TRANSLATIONAL RESEARCH IN MECHANICS AND MATERIALS

WITH EMPHASES ON SUSTAINABILITY AND DURABILITY

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INTRODUCTION

TRANSLATIONAL RESEARCH

SUSTAINABILITY

NANO S&E

MULTISCALE-SCALE SYSTEMS

SUMMARY & ACKNOWLEDGMENTS

REFERENCES

A 21st Century World

Information Explosion

Global Economy

Cognitive Revolution

International Competition

Diverse Workforce

Finite Resources
Energy

Defense Reinvestment

Environmental Sustainability

International Collaboration

Random Violence

Demographic Shifts

Civil and Mechanical Infrastructure

Bridges – More than 600,000 in U.S.

Pipelines – 2 million miles of natural gas lines in U.S.

Commercial Aircraft – 9,000 in use in U.S.

Wind Turbines – 21,000 MW capacity in the U.S.

Civil Infrastructure Systems Research: Strategic Issues

national science foundation

NSF 93-5
K. P. CHONG, Task Group Chair

CIS major recommendations

1. Deterioration Science – examines how materials and structures break down and wear out over time;
2. Assessment Technologies – determine how durable, safe and environmentally benign the (building) structures are;
3. Renewal Engineering – extend and enhances the life of CIS and components;
4. Institutional Effectiveness and Productivity – decision processes on the CIS on the economic and productivity issues.

WTEC Support of Simulation-Based Engineering & Science Study

- 2007. Initiated by Ken Chong at NSF; two-dozen program officers participate
- 2009. International study: Glotzer & Kim, 59 sites studied abroad.
- 2010. Research Directions Workshop: Cummings & Glotzer
- 2011. On June 24 Obama Administration announces Materials Genome Initiative (MGI) citing SBES results

INTRODUCTION
TRANSLATIONAL RESEARCH
SUSTAINABILITY
NANO S&E
MULTISCALE-SCALE SYSTEMS
SUMMARY & ACKNOWLEDGMENTS
REFERENCES

Translational Research

- Is interdisciplinary by nature
- Involves a team usually
- Relies on partnerships
- Results in clear benefit to society

9

A Modified Pasteur's Quadrant

(derived from http://en.wikipedia.org/wiki/Pasteur's_Quadrant)

Applied, Basic and Translational research

fundamental understanding?	**Yes**	Pure basic research (**Bohr**)	Use-inspired basic research (**Pasteur**) Multidiscipline translational research **(Smalley, Gao)**
	No	Incremental applied research	Pure applied research (**Edison**)
		No	**Yes**
		Considerations of use?	

MODIFIED BY K. P. CHONG

Some examples of advances initiated by NSF funding

- Computer-aided design (CAD)
- Microelectromechanical systems (MEMS)
- Fiber optics
- Tissue engineering
- Doppler radar
- The Internet
- MRI/NMR
- Thin films; electronic materials
- 187 Nobel laureates

INTRODUCTION
TRANSLATIONAL RESEARCH
SUSTAINABILITY
NANO S&E
MULTISCALE-SCALE SYSTEMS
SUMMARY & ACKNOWLEDGMENTS
REFERENCES

SUSTAINABILITY

Definition of Sustainability: development that meets the needs of the present without compromising the ability of future generations to meet their own needs" -- [the Brundtland Commission, 1983, 'Our common futures"]

According to ASCE, "a sustainable civil infrastructure provides environmental, economic, and social well-being now and for the future."

Impact on U.S. Economy

- In the U.S., construction and building is a $1.2 trillion per year industry, represents 5 percent of the gross domestic product, and employs nearly 12 million workers
- The construction industry directly affects as much as 12 % of the U.S. economy when mfg. of construction materials and components, building contents and furnishings, and renovation and maintenance are included
- Buildings represent the single largest end-user of energy (40%) and electricity (72%) and contributor of carbon dioxide emissions (39%) when compared with the transportation and industrial sectors
- Other challenging areas are: energy, air & water polution, smart grids, climate change, carbon footprint,…

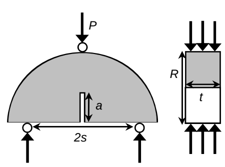
ASCE 2009 Report Card

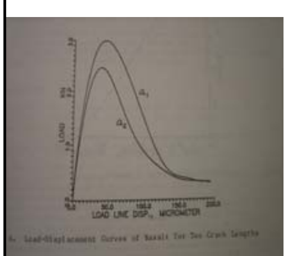
Aviation	D
Bridges	C
Dams	D
Drinking Water	D-
Energy	D+
Hazardous Waste	D
Inland Waterways	D-
Levees	D-
Public Parks & Recreation	C-
Rail	C-
Roads	D-
School	D
Solid Waste	C+
Transit	D
Wastewater	D-

Civilian Infrastructure -- $2.2 T

Military Infrastructure -- $0.5 T

Semi-Circular Bend Specimen





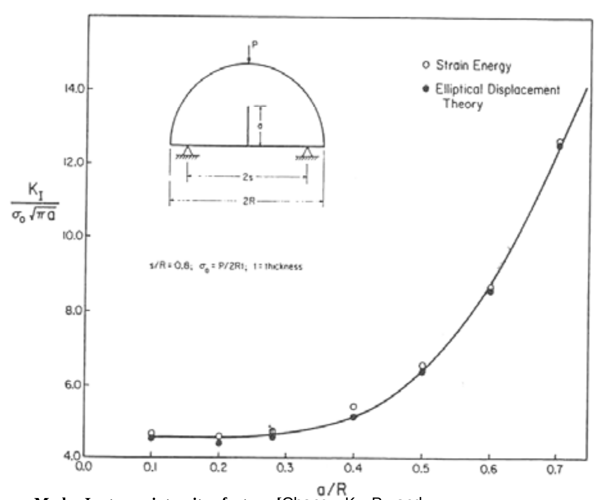
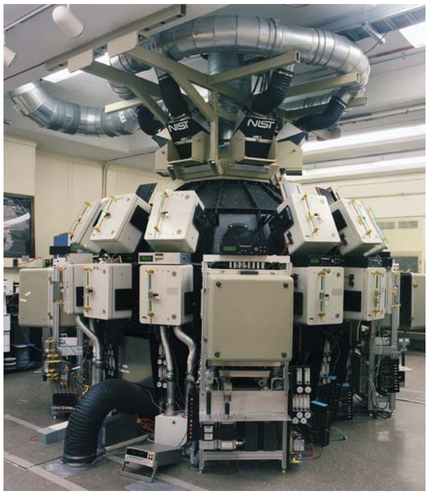


Figure. Mode I stress intensity factor. [Chong, K. P. and Kuruppu, M. D. 1984. New specimen for fracture toughness determination of rock and other materials, *Int. J. fracture*, V 26, R59-R62.]

Integrating Sphere-based UV Chamber



NIST SPHERE

- **Simulated Photodegradation via High Energy Radiant Exposure**
- **2 m integrating sphere**
- **8400 W UV → 22 "SUNS", 24/7**
- **95% exposure uniformity**
- **Visible and infrared radiation removed**
- **Temperature and relative humidity around specimens precisely controlled**
- **Capability for mechanical loading**

- **Martin and Chin, U.S. Patent 6626053**
- **Chin et al, Review of Scientific Instruments, 75(11), 4951-4959, 2004.**

Key *Drivers* for Change in Construction

- Energy independence, environmental security, and sustainability
- Renewal of Nation's aging physical infrastructure
- Demand for better quality, faster, and less costly construction
- Competition due to globalization and offshoring
- Homeland security and disaster resilience

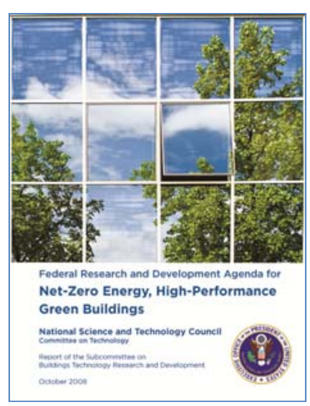
NRC Identified Activities with Potential for Breakthrough Improvements

- Widespread use of interoperable technology applications and Building Information Modeling (BIM)
- Improved job-site efficiency through more effective interfacing of people, processes, materials, equipment, and IT
- Greater use of prefabrication, preassembly, modularization, and off-site fabrication and processes
- Innovative demonstration Installations
- Effective performance measures to drive efficiency and support innovation

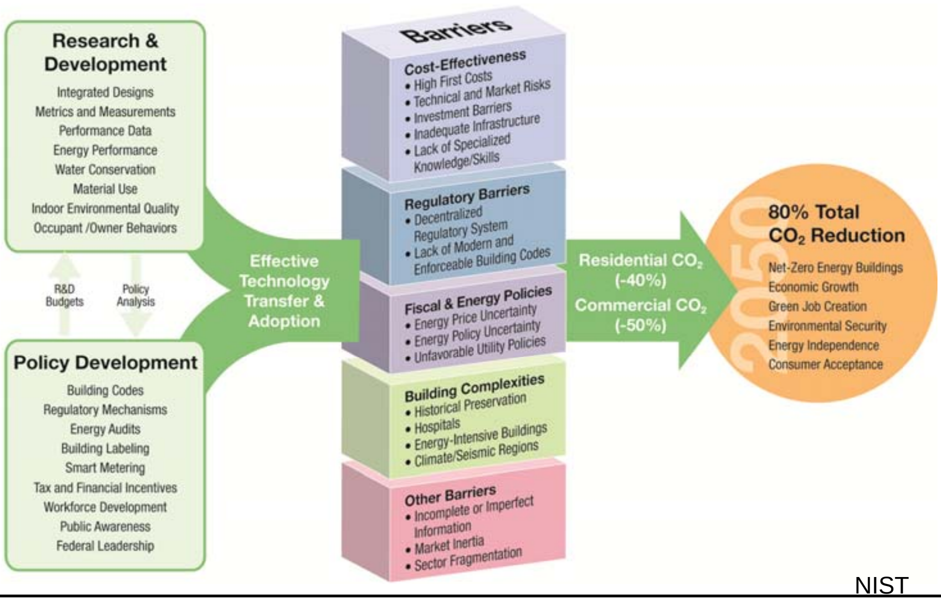
Federal R&D Agenda

- Integrated, Performance-Based Design and Operation
- Net-Zero Energy Building Technologies and Strategies
- Water Use and Rainwater Retention
- Material Utilization, Waste, and Life Cycle Environmental Impacts
- Occupant Health and Performance
- Overcoming Barriers to Implementation

The scope of this report is limited to R&D on new technologies, protocols, and practices at the building site, unless they apply as well to groups of buildings or communities.

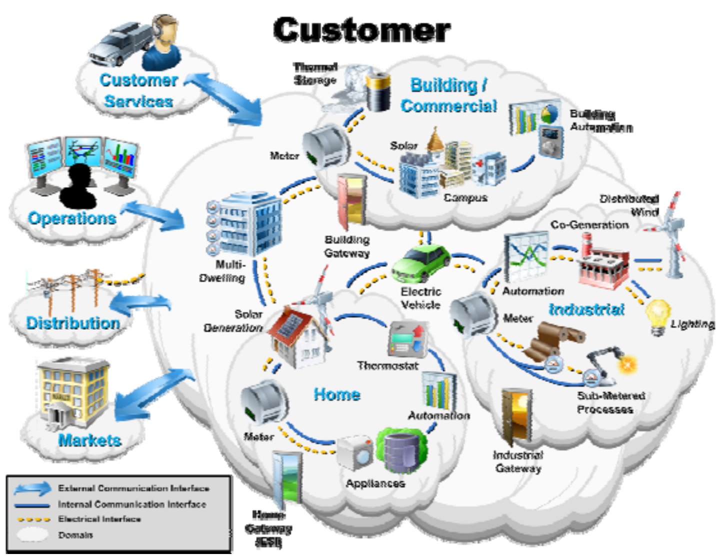


Policy Framework



NIST

Energy Efficient, Smart Buildings Critical to Smart Grid Success



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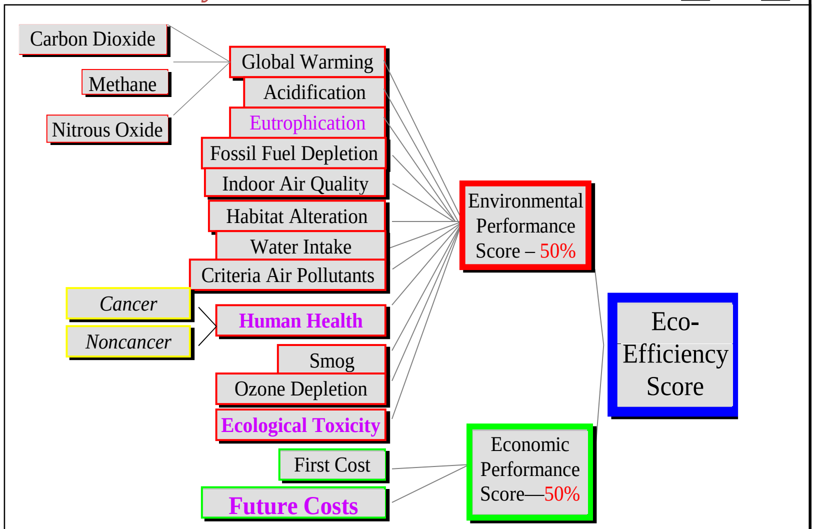
Sustainability Decision Tool: BEES 4.0 Model



NIST

BEES = Building for Environmental and Economic Sustainability

Steven Chu

- "There's a friend of mine, …Art Rosenfeld, who's pushing very hard for …and that's when you have a flat-top roof building, make it white…and if you make the pavement more of a concrete type of color rather than a black type of color… it's the equivalent of reducing the carbon emissions due to all the cars on the road for 11 years."

100m^2(~1000 ft^2) of a white roof, replacing a dark roof, offset the emission of 10 tonnes of CO_2

25

Strategic Research Needs in the Construction Area

- **Workers Safety and Health during Construction.**
- **Energy Efficient and High Performance Facilities.**
- **Construction Productivity Improvement Techniques**
- **Robotics & Automation and Rapid Prototyping.**
- **Advanced Visualization Technique.**
- **Automated Data Acquisition and Management.**
- **Virtual Project Management Techniques.**
- **Real Time Construction Site Monitoring and Management Technologies.**
- **Revitalization and Urban Redesign.**
- **Integrated Supply Chain Management.**

R. Kangari, Georgia Tech

Success Story

Totally Automated Building Construction

Benefits:

- Innovative Construction Technologies
- Innovative Materials
- Low Cost, High Quality, Speed
- Construction Productivity Improvement Tech
- Workers Safety During Construction

By: Professor R. Kangari, Georgia Tech

Success Story

Real Time Data Management in Construction

Benefits:

- Effective Management by Real Time Construction Site Monitoring Tech
- Lower Cost by Integrated Supply Chain Management
- Higher Productivity through Automated Data Acquisition and Management
- Lower Cost by Virtual Project Management Tech

By: Professor R. Kangari, Georgia Tech

Success Story

Automated Construction Equipment

Benefits:

- Improved Workers Safety and Health
- Higher Productivity, and Speed
- Effective Management by Real Time Construction Site Monitoring Tech
- Higher Productivity through Automated Data Acquisition and Management
- Lower Cost by Virtual Project Management Tech

By: Professor R. Kangari, Georgia Tech

INTRODUCTION
TRANSLATIONAL RESEARCH
SUSTAINABILITY
NANO S&E
MULTISCALE-SCALE SYSTEMS
SUMMARY & ACKNOWLEDGMENTS
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NSF/WTEC benchmarking with experts in over 20 countries

"Nanostructure Science and Technology"

Book Springer, 1999

Nanotechnology

is the ***control and restructuring of matter*** at dimensions of roughly 1 to 100 nanometers

where new phenomena

enable new applications.

M.C. Roco, NSF, 2008

NNI SIGNATURE INITIATIVES

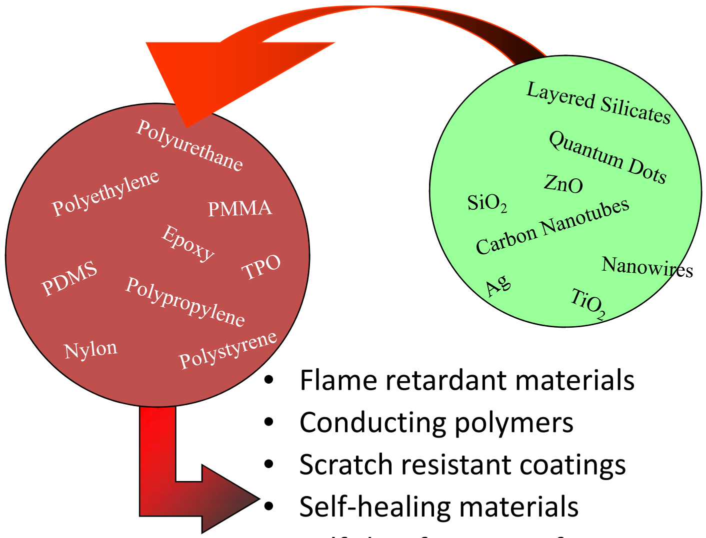
nano-electronics

nano-mfg.

nano-solar

Polymer Nanocomposites

NIST

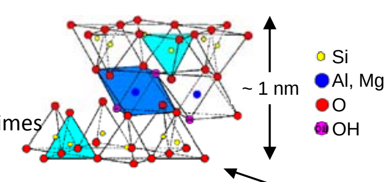


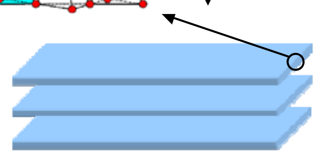
- Flame retardant materials
- Conducting polymers
- Scratch resistant coatings
- Self-healing materials
- Self-disinfecting surfaces…

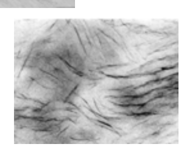
Nano-Clay Filled Polymers

NIST

- Certain types of clay naturally form platelet structures
  - Thickness just less than 1 nm
  - High aspect ratios
    - Lengths and widths are 25 to 2000 times the thickness
  - Gallery spacing between platelets between 1.5 nm and 2 nm
    - Contain cations for charge balance
      - Hold platelets together
- Use of just 1% to 5% by volume can dramatically alter material behavior
  - Properties related to flammability improved
  - Mechanical properties improved
  - Improvements often depend on ability to separate and disperse platelets
    - Organic treatment needs to be thermally stable.

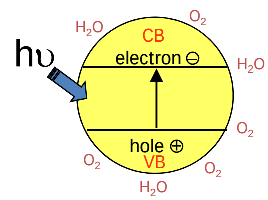






Metal Oxide Nanoparticles in Coatings

- TiO_2 and ZnO used in nanosize forms in sunscreens
  - Photoreactive behavior
    - Good absorbers of UV light
    - Deactivate and destroy:
      - Bacteria, viruses, fungi
      - Organic and inorganic pollutants in air and water
      - Cancer cells
    - Producing energy via photoelectrochemical cells
- Applications include:
  - "Self-disinfecting" surfaces
  - Paints and coatings with improved durability
  - Indoor air cleaners
  - Water treatment
  - Mitigation of air-borne biological agents
  - Solar cells



If charge carriers get to surface:
O_2^- superoxide
OH· hydroxyl radical
H_2O_2 hydrogen peroxide

and other activated oxygen species can be generated.

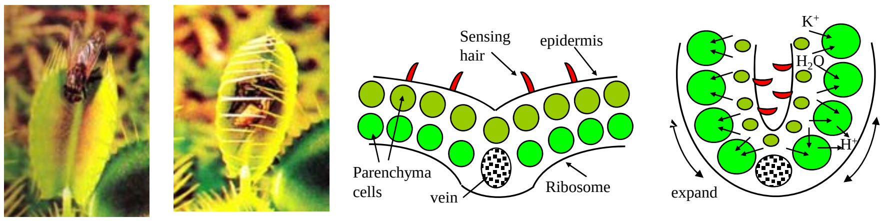
All are capable of further reaction with organic materials for good or bad

NIST

Nature-Inspired Materials

- Understanding geological and biological processes to create novel materials
  - use current theoretical and experimental approaches to understand important biological scaling laws
  - uncover fundamental future design principles for building the next generation of materials
  - harness biological and geological processes to enhance the built environment

Leaf Folding of Venus Fly Trap : smooth integration of sensing and actuation

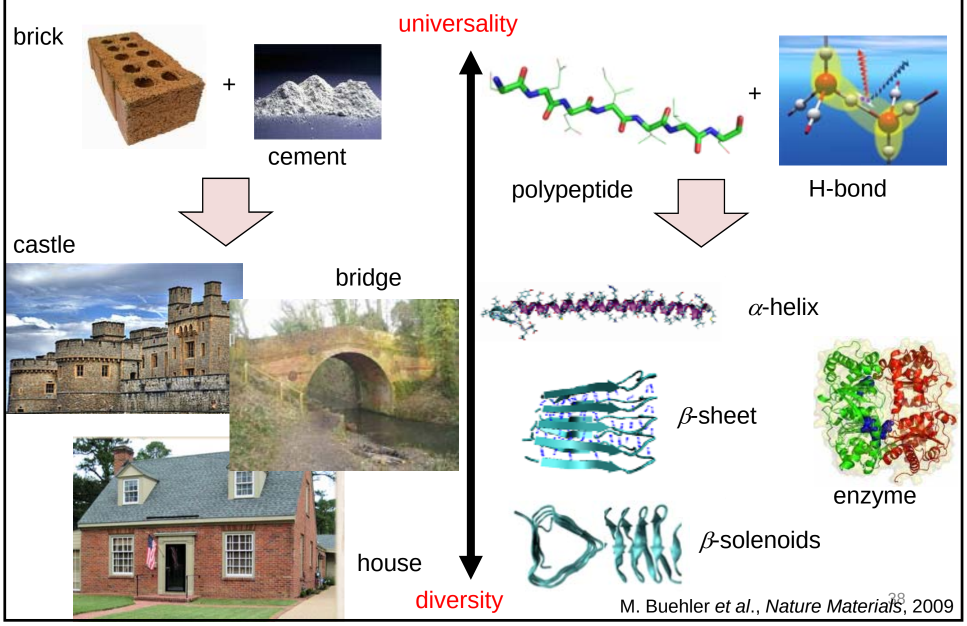


(a) (b) (c) (d)

Venus flytrap in action. When an insect touches at least two sensory hairs (a, c) the trap closes rapidly (b,d). The closure is caused by the rapid expansion growth of the outer leaf epidermis which involves ion transport (d).

Taya, 2007

Universal building blocks, diverse structures (and thus, functions)



M. Buehler *et al*., *Nature Materials*, 2009

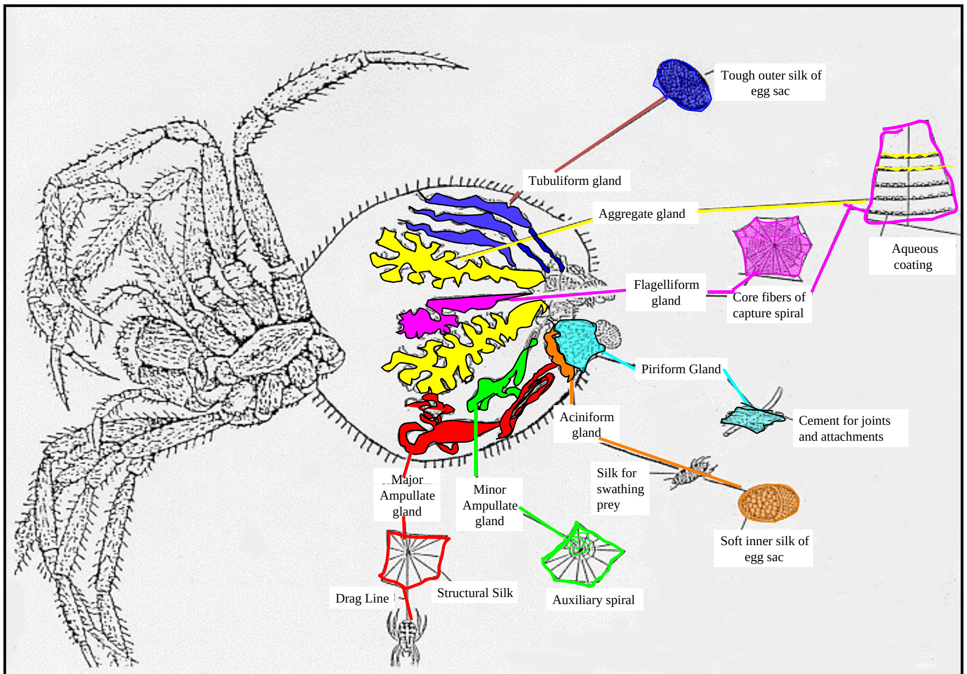


FIGURE 1. Orb-web weaving spiders have seven types of silk glands. Each type of gland produces a distinct silk for a specific function. The different silks have unique mechanical (Table 1) and chemical (amino acid compositions) properties.

What's special about spider silk?

	Material Strength ($N\ m^{-2}$)	Elasticity (%)	Energy to Break ($J\ kg^{-1}$)
Dragline Silk	4×10^9	35	1×10^5
Minor Silk	1×10^9	5	3×10^4
Flagelliform silk	1×10^9	200+	1×10^5
KEVLAR	4×10^9	5	3×10^4
Rubber	1×10^9	600	8×10^4
Tendon	1×10^9	5	5×10^3

TABLE 1. Various biological and manmade materials are listed with their strengths, elasticities, and energies to break. Note the over ten-fold increase in the energy to break of dragline silk compared to KEVLAR. This dramatic increase is due to the elasticity of dragline silk. Also note the differences in elasticity among dragline, flagelliform and minor ampullate silks.

Randy Lewis, et al; U. WYO

INTRODUCTION

TRANSLATIONAL RESEARCH

SUSTAINABILITY

NANO S&E

MULTISCALE-SCALE SYSTEMS

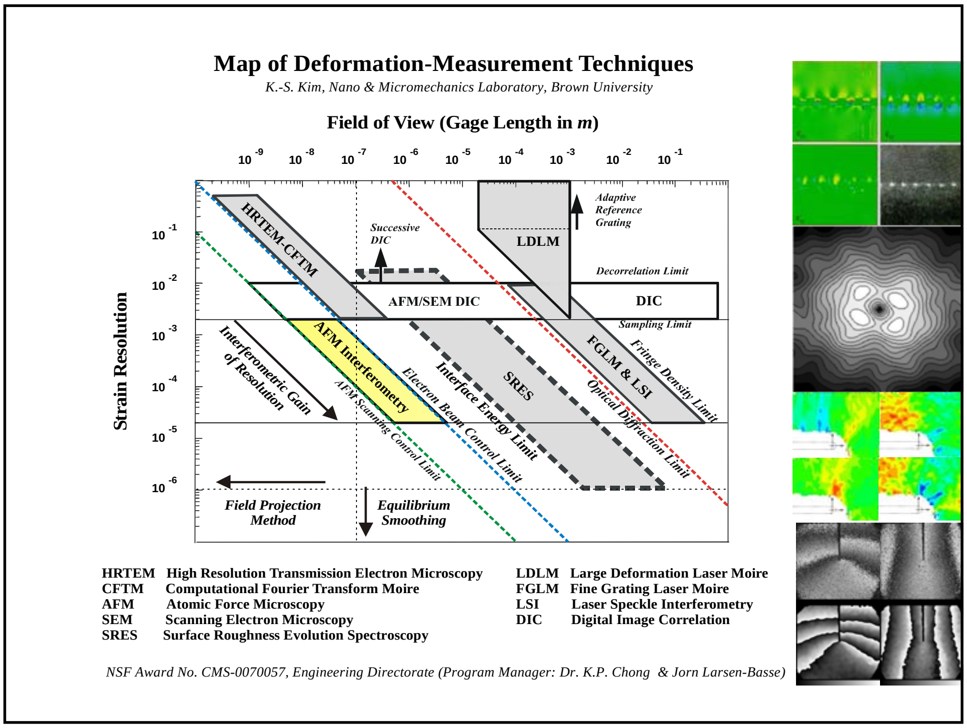
SUMMARY & ACKNOWLEDGMENTS

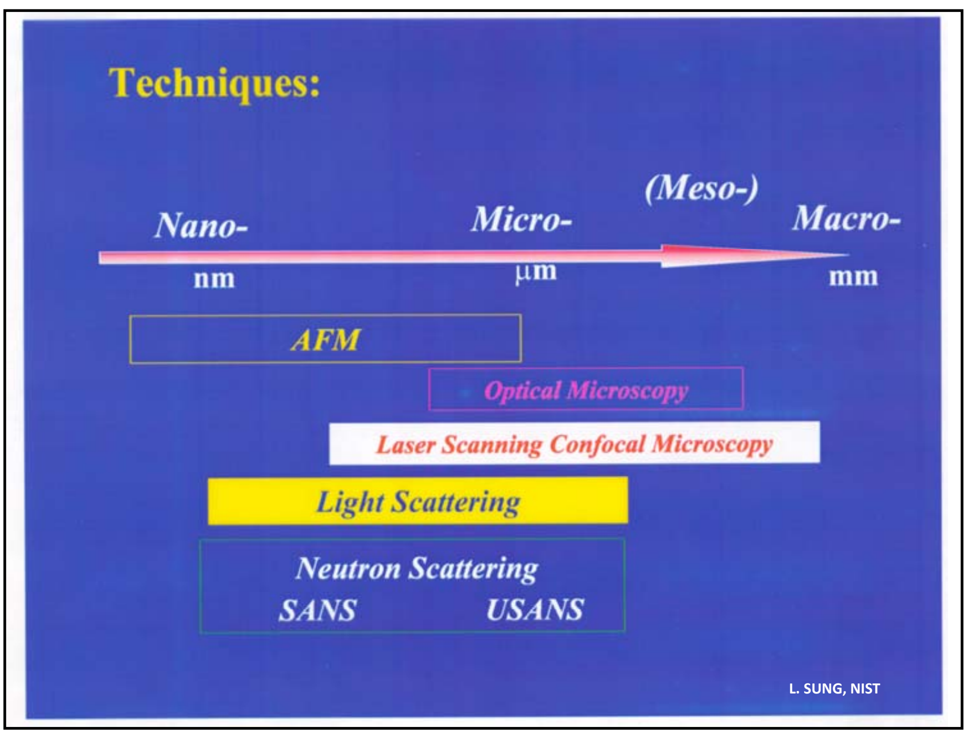
REFERENCES

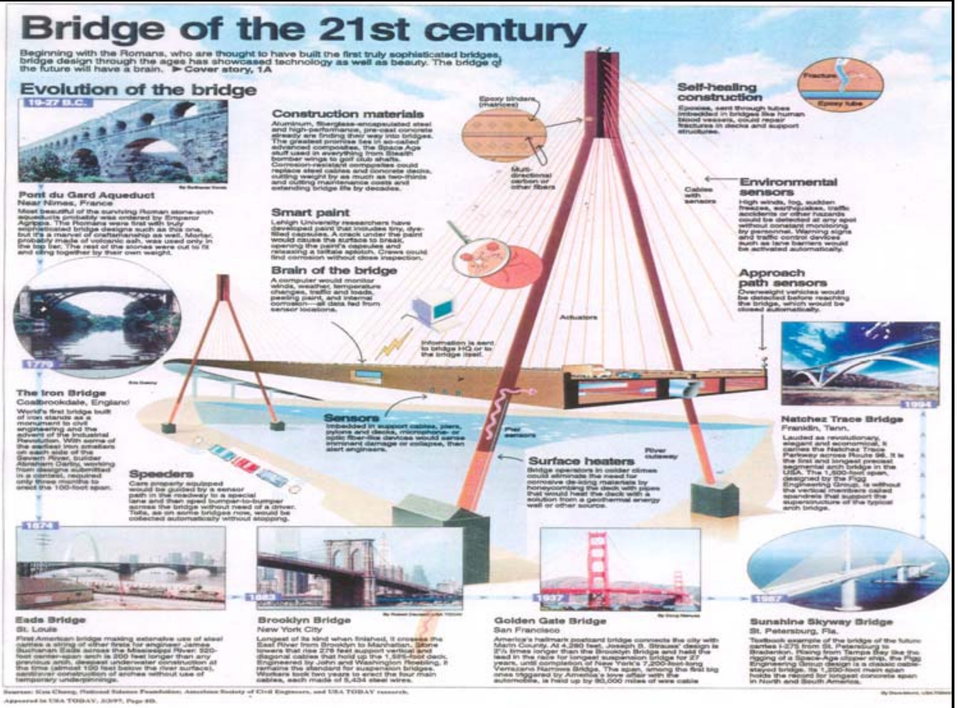
MATERIALS		STRUCTURES	INFRASTRUCTURE	
nano-level (10^{-9})	micro-level (10^{-6})	meso-level (10^{-3})	macro-level (10^{+0})	systems-level (10^{+3}) m
Molecular Scale	*Microns*		*Meters*	*Up to Km Scale*
*nano-mechanics	*micro-mechanics	*meso-mechanics	*beams	* bridge systems
*self-assembly	*micro-structures	*interfacial-structures	*columns	* lifelines
*nanofabrication	* smart materials	*composites	*plates	*airplanes

Fig. 1. Physical scales in materials and structural systems

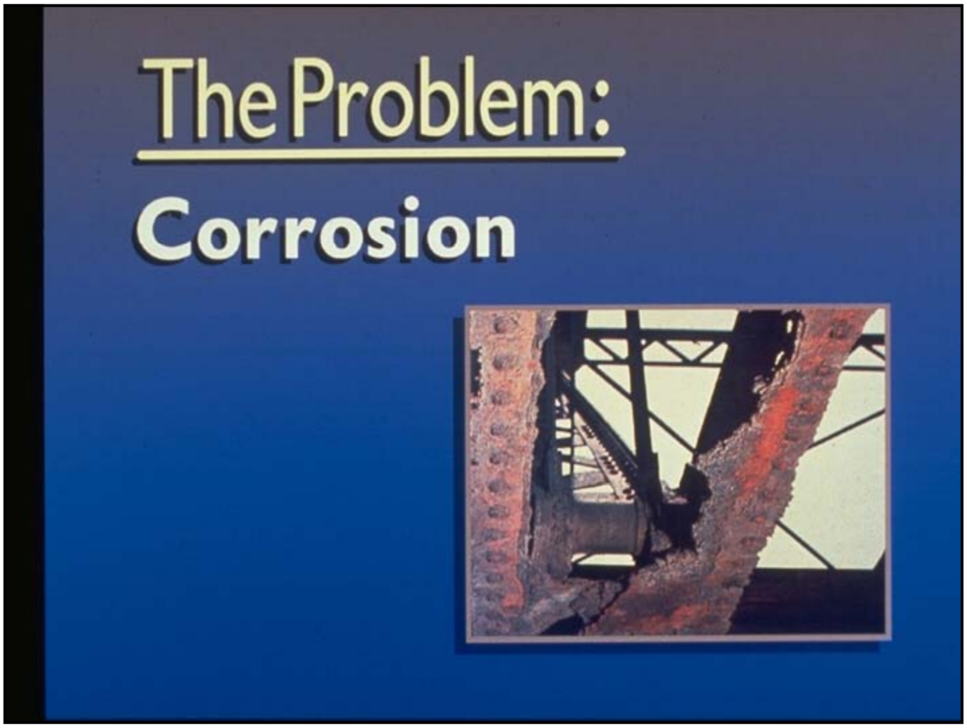
BORESI, CHONG and LEE, *ELASTICITY IN ENGINEERING MECHANICS*, WILEY, 2011.


Map of Deformation-Measurement Techniques
K.-S. Kim, Nano & Micromechanics Laboratory, Brown University
Field of View (Gage Length in m)
Strain Resolution
HRTEM-CFTM
Successive DIC
LDLM
Adaptive Reference Grating
Decorrelation Limit
AFM/SEM DIC
DIC
Sampling Limit
AFM Interferometry
Interferometric Gain of Resolution
SRES
FGLM & LSI
Fringe Density Limit
Optical Diffraction Limit
Interface Energy Limit
Electron Beam Control Limit
AFM Scanning Control Limit
Field Projection Method
Equilibrium Smoothing
HRTEM High Resolution Transmission Electron Microscopy
CFTM Computational Fourier Transform Moire
AFM Atomic Force Microscopy
SEM Scanning Electron Microscopy
SRES Surface Roughness Evolution Spectroscopy
LDLM Large Deformation Laser Moire
FGLM Fine Grating Laser Moire
LSI Laser Speckle Interferometry
DIC Digital Image Correlation
NSF Award No. CMS-0070057, Engineering Directorate (Program Manager: Dr. K.P. Chong & Jorn Larsen-Basse)


Techniques:
(Meso-)
Nano-
Micro-
Macro-
nm
µm
mm
AFM
Optical Microscopy
Laser Scanning Confocal Microscopy
Light Scattering
Neutron Scattering
SANS
USANS
L. SUNG, NIST



Golden Gate Bridge, San Francisco, CA



Chong Cycle; 500h*

Freeze (68 h)

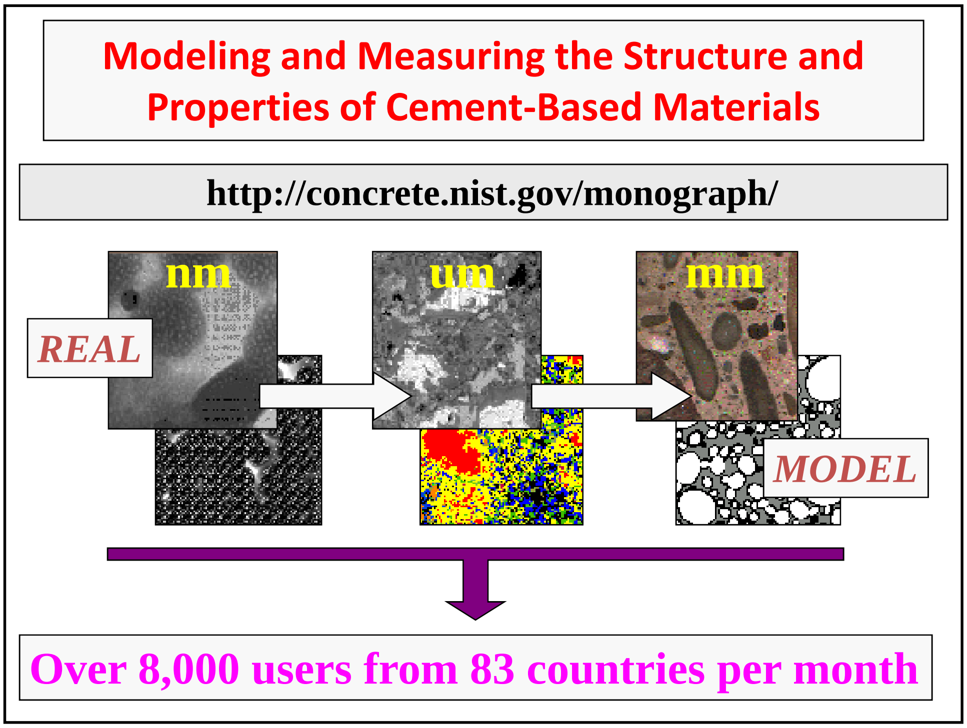
↓

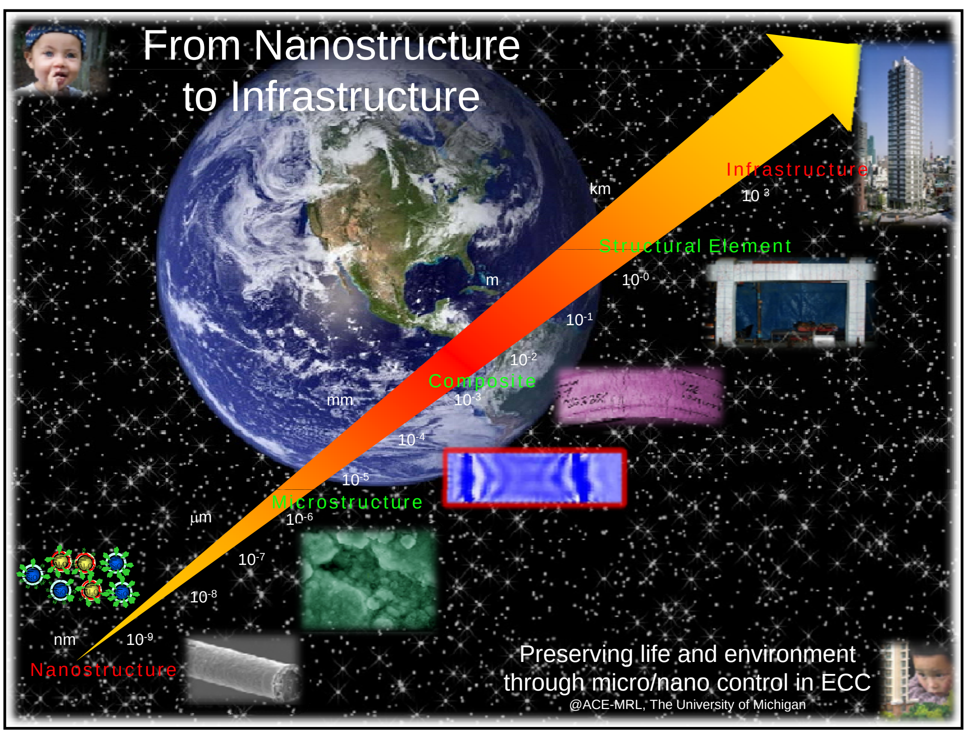
4-h Ultra-violet light/
4-h humidity condensation (216 h)

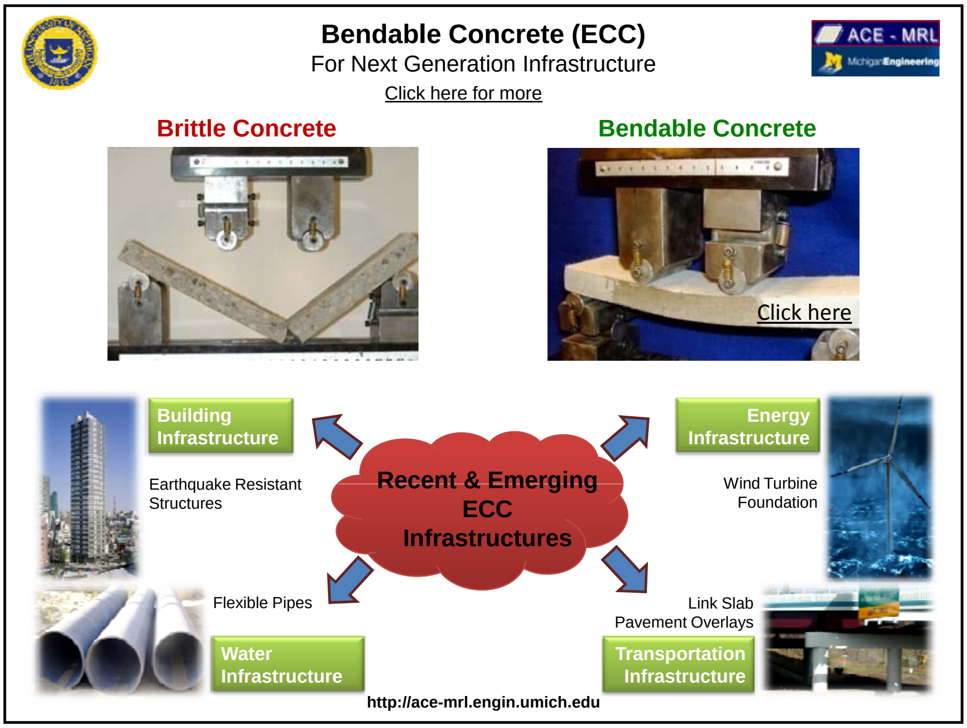
↓

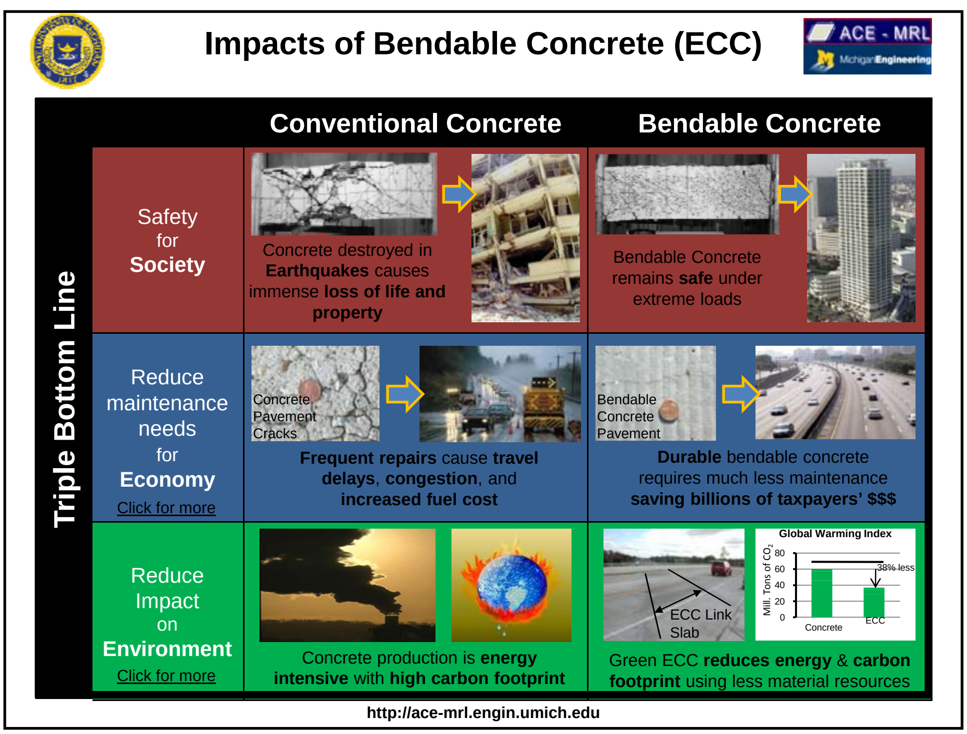
1-h hot salt-fog/1-h ambient air (216 h)

ISO 20340:2009 * x6


Modeling and Measuring the Structure and Properties of Cement-Based Materials
http://concrete.nist.gov/monograph/
nm
um
mm
REAL
MODEL
Over 8,000 users from 83 countries per month


From Nanostructure to Infrastructure
Infrastructure
km
10 3
Structural Element
m
10 0
10-1
10-2
Composite
mm
10-3
10-4
10-5
Microstructure
µm
10-6
10-7
10-8
nm
10-9
Nanostructure
Preserving life and environment through micro/nano control in ECC
@ACE-MRL, The University of Michigan


Bendable Concrete (ECC)
For Next Generation Infrastructure
Click here for more
ACE - MRL
Michigan Engineering
Brittle Concrete
Bendable Concrete
Click here
Building Infrastructure
Earthquake Resistant Structures
Recent & Emerging ECC Infrastructures
Energy Infrastructure
Wind Turbine Foundation
Flexible Pipes
Water Infrastructure
Link Slab
Pavement Overlays
Transportation Infrastructure
http://ace-mrl.engin.umich.edu


Impacts of Bendable Concrete (ECC)
ACE - MRL
Michigan Engineering
Triple Bottom Line
Conventional Concrete
Bendable Concrete
Safety for Society
Concrete destroyed in Earthquakes causes immense loss of life and property
Bendable Concrete remains safe under extreme loads
Reduce maintenance needs for Economy
Click for more
Concrete Pavement Cracks
Frequent repairs cause travel delays, congestion, and increased fuel cost
Bendable Concrete Pavement
Durable bendable concrete requires much less maintenance saving billions of taxpayers' $$$
Reduce Impact on Environment
Click for more
Concrete production is energy intensive with high carbon footprint
ECC Link Slab
Global Warming Index
Mill. Tons of CO2
80
60
40
20
0
38% less
Concrete
ECC
Green ECC reduces energy & carbon footprint using less material resources
http://ace-mrl.engin.umich.edu

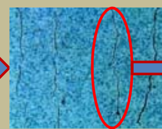
The Future: Smart Concrete & Intelligent Infrastructure

ACE - MRL
Michigan Engineering

Self Healing ECC

Click here for more

Micro-mechanical tailoring of material limits the cracks widths under 60 µm during service loads



Before Self-healing

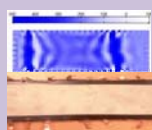
Micro-cracks self-heal under natural moisture conditions

After Self-healing

Enhances Infrastructure Durability

Self Sensing ECC

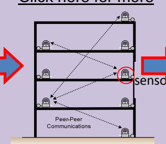
Click here for more



ECC is a semi-conducting material with piezo-resistivity

+

Wireless sensing unit



Wireless structural monitoring system

In-time detection of structural weakness

De la Concorde overpass

Failure caused by structural weakness missed during inspection

Acknowledgment: ECC research has been sponsored by the **NSF** through grants CMS 0329416, CMMI 0700219, and OCI 0636300 to the University of Michigan.

http://ace-mrl.engin.umich.edu

Self-Healing ECC

ACE - MRL
Michigan Engineering

Material Research at ACE-MRL restricts the crack width allowing the material to heal itself in natural environment

Cracks decrease the service life of infrastructure by allowing corroding agents to seep in

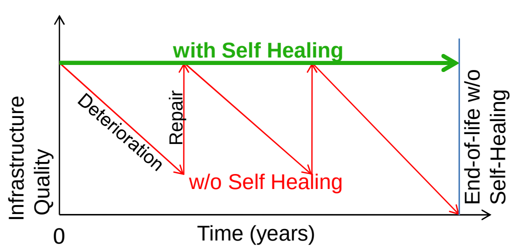
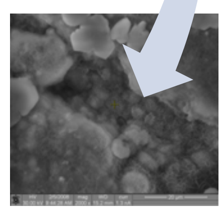


Fig: Effect of Self-Healing of ECC on Infrastructure Quality with time



Self-healed Crack
<click to see various cycles>

http://ace-mrl.engin.umich.edu

Hit <Esc> to Return

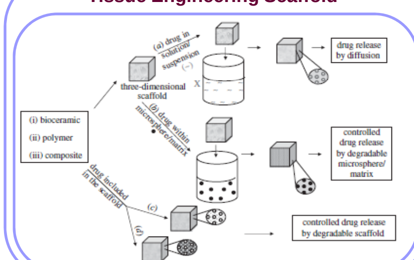
Mechanics of Composite Material Reinforced by Randomly-Dispersed Particles

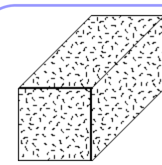
- Theoretical Procedures
  (1) Stage 1: Homogenized Microstructure Properties
  (2) Stage 2: Random Number Generator – Euler Angles
  (3) Stage 3: Macroscopic Damage Propagation
  (4) Stage 4: Microscopic Stress Distribution

Background

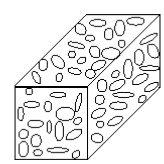
Artificial Bone

Tissue Engineering Scaffold

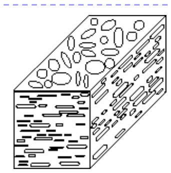




Short-fiber reinforced composite



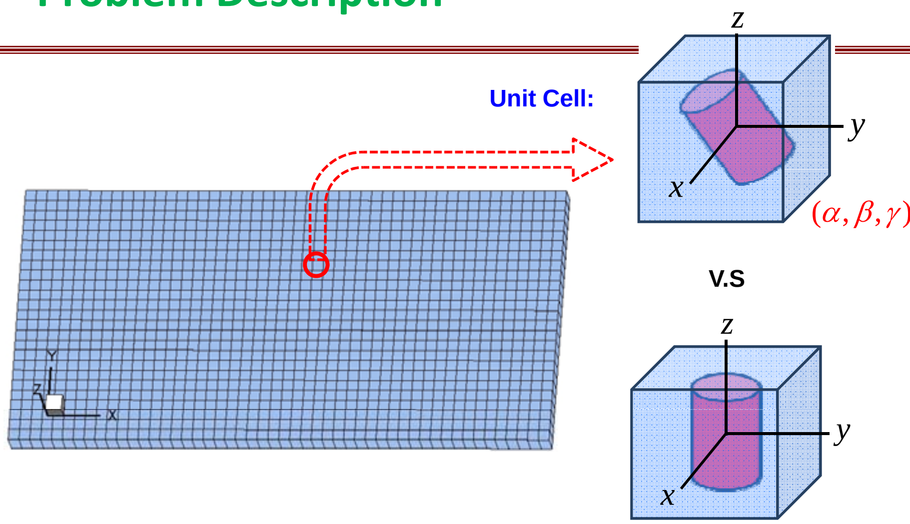
Aggregate reinforced composite



Flat-flakes reinforced composite

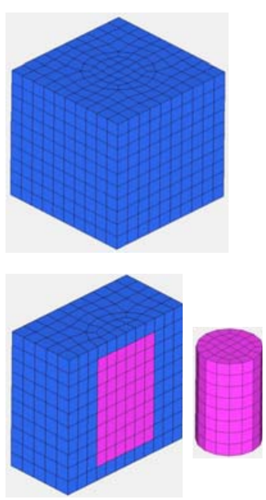
Reinforcements randomly dispersed in Matrix

Problem Description



Representative Volume Element (RVE) : $(\alpha = 0^0, \beta = 0^0, \gamma = 0^0)$

Stage 1:
Homogenized Microstructure Material Properties



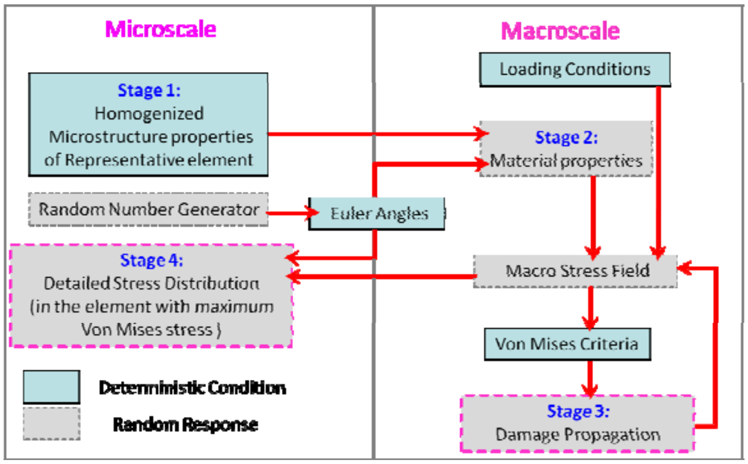
FE Models of RVE

$$\sigma_{ij} = A_{ijkl}\varepsilon_{kl}$$

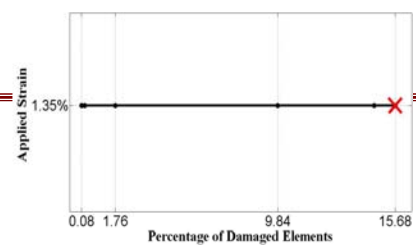
$$\begin{pmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \tau_{23}\\ \tau_{31}\\ \tau_{12}\end{pmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16}\\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26}\\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36}\\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46}\\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} & C_{56}\\ C_{61} & C_{62} & C_{63} & C_{64} & C_{65} & C_{66}\end{bmatrix}_{6\times 6} \begin{pmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ 2\varepsilon_{23}\\ 2\varepsilon_{31}\\ 2\varepsilon_{12}\end{pmatrix}$$

case No.	Boundary Conditions		
1	$\varepsilon_{11} = 1$	Other	$\varepsilon_{ij} = 0$
2	$\varepsilon_{22} = 1$	Other	$\varepsilon_{ij} = 0$
3	$\varepsilon_{33} = 1$	Other	$\varepsilon_{ij} = 0$
4	$2\varepsilon_{23} = 1$	Other	$\varepsilon_{ij} = 0$
5	$2\varepsilon_{31} = 1$	Other	$\varepsilon_{ij} = 0$
6	$2\varepsilon_{12} = 1$	Other	$\varepsilon_{ij} = 0$

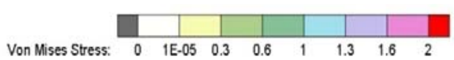
Multiscale Analysis

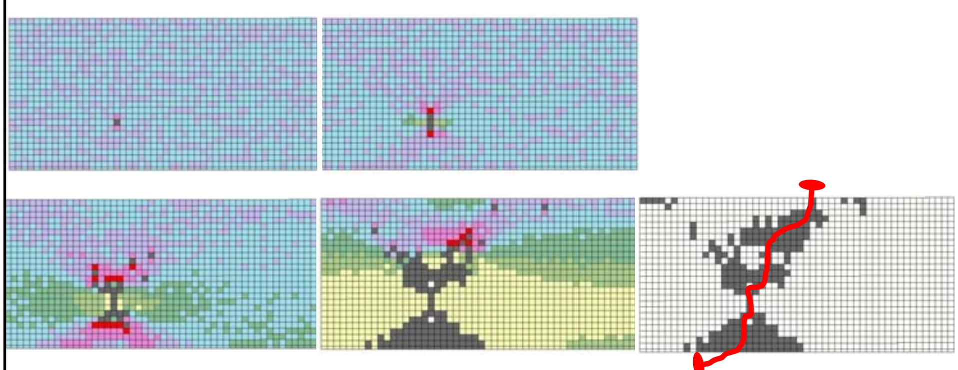


Stage 3:
Damage Propagation – Case 1



$$E_m / E_p = 1/10$$





- Multiscale Analysis Method
- The randomness of reinforcements has effects on the mechanical behavior of composite material
- The material properties of the reinforcement and the matrix play an important role in resisting the damage propagation of composite (Material Design)

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Nanoscience and engineering in mechanics and materials

Ken P. Chong

Mechanics and Materials Program, National Science Foundation, Arlington, VA 22230, USA

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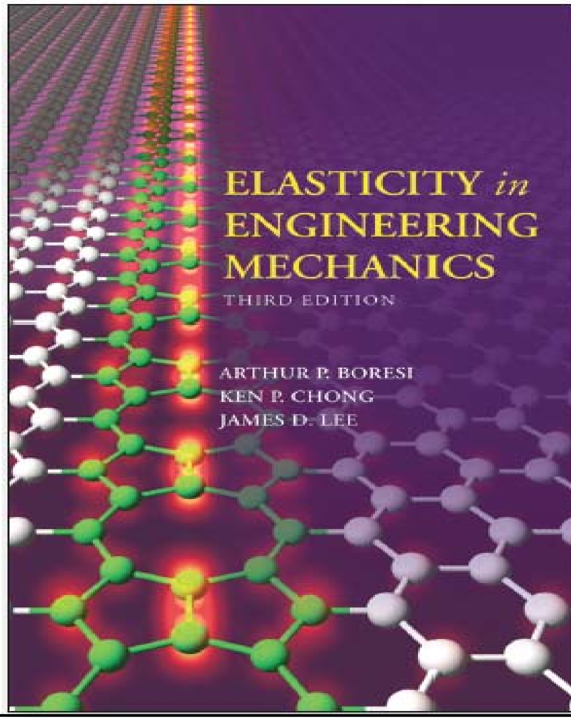

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Defining the vision and implementation plan

National Nanotechnology Initiative

1999: 10-year vision

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plan

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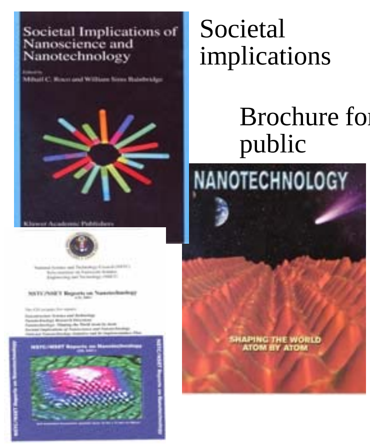
benchmark

Reports

Societal
implications

Brochure for
public



Planning with feedback after each: 5 years, 1 year, 1 month; and various levels: national/NSET, agency, program

In preparation: Topical reports; new 2004:10 year vision

MC. Roco, 10/09/03

Defining the vision for the second strategic plan (II)

National Nanotechnology Initiative

2004

2004: 10-year vision/plan

Agriculture and Food

Energy

Societal Implications 2004

Reports

Government Plan (annual)

Survey manufacturing

Other topical reports on www.nano.gov

2004: Update 10 year vision, and develop strategic plan

MC Roco, 3/16/05

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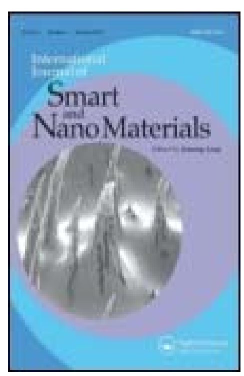

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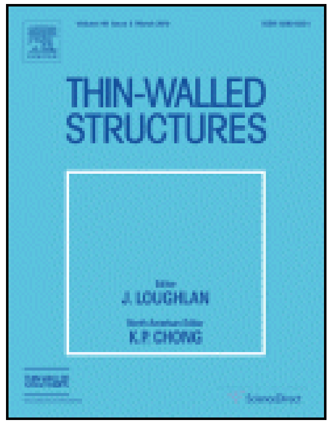

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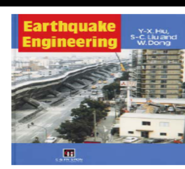

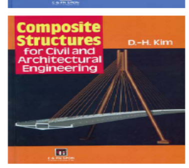

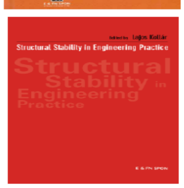

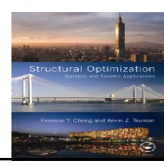

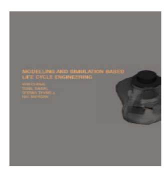

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