Biomimetic Energy Absorbent Materials and Structures (BEAMS)

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Abstract

- In this project, we will employ our expertise in material science and experimental and computational mechanics to study the mechanisms of energy absorption in biological systems, to develop a novel class of Biomimetic Energy Absorbent Material Systems (BEAMS).

Purpose and Innovative Approach:
- Advanced modeling and numerical simulation of response of structures under blast and shock loading at different scales: from structural components to full-scale structural systems
- Development of robust failure material models for structures capable of simulating material fracture under dynamic loading
- Development of novel energy absorbent structural materials based on the concepts of activity, heterogeneity and hierarchy

Relevance

Each of the systems that are studied here, represents an intellectually challenging field of study, in the context of mechanical behavior, materials and their functionality. Our study will be carried out using robust experiments at both micro and macro scale, combined with theoretical analysis and detailed numerical simulations of structural deformation under loading.

Objectives:
- Achieve fundamental understanding of failure mechanisms of structures under blast and shock loading
- Develop high-performance explosion-resistant material systems

Impact:
- Development of novel materials with superior energy absorption characteristics
- Construction of robust computational platform for simulating the response of structures under high intensity dynamic loading

Technical Approach

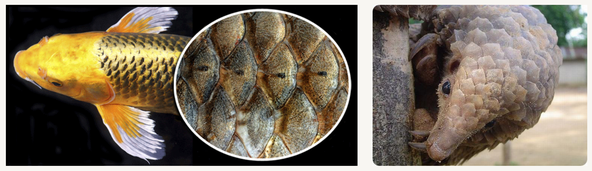
We will study the energy absorption and structural behavior of different fundamental systems:
- Cellular materials - including both materials with random heterogeneity (e.g. bone) and functionally graded variations (e.g. bamboo)
- Protective layer
- Hierarchical organization.

These systems differ in scale, properties and applications, but are representative of most of energy absorbent biological materials, as shown in the table. As an example, the heterogeneous and hierarchical structural organization of elk antlers. The antler is a tough and energy absorbent structure that is capable of absorbing high energy impact and its functionality is crucial to the survival of the animal.

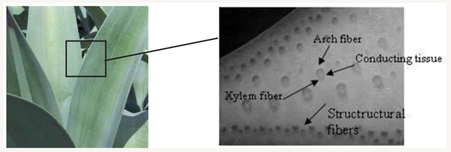
	Cellular materials		Protective layer	Hierarchical organization
	Heterogenous	Functionally graded		
Cork	X			
Toucan beak	X		X	
Bamboo		X		
Walnut			X	
Banana peel		X	X	
Teeth			X	
Nacre				X
Lobster			X	X
Elk antler		X		X

Key structural characterizations of selected biological materials, which are envisioned to be responsible for their energy absorption. These biological materials will be studied in the three testbeds discussed above.

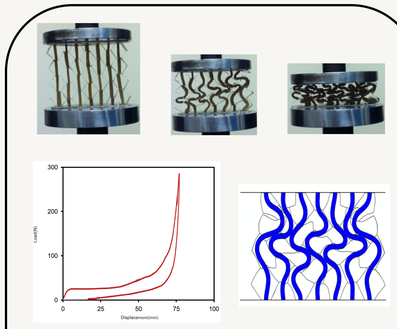
Structural organization of elk antlers at macro and micro scales. The antlers have remarkable impact and fracture resistance



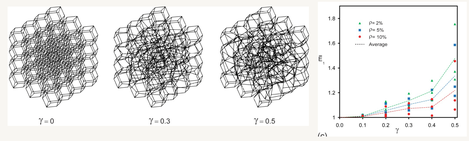
Biological scaled armor systems



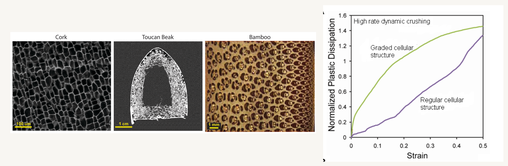
Cellular structure of sisal leaf



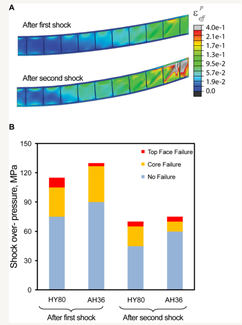
Crushing of a hybrid cellular structures (experiments and numerical simulations)



3D irregular cellular structures



Biomimetic cellular structures and their energy absorption



Detailed 3D numerical simulations of structural failure under two consecutive blast loadings

Accomplishments Through Current Year

- Fundamental study of response of sandwich structures under high intensity dynamic loading
- Simulation of structures subjected to multiple shocks
- Studying the energy absorption of heterogeneous and functionally graded materials
- Research collaboration with Textron and URI through John Adams Foundation

Future Work

- Investigate the residual structural capacity and safety of shock-loaded structures
- Investigate the response of structures under fire and at elevated temperature
- Novel cellular structures with structural hierarchy and biomimetic armored materials with multifunctional advantages and superior mechanical properties

Opportunities for Transition to Customer

We will use the insight provided from our study to modify the structural organization of energy absorbent engineered materials (e.g. foams) and also to develop novel biomimetic material systems.

Patent Submissions

N/A

Publications Acknowledging DHS Support

Journal Articles:
- A. Ajdari, H. Nayeb- Hashemi, A. Vaziri, "Dynamic crushing and energy absorption of regular, irregular and functionally graded cellular structures", *Int. J. Solids and Structures*, 2011, 48, pp. 506-516.
- Babee, B. Hapghpanah Jahromi, A. Ajdari, H. Nayeb-Hashemi,& A. Vaziri, "Mechanical properties of open-cell rhombic Dodecahedron cellular structures", *J. Mechanics and Physics of Solids*, under review.
- A. Vaziri, A. Ajdari, H. Ali., A. Ageladiou Twohig "Structural analysis of reinforced concrete chimneys subjected to uncontrolled fire", *Engineering Structures*, under review.
- M. Ashrafi, A. Ajdari, H. Nayeb-Hashemi & A. Vaziri, "Single lap joints with non-flat interfaces", I *Int. J. Adhesion and Adhesives*, in preparation.

Conference Abstracts:
- A. Vaziri, A. Ajdari "Homogenization and failure of metal sandwich panels subjected to air shocks", *IMPLAST 2010.*
- A. Ajdari, S. Babaeezadeh & A. Vaziri, "Dynamic crushing and energy absorption of cellular structures", *IMPLAST 2010.*
- S. Babaee, B. Haghpanah, A. Ajdari, H. Nayeb-Hashemi,& A. Vaziri, "Mechanical properties of three-dimensional open, closed and partially-closed rhombic dodecadedron cellular structure", *IMECE 2010*, 2010.
- A. Vaziri, B. Haghpanah & A. Ajdari, "Failure and fracture of shock-loaded sandwich panels", *IMECE 2010*, 2010.
- A. Ajdari, S. Babaee & A. Vaziri, "Dynamic crushing of heterogeneous and functionally graded cellular structures", *New England Workshop on the Mechanics of Materials and Structures*, 2010.
- S. Babaee, A. Ajdari & A. Vaziri, "Heterogeneous and functionally graded three-dimensional cellular materials" , *2011 SEM Annual Conference and Exposition on Experimental and Applied Mechanics.*
- A. Ajdari, S. Babaee & A. Vaziri, "Mechanical properties and energy absorption of heterogeneous and functionally graded cellular structures", *International Conference on the Mechanical Behavior of Materials, 2011.*
- A. Ajdari, S. Babee, H. Nayeb-Hashemi & A. Vaziri, "Cellular structures with irregular structural organization", *Engineering Mechanics Institute Conference (EMI2011).*
- S. Babaee, B.H. Jahromi, A. Ajdari, H. Nayeb-Hashemi, A. Vaziri, "Energy absorption of 2D and 3D Cellular structures", *Sixth MIT Conference on Computational Fluid and Solid Mechanics*, Cambridge, MA 2011.
- A. Ajdari, A. Vaziri, "Structural hierarchy in 2D honeycombs", *USNCCM 11*, Minneapolis, MN 2011.
- A. Ajdari, S. Babaee, A. Vaziri, "Energy absorption of 3D closed-cell rhombic dodecahedron structures", *ASME App. Mech.* Mat., Chicago, IL, 2011.

Other References

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- Multi-national grant from QNRF ($910k) -New approaches for structural protection in oil and gas industry
- John Adams Foundation Award – in collaboration with Textron and URI ($100k) - Dynamic mechanical properties of polymers and aluminum alloys

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