

Biomolecule Unfolding and Mechanics of Nacre

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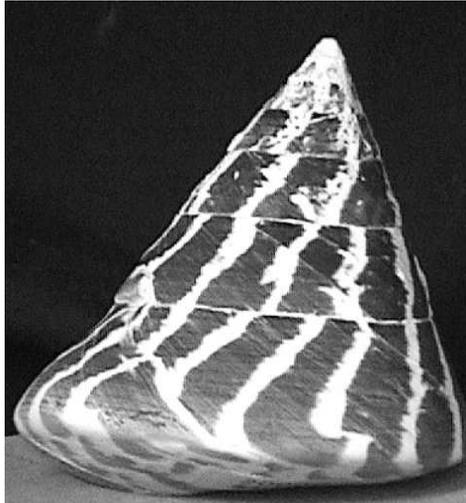
Massachusetts Institute of Technology
Cambridge, MA 02139

MIT Army Institute of Soldier Nanotechnology (ISN)

August, 2004

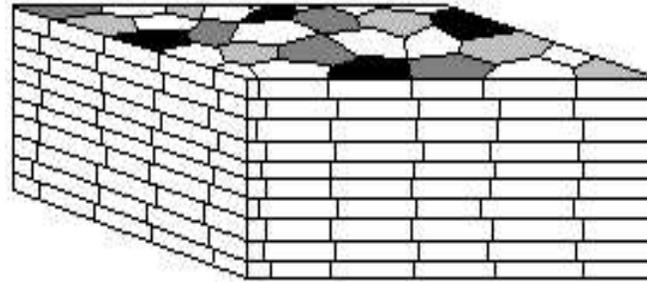
Structure of Nacre

Nacre of Seashell Provides Novel Means of Improving Material Performance

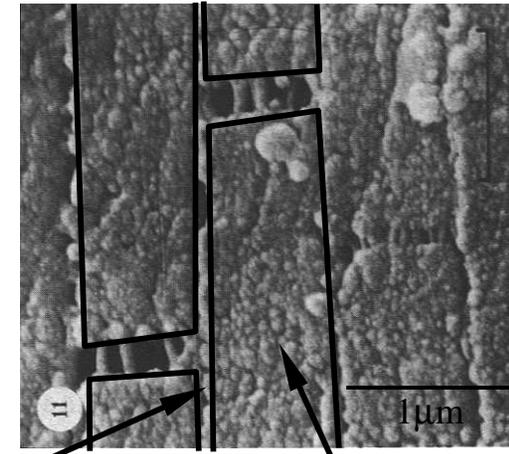
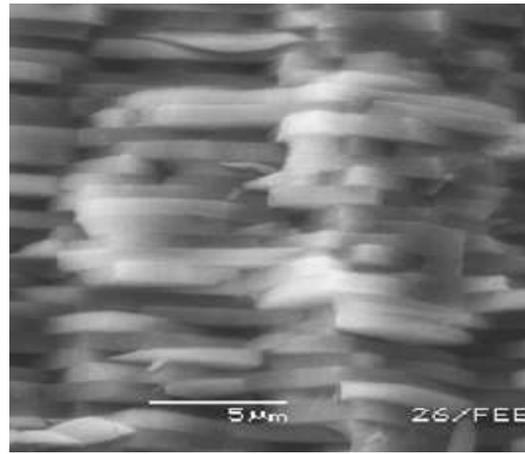
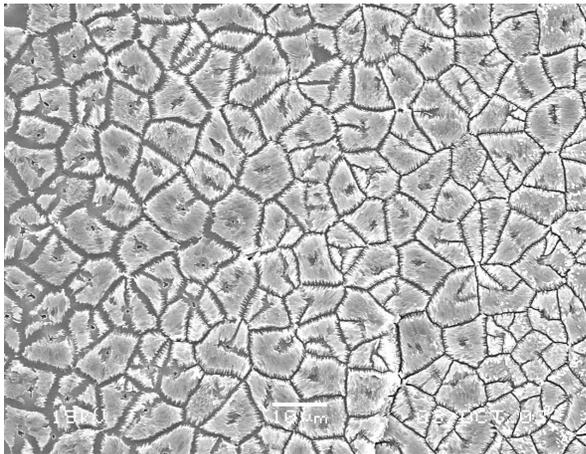


Trochus Niloticus

c-axis



Nacreous structure



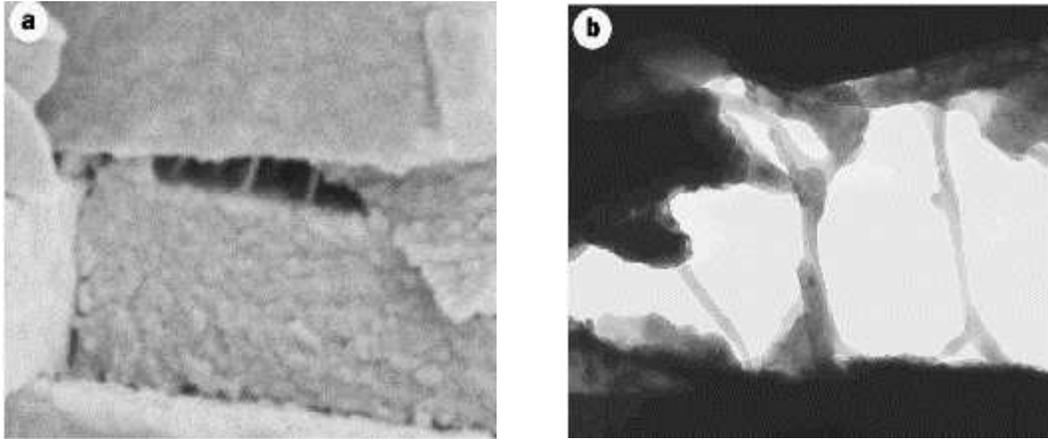
Organic Matrix

Aragonite Minerals

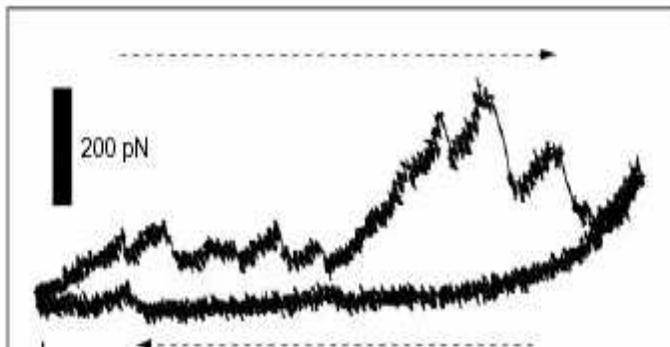
Nacre offers superior toughness

Organic Matrix in Nacre

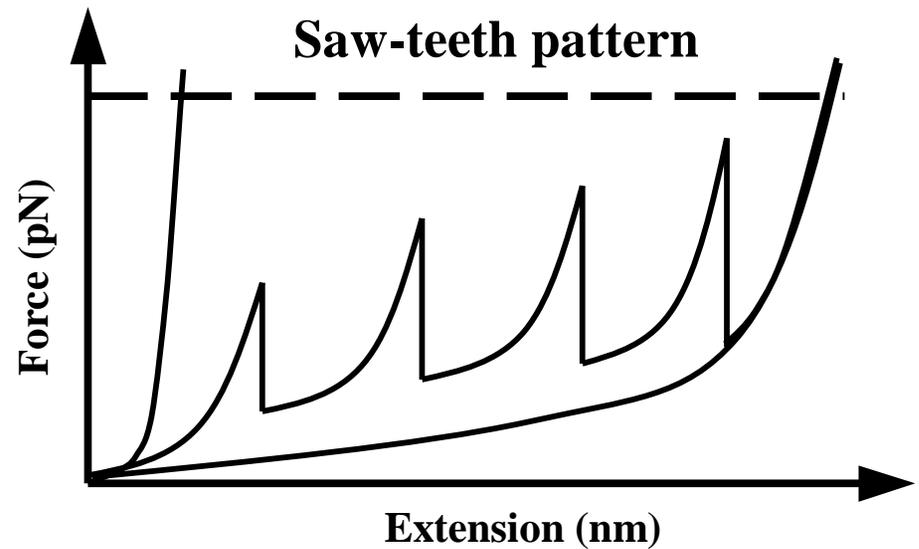
Organic Matrix in Nacre



Smith et al, Nature (1999)



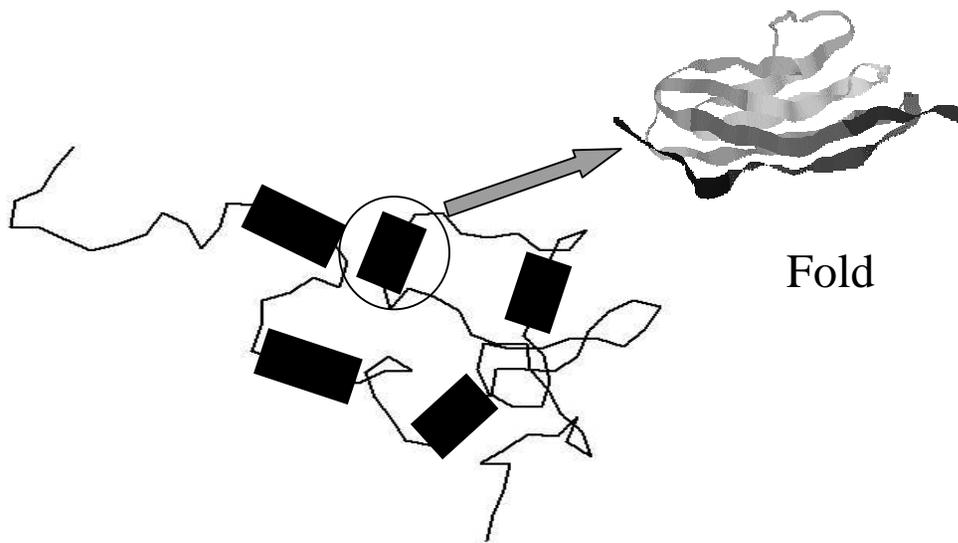
Force-extension curves of organic matrix (Smith et. al, Nature, 1999)



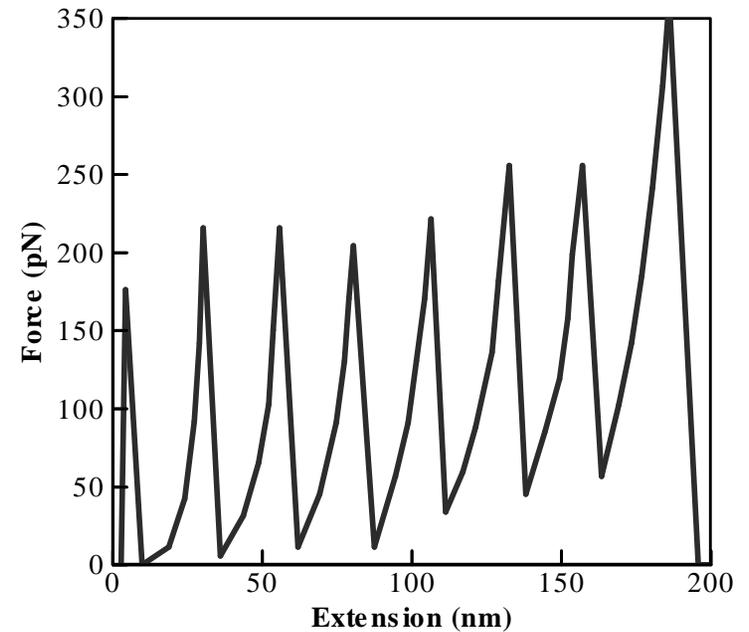
Protein Unfolding

Saw-Teeth Patterns

The saw-teeth patterns have been observed in the force-extension behavior of many loading carrying proteins, such as titin immunoglobulin, tenascin, spectrin, lustrin A...



Fold module in proteins



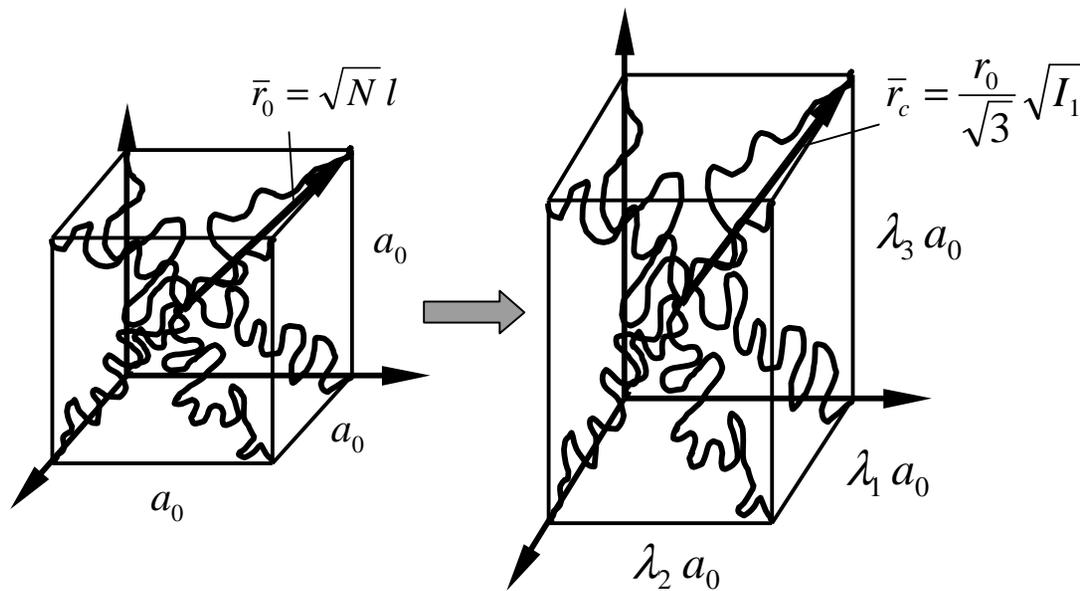
Saw-teeth pattern in titin

Protein Unfolding

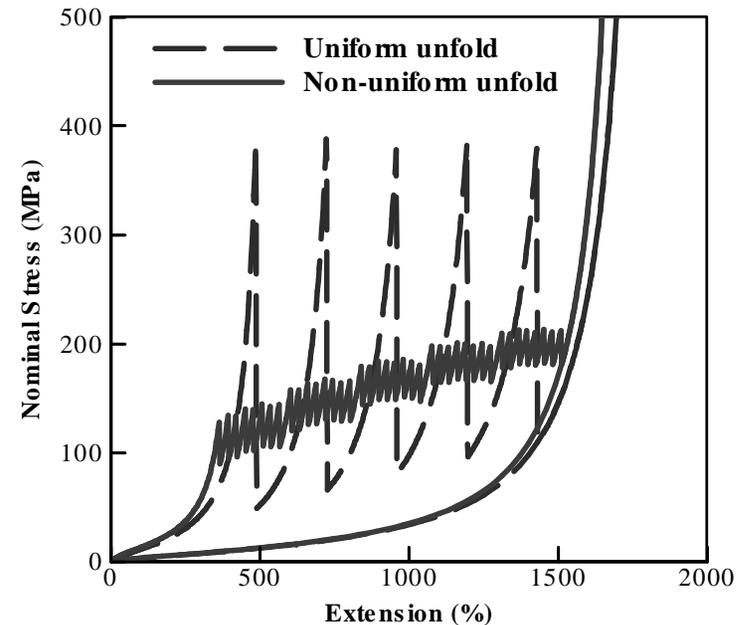
Constitutive Model of biological materials containing folding modules:

2D Network for Membranes

3D Network for Bulk Materials

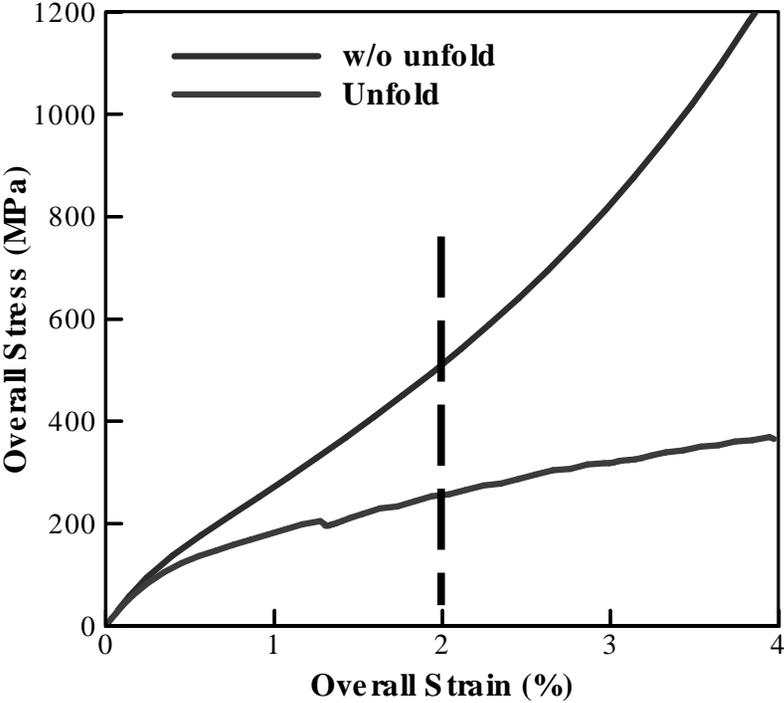
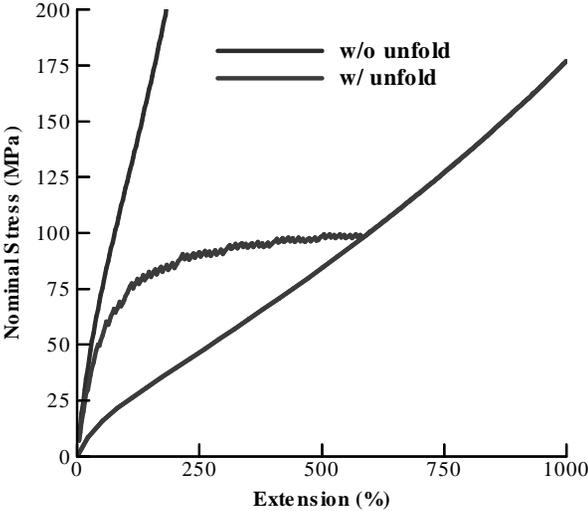
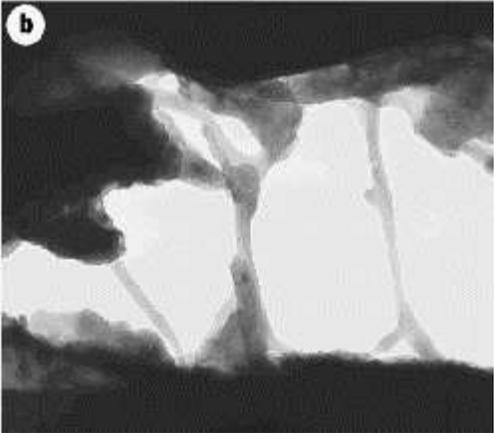
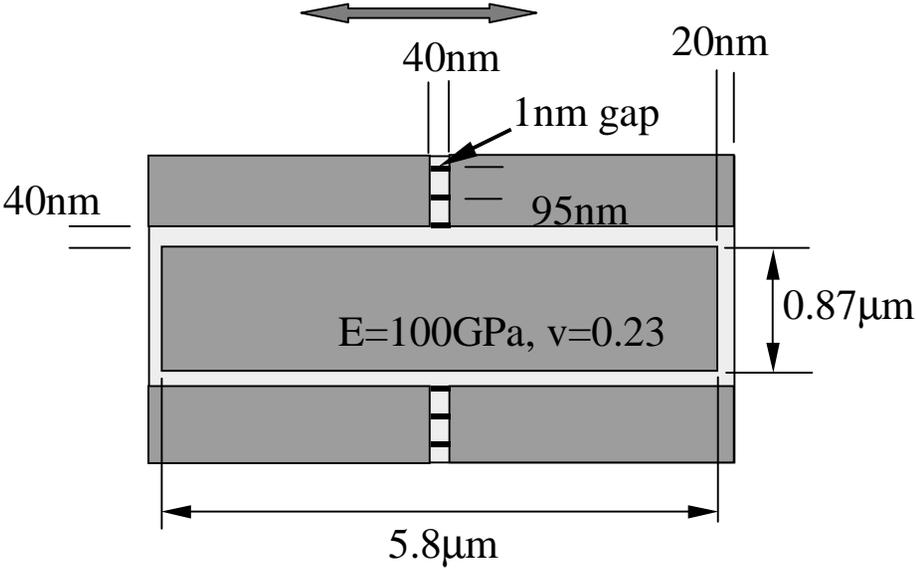


3D Network



Mechanics of Nacre

Micromechanical Modeling

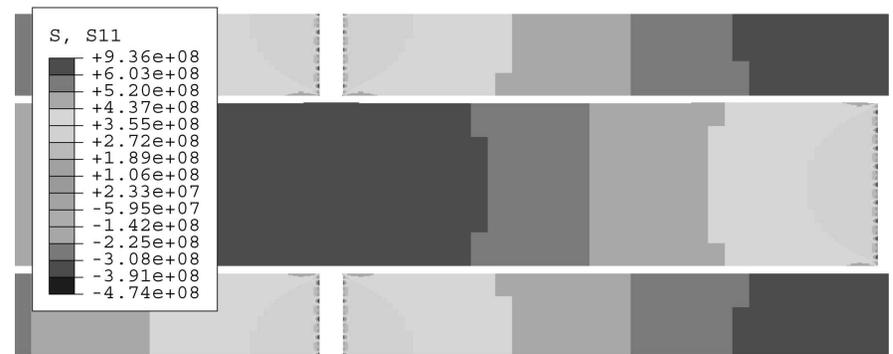


Mechanics of Nacre

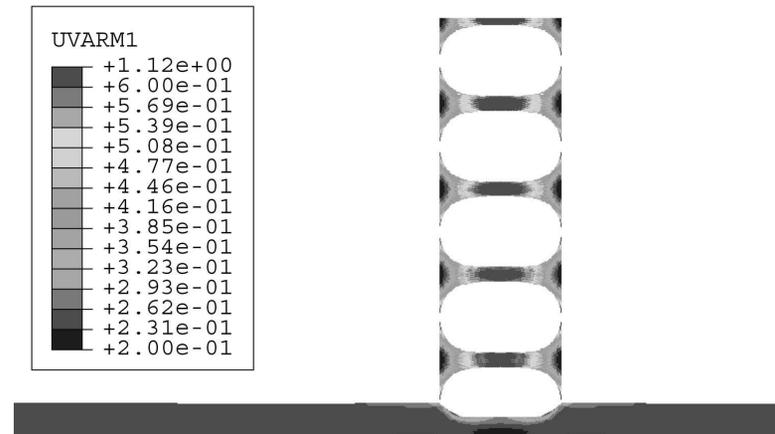
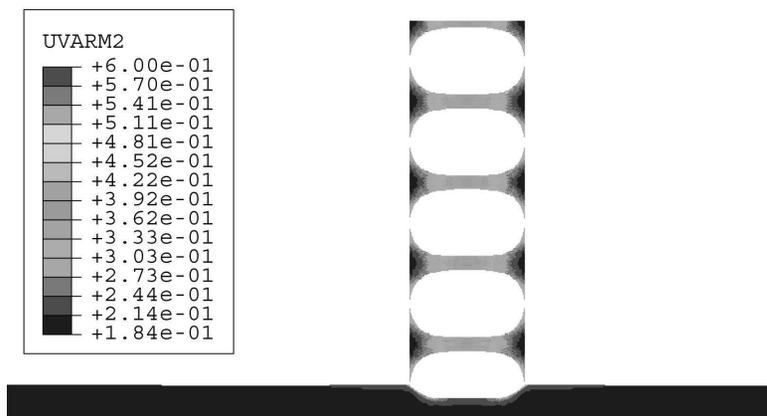
Micromechanical Modeling

With unfolding

Without unfolding



Stress component S11



Chain limiting stretch ratio

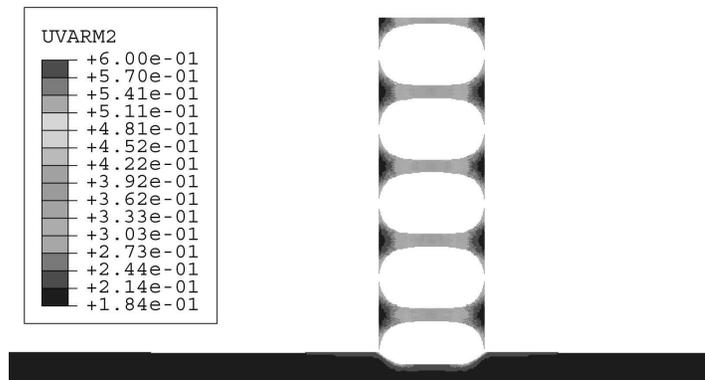
Overall strain 2%

Mechanics of Nacre

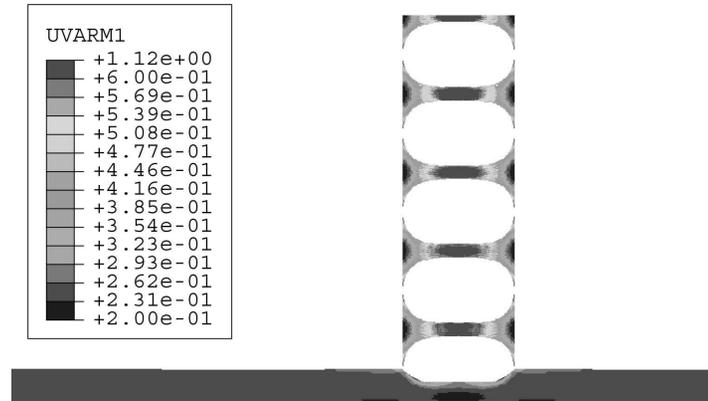
Micromechanical Modeling

Overall strain 2%

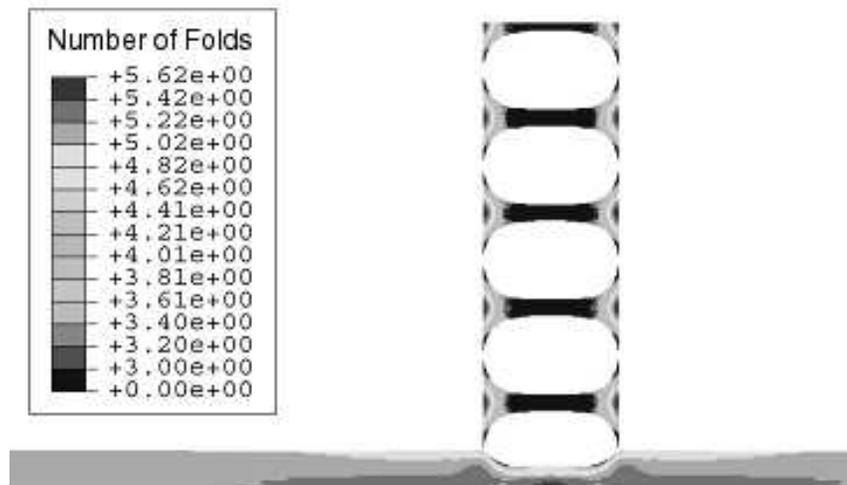
With unfolding



Without unfolding



Chain limiting stretch ratio



Challenges and Future Work

- **How does metrology affect your present work in nanomaterials?**
 - **Strongly!!**
 - **We based our constitutive model on the observations from mechanical tests at nanometer scale.**
 - **We want to see experimental results to support our model predictions.**
- **What questions relating to nanomaterials would you like to see addressed in this workshop and report/roadmap?**
 - **Mechanical property measurements of the organic matrix.**
 - **Can we measure the force-extension behavior of single lustrin A?**
 - **Can we measure/observe unfolding events in nacre and other biomaterials under different loading conditions?**
- **What metrology issues are of the most significance to you for your work in the coming 5 to 10 years?**
 - **How do mechanical properties of biomaterials affect their functions?**
 - **Can we figure out the pathway of damage propagation in highly hierarchical biological materials, such as nacre, bone? In situ?**