

Consortium
on
Smart, Tunable and Safe Well Cement
at
Rice University

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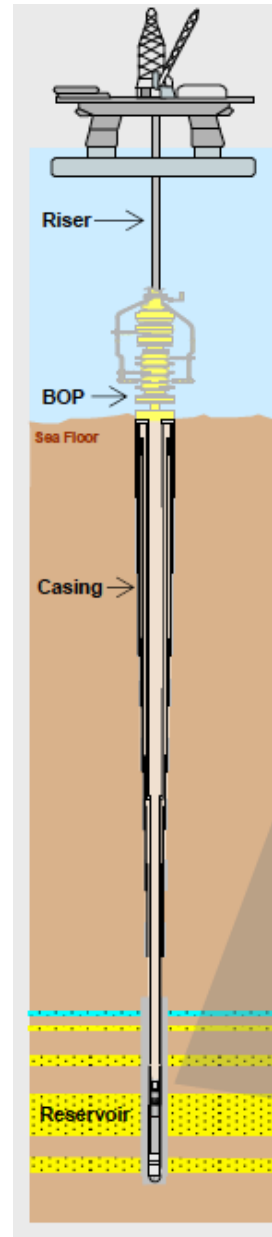


Well Cement

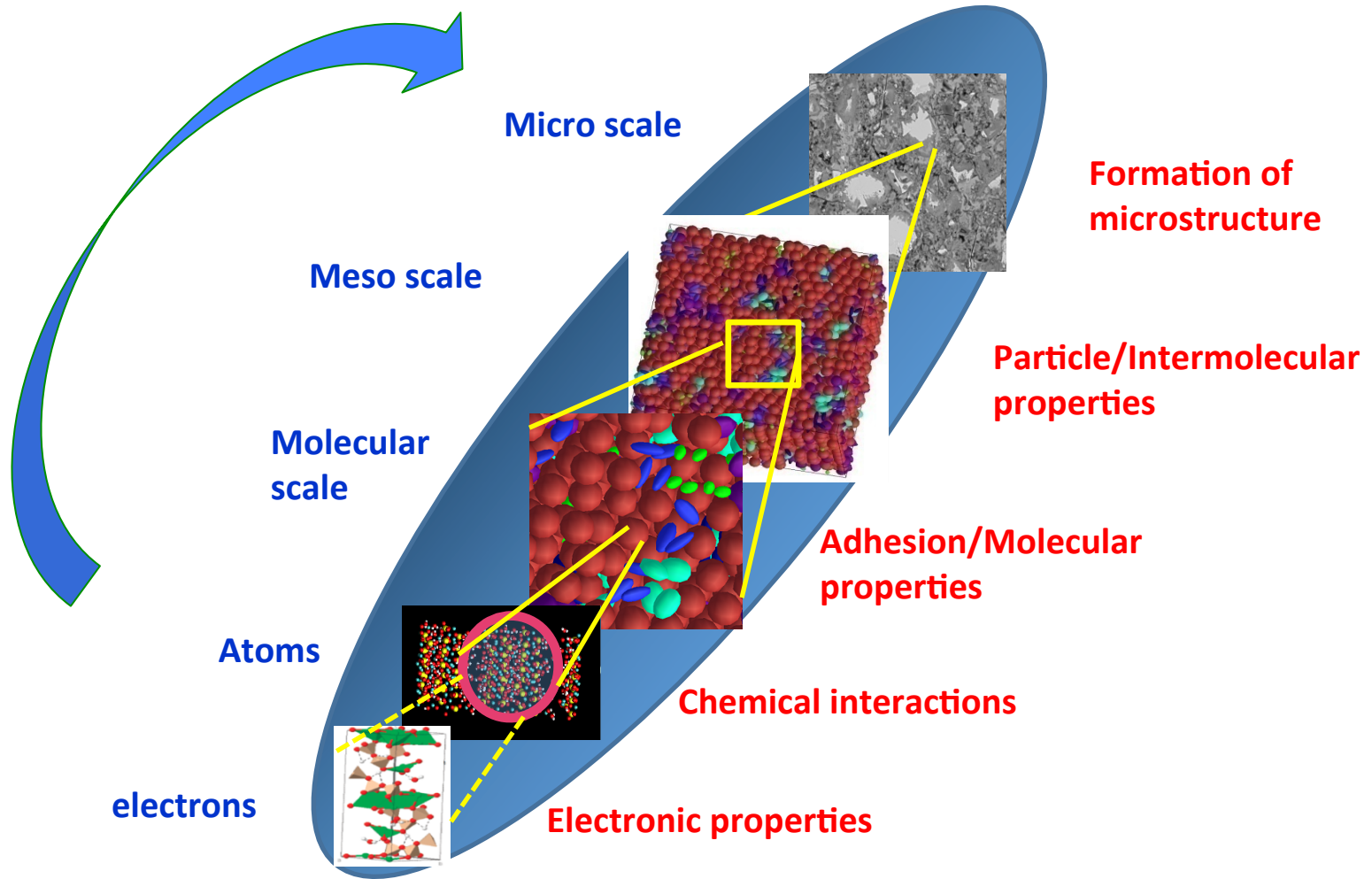
Motivation: New resources need **new technologies** and responsible development

Most commonly used well cement: class G and H

- predictable thickening time
- high sulphate resistance
- fluid loss control
- consistency
- controllable density
- low viscosity
- low free fluid
- strength, ductility



Hierarchical Structure of Well Cement



Derivatives of Well Cement

- Schlumberger CemCRETE technology
- Clacium Aluminate cement (Halliburton Themalock Cement™)
- Modified Sorel cements (e.g. BJ Magne Plus™, Baker Hughes Magne Set™)
- Foamed cements (e.g. Halliburton AquaSeal™)
- Storable oil well cement (e.g. BJ liquid stone™)
- Microfine cements
- Expansive cement
- Mud-to-cement conversion technologies

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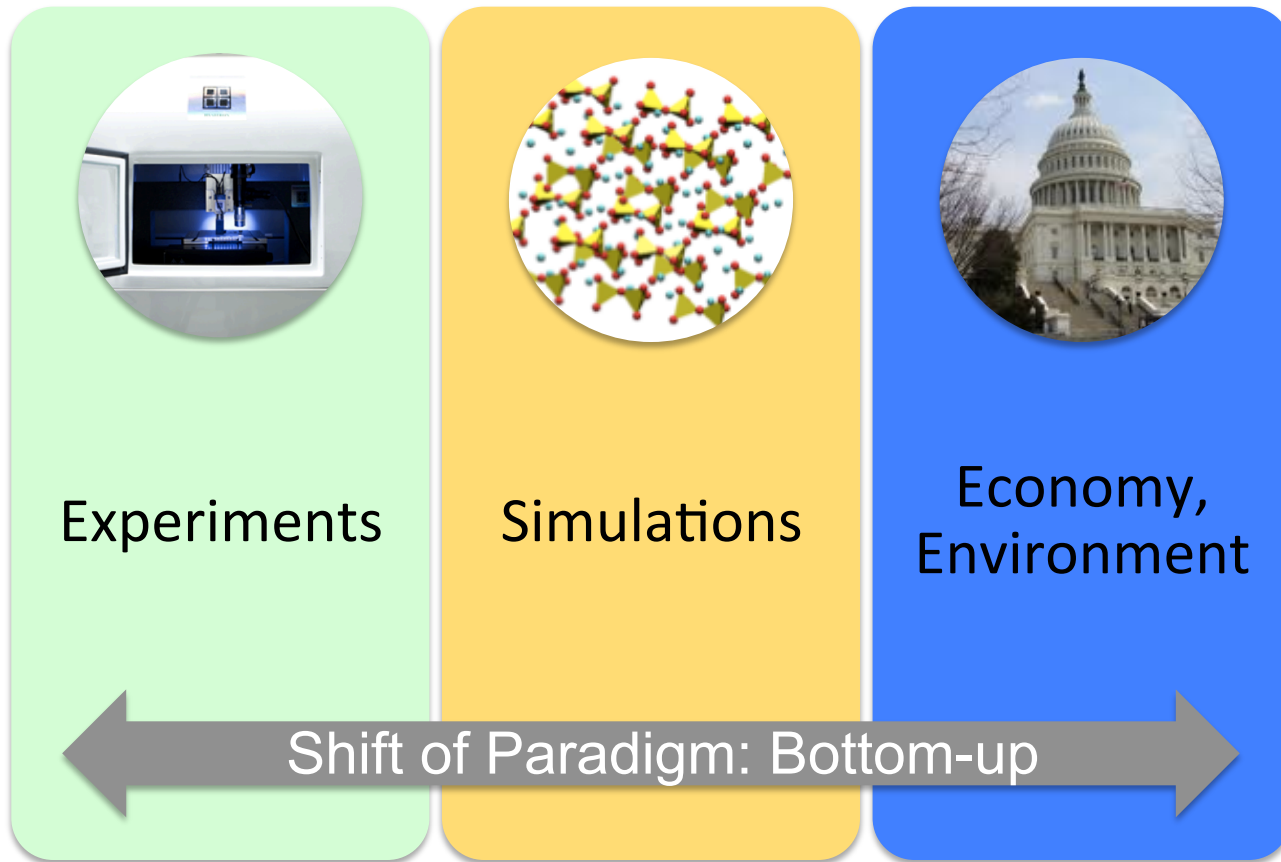
All based on empirical methods and trial and error approaches

Objective

A bold approach to create a multidisciplinary consortium on Smart, Tunable and Safe Well cement, starting from the genesis of cement.

- **Why:** New conventional, unconventional and deep water resources need new technologies; environmental blight in well cementing= threat (e.g. 2010 Gulf of Mexico)
- **What:** Form a comprehensive platform integrating **computations**, **experiments** and **socioeconomics** for smart and safe design of well cement
- **Where:** Centered at Rice University with support of local and international companies
- **When:** 2015-2020
- **Who:** Led by Rice with support from service companies and oil and gas producers
- **How:** A consortium to engage industry participation and support

The Three Trusts of the Consortium



World-Class Team at Rice

Rouzbeh Shahsavari
(Civil Eng, Materials Science)



Design, Multiscale
Computations

James Tour
(Chemistry)



Polymer-cement
composites, organic
chemistry (**among the
most cited chemists in
the world**)

George Hirasaki
(Chemical Eng)



Surfactant/foam
transport, Fluid-solid
interactions, EOR

Pulichel Ajayan
(Material Science)



Design, synthesis and
assembly of novel
nanoscale materials



Kenton Whitemire
(Chemistry)



Inorganic chemistry,
NMR, TEM

Ken Medlock
(Economics & Public Policy)



Cost-effectiveness, public issues

Andy Barron
(Chemistry)



Synthesis, characterization corrosion
(hallow ceramics propants)

Satish Nagarajaiah (Civil Eng)



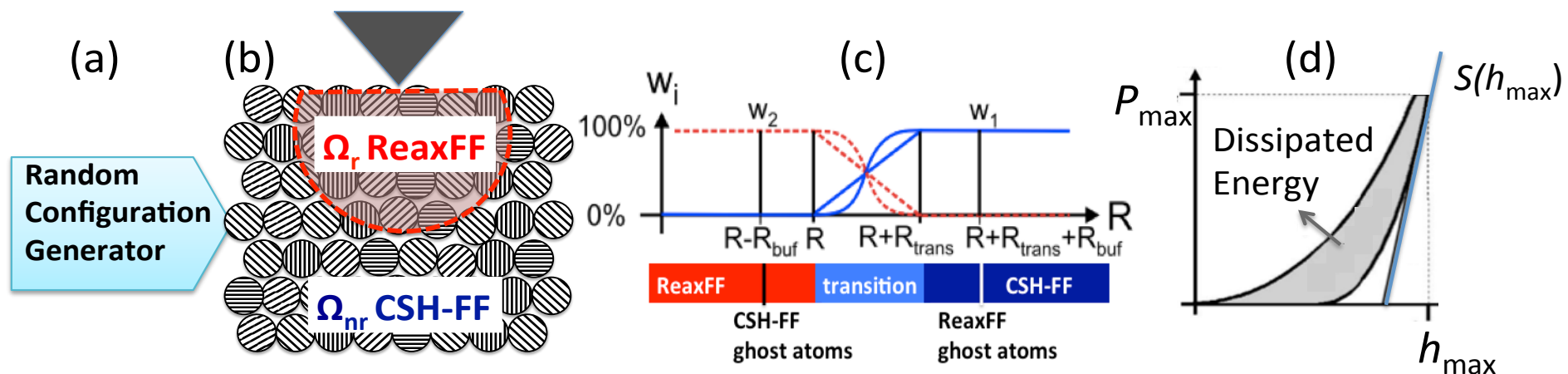
Smart structures,
control, sensing

Example 1

Tuning Chemo-mechanics of Well Cement via Computations

Computations: Rapid Screening of Properties

Computational nanoindentation predicts Stiffness, Strength, Toughness



- Providing guiding hypotheses for experiments
- Eliminating/minimizing the empirical trial and errors
- Expediting discovery of new materials

Example 2

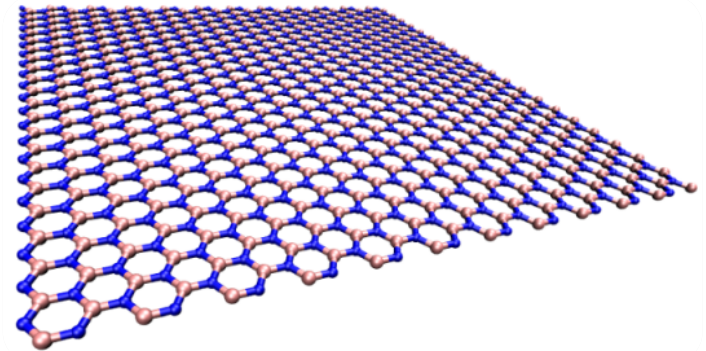
Multifunctional Boron Nitride Cement Composites

Multifunctional Cement Composites

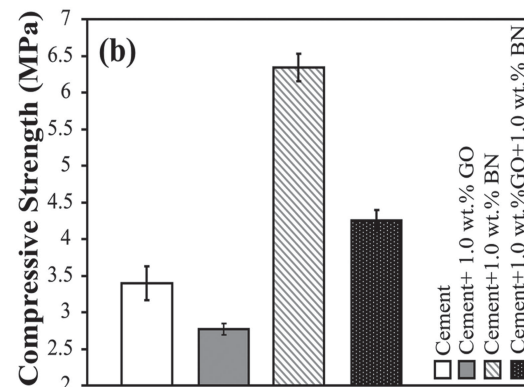
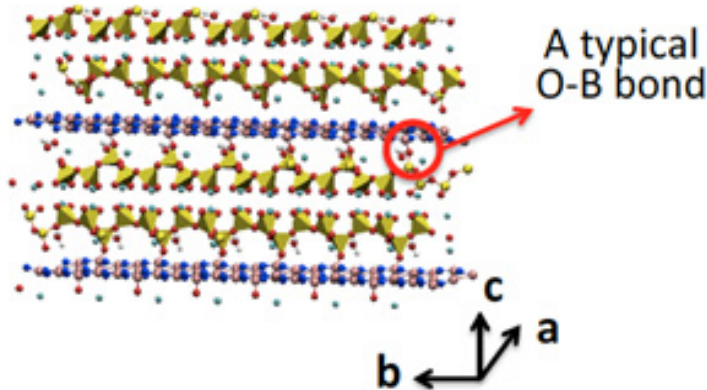
Multifunctional Additives (Boron Nitride)

- Super thermal conductive
- Super hydrophobic
- Mechanical Strong and Stiff
- Thermally stable up to 1100 °C
- Self-sensing

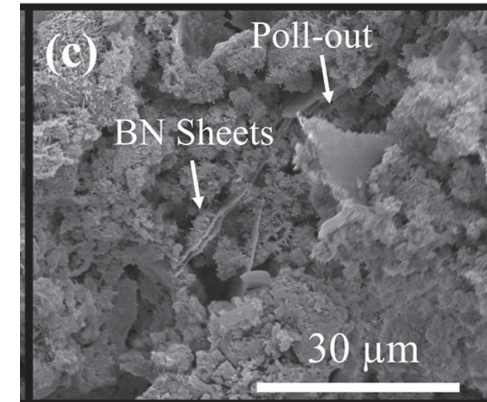
Emerging 2D nanosheets
Quantum confinement effect



Computations



Experiments



Example 3

Optimizing Microstructure Topology and Heterogeneity

Topology & Heterogeneity optimization

Example: Cantilever beam

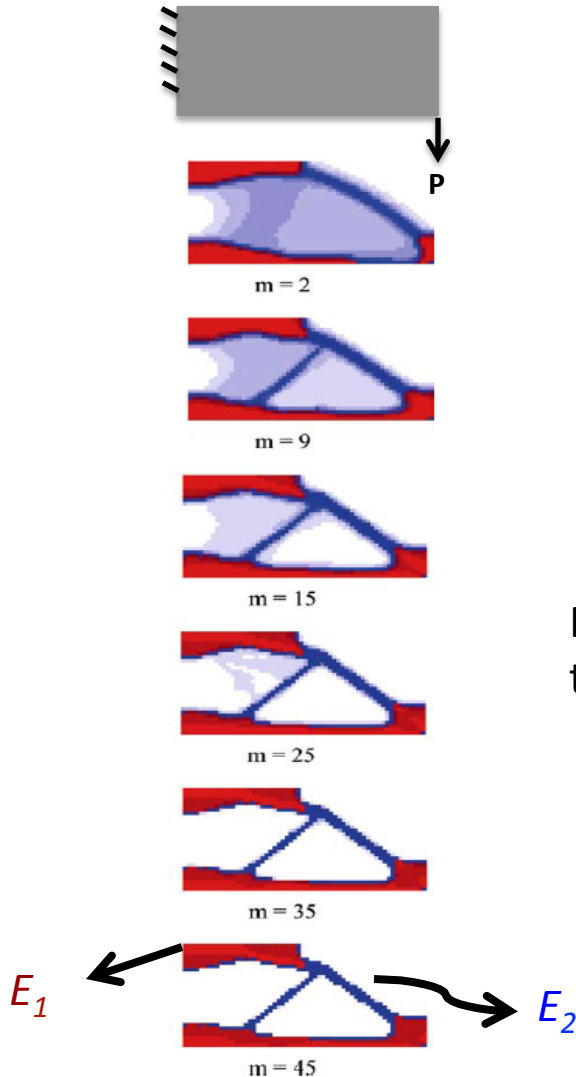
Example: What is the optimum design of a cantilever beam with two materials ? $E_1 = 20 E_2$

Modern topology optimizations by phase field method from theory of phase transitions in materials science:

$$J(u, \Omega) = - \int_{\Omega} F(u) d\Omega = -\beta \int_{\Omega} C \varepsilon(u) \cdot \varepsilon(u) d\Omega - \gamma \int_{\Omega} |\sigma(u)|^2 d\Omega$$

$$L_{\varepsilon}(u, \theta) = - \int_{\Omega} F(u, \theta) dx + \varepsilon \mu \int_{\Omega} \varphi |\nabla \theta(x)| dx + \frac{\eta}{\varepsilon} \int_{\Omega} W(\theta(x)) dx + \lambda^T G(u, \theta)$$

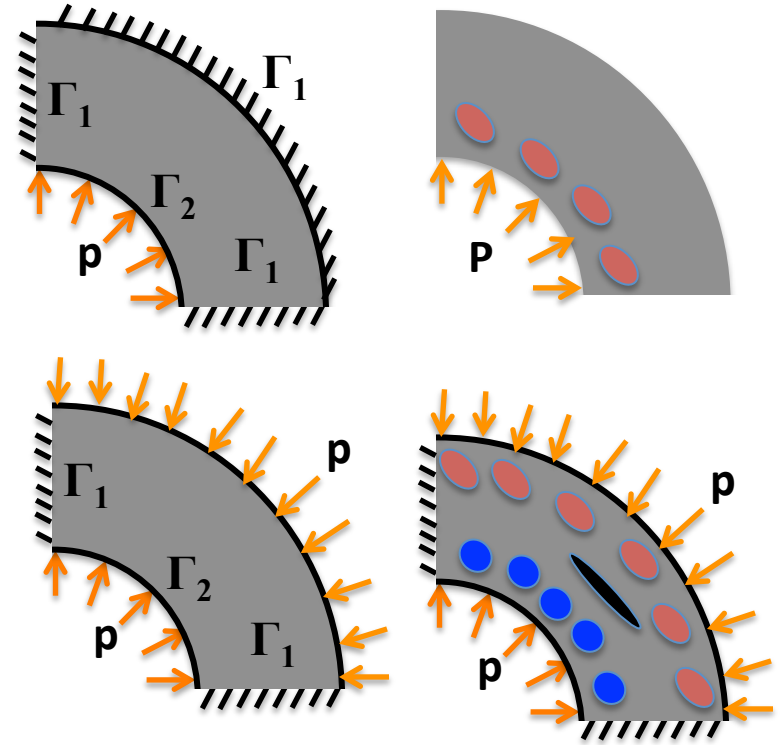
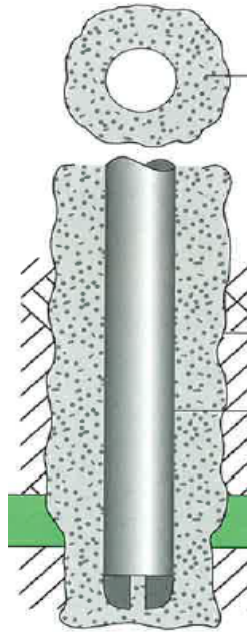
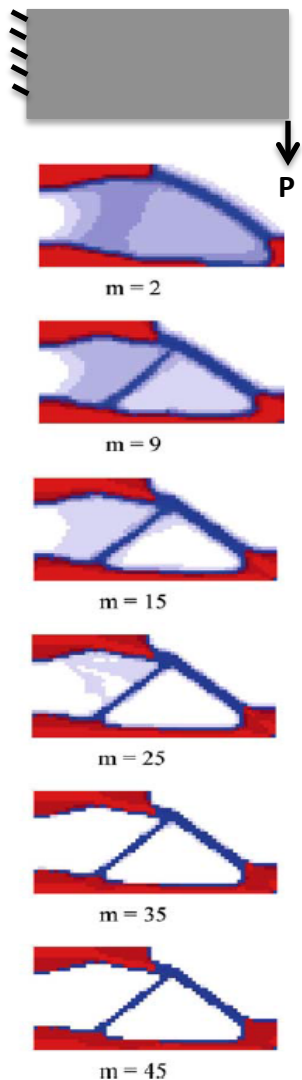
$$F'(u) - \varepsilon \mu \operatorname{div}[\nabla \theta \varphi'(|\nabla \theta|)/|\nabla \theta|] + \frac{\eta}{\varepsilon} W'(\theta) + \lambda^T G' = 0 \text{ for } x \in \Omega; \quad \text{and} \quad \frac{\partial \theta}{\partial n^+} = 0 \text{ on } \partial \Omega$$



Topology & Heterogeneity optimization

Example: Cantilever beam

Maximizing Ductility and Strength

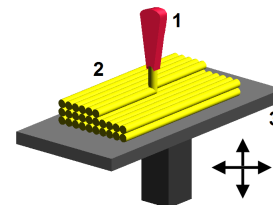
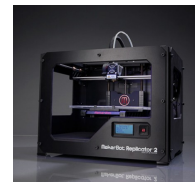


-3D Printing and Laboratory Testing

Use of block copolymers (hydrophobic + hydrophilic) to segregate phases

-Coating Steel Casing

-Applying voltage



Take Home Ideas

- Integrating experiments and simulations from the molecular level up is the most promising approach for breakthrough technologies in well cementing and well integrity
- The Rice University's Consortium on well cementing is based on the **state-of-the-art Experiments, Simulations and Socioeconomics** to provide a **system approach** for developing smart and safe well cement
- If you need further information about joining this consortium, please contact Dr. Rouzbeh Shahsavari (rs28@rice.edu)