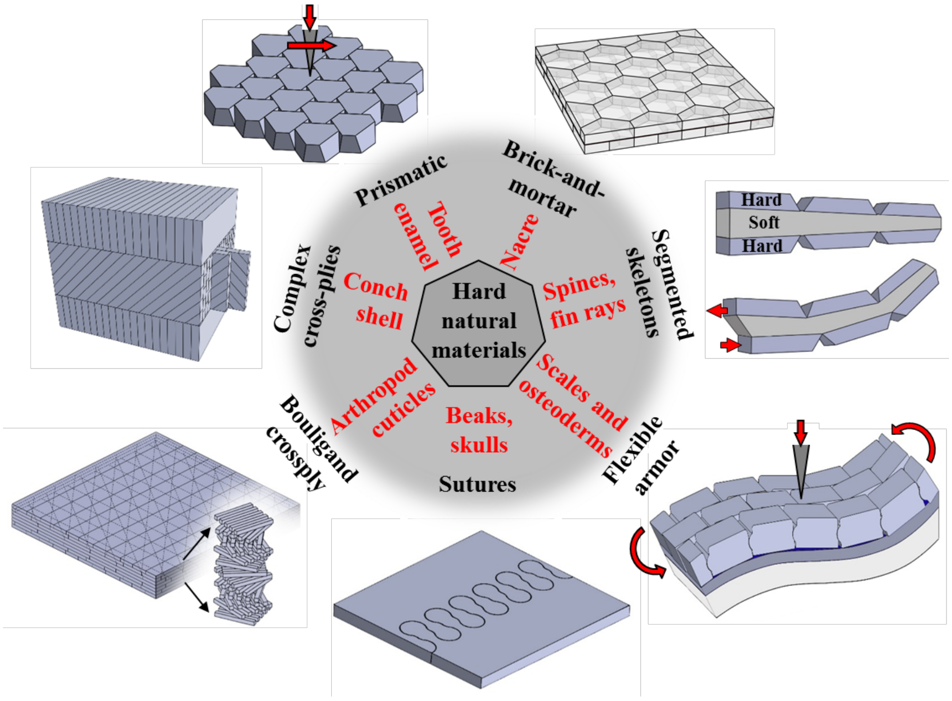

Figure 1: Bio-inspired materials and structures derived from hard biological materials

References

[1] Brechet Y, Embury JD. Architectured materials: Expanding materials space. Scr Mater 2013;68:1-3.
[2] Barthelat F. Architectured materials in engineering and biology: fabrication, structure, mechanics and performance. International Materials Reviews 2015;60:413-30.
[3] Ashby MF. Hybrids to fill holes in material property space. Philosophical Magazine 2005;85:3235-57.
[4] Siegmund T, Barthelat F, Cipra R, Habtour E, Riddick J. Manufacture and Mechanics of Topologically Interlocked Material Assemblies. Applied Mechanics Reviews 2016;68:040803-.
[5] Dunlop JWC, Weinkamer R, Fratzl P. Artful interfaces within biological materials. Materials Today 2011;14:70-8.
[6] Barthelat F, Yin Z, Buehler MJ. Structure and mechanics of interfaces in biological materials. Nature Reviews Materials 2016;1.
[7] Wegst UGK, Bai H, Saiz E, Tomsia AP, Ritchie RO. Bioinspired structural materials. Nature Materials 2015;14:23-36.
[8] Zhu D, Ortega CF, Motamedi R, Szewciw L, Vernerey F, Barthelat F. Structure and Mechanical Performance of a "Modern" Fish Scale. Advanced Engineering Materials 2012;14:B185-B94.
[9] Alben S, Madden PG, Lauder GV. The mechanics of active fin-shape control in ray-finned fishes. Journal of the Royal Society Interface 2007;4:243-56.
[10] Chintapalli RK, Breton S, Dastjerdi AK, Barthelat F. Strain rate hardening: A hidden but critical mechanism for biological composites? Acta Biomaterialia 2014;10:5064-73.
[11] Mirkhalaf M, Dastjerdi AK, Barthelat F. Overcoming the brittleness of glass through bio-inspiration and micro-architecture. Nature Communications 2014;5.

[12] Mirkhalaf M, Tanguay J, Barthelat F. Carving 3D architectures within glass: Exploring new strategies to transform the mechanics and performance of materials. Extreme Mechanics Letters 2016;7:104-13.
[13] Martini R, Balit Y, Barthelat F. A comparative study of bio-inspired protective scales using 3D printing and mechanical testing. Acta Biomaterialia 2017;55:360-72.