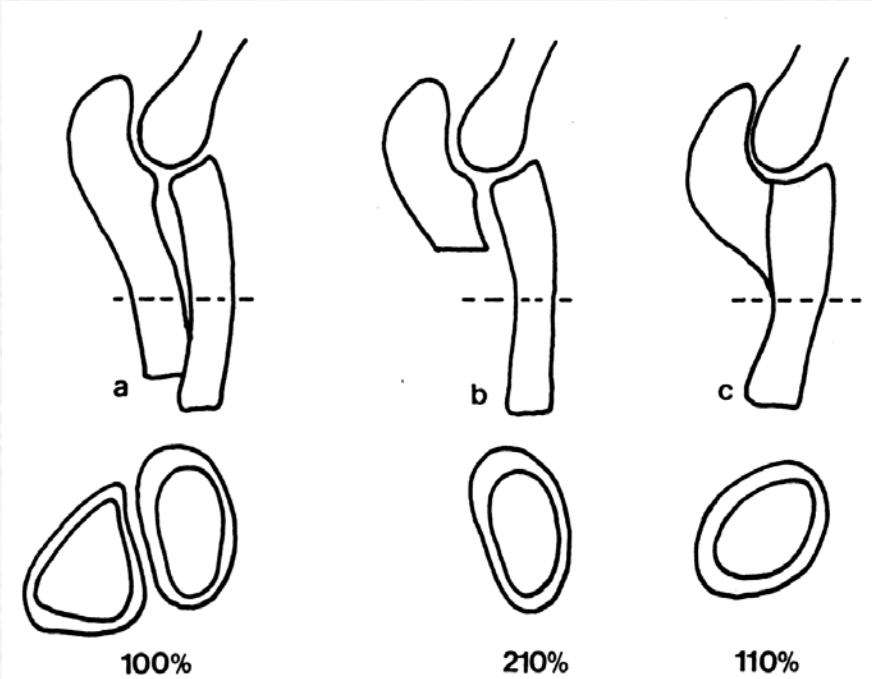
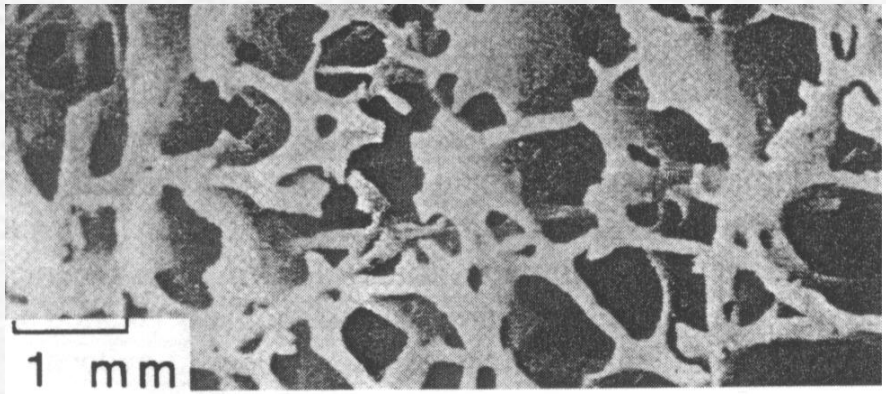
Inherently Adaptive Structural Materials



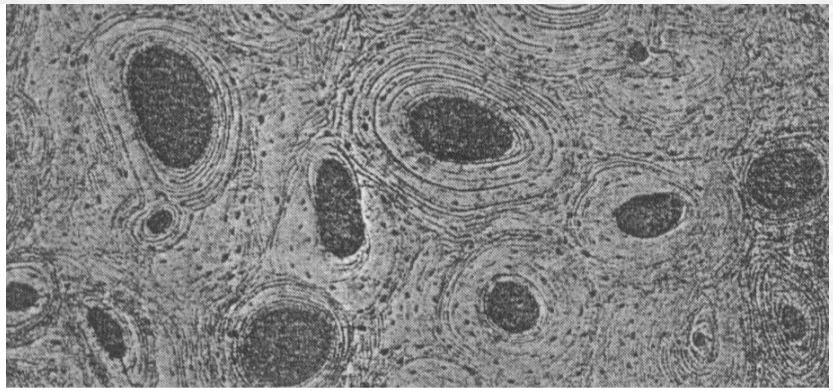
Outline of the Presentation

- **Structural and Adaptive Qualities of Bone**
- Biomimetic Principles of Adaptive Materials
- Design & Evaluation of Integrated Adaptive Systems
- Processing of Nanocomposites
- Modeling and Validation of Structural Principles

Development of Bone Structure



Cancellous Bone



Compact Bone

Mechanisms of Bone Adaptation

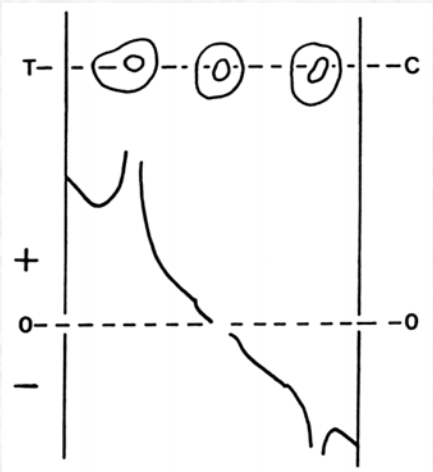
Loads → Build of Bone ← Remodeling

↓

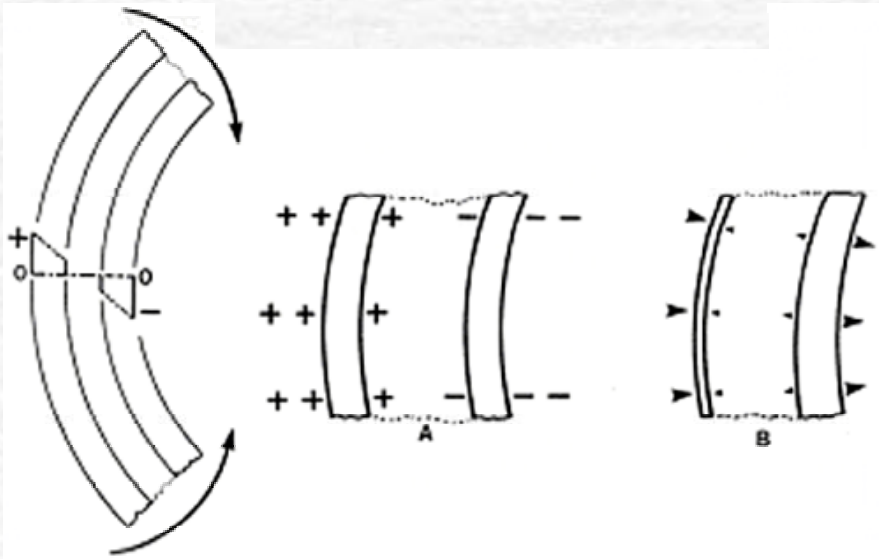
Strains

↓ ↑

Comparison → Signal

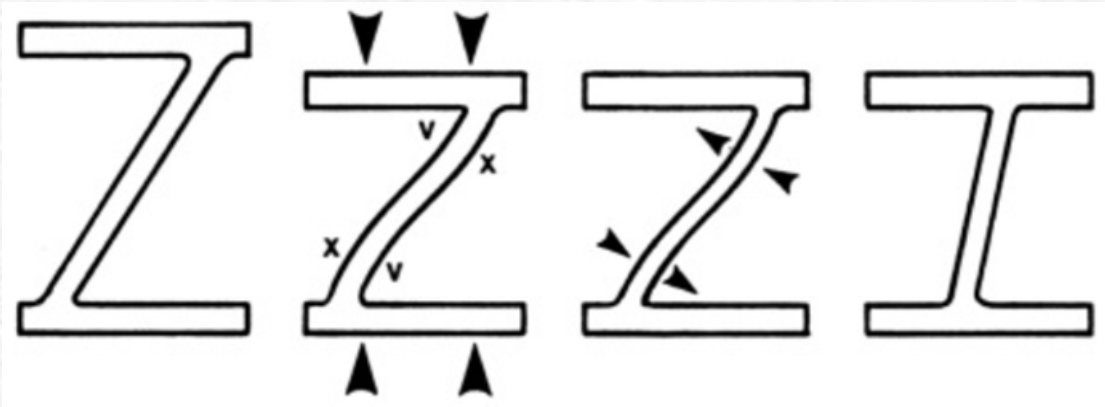


Electrical Potential Gradient Under Bending

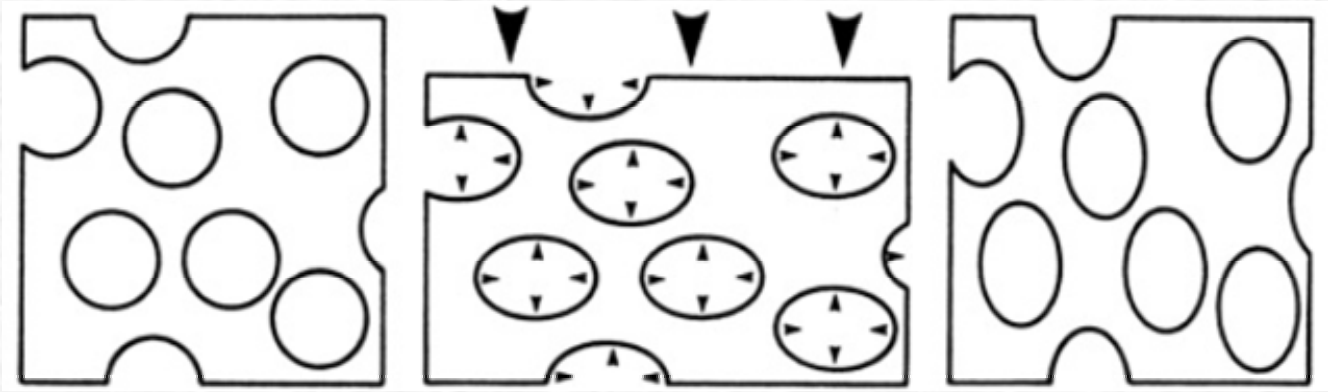


Bone Remodeling Under Bending

Consequences of Bone Adaptation



Arrangement of Struts Along Principal Strain Lines



Optimization of Topology

Outline of the Presentation

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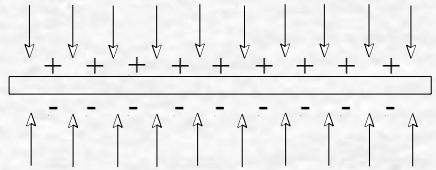
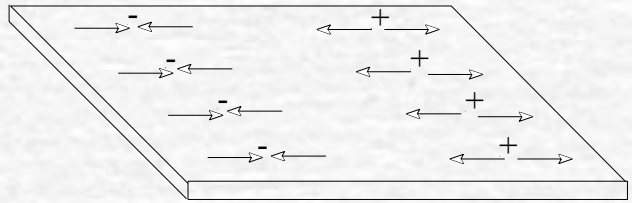
Key Constituents and Processes

- Piezoelectricity

  $V = g.s.t$

  $Q = d.s.A$

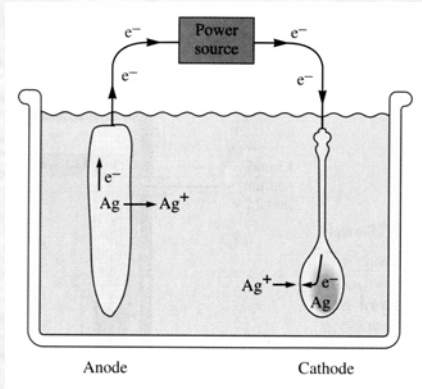




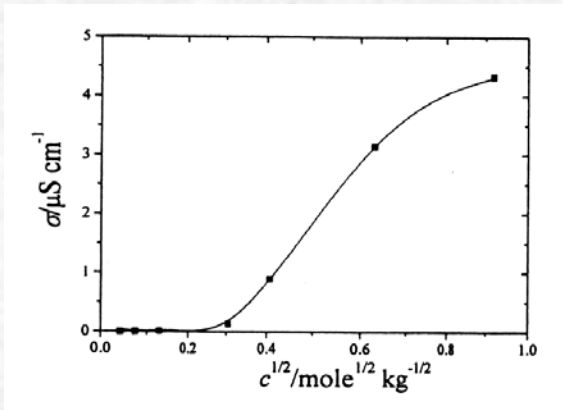
- Electrolysis

  $V = Vo + i.R + Ve$

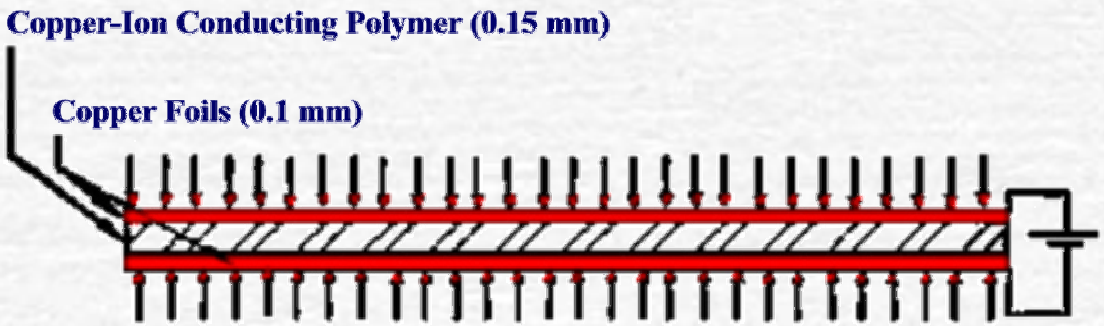
  $Q = n.F$

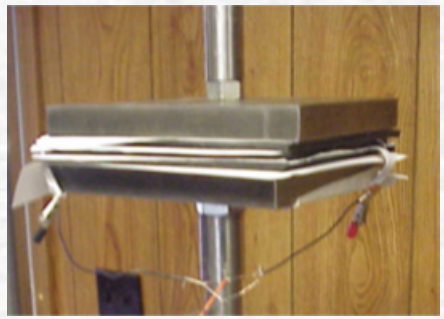


- Solid Electrolytes

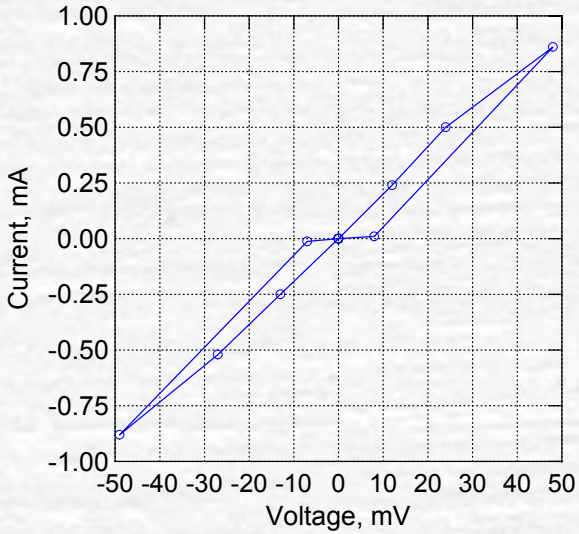


Experimental Validation of Electrolysis Through Solid Electrolyte

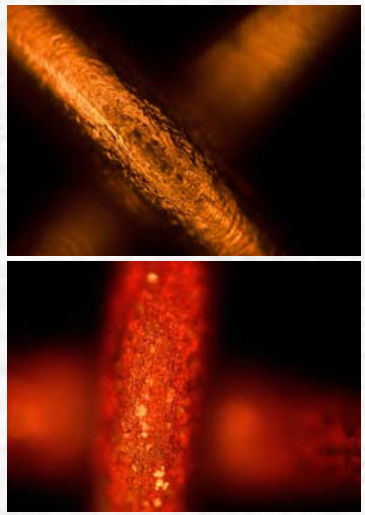




Electrolytic Cell

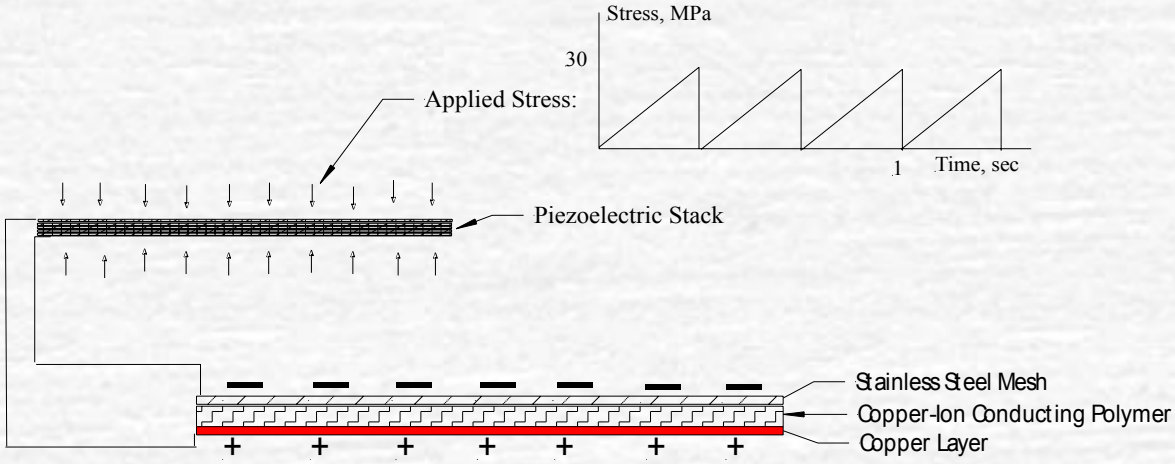


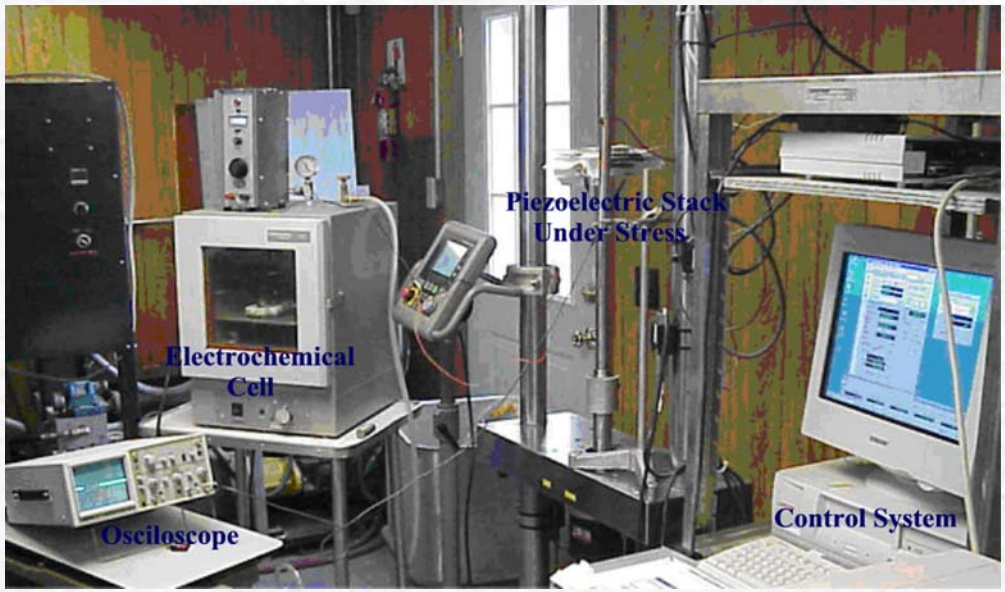
Voltammogram



Micrographs

Design & Validation of Piezo-Driven Electrolysis





Outline of the Presentation

- Structural and Adaptive Qualities of Bone
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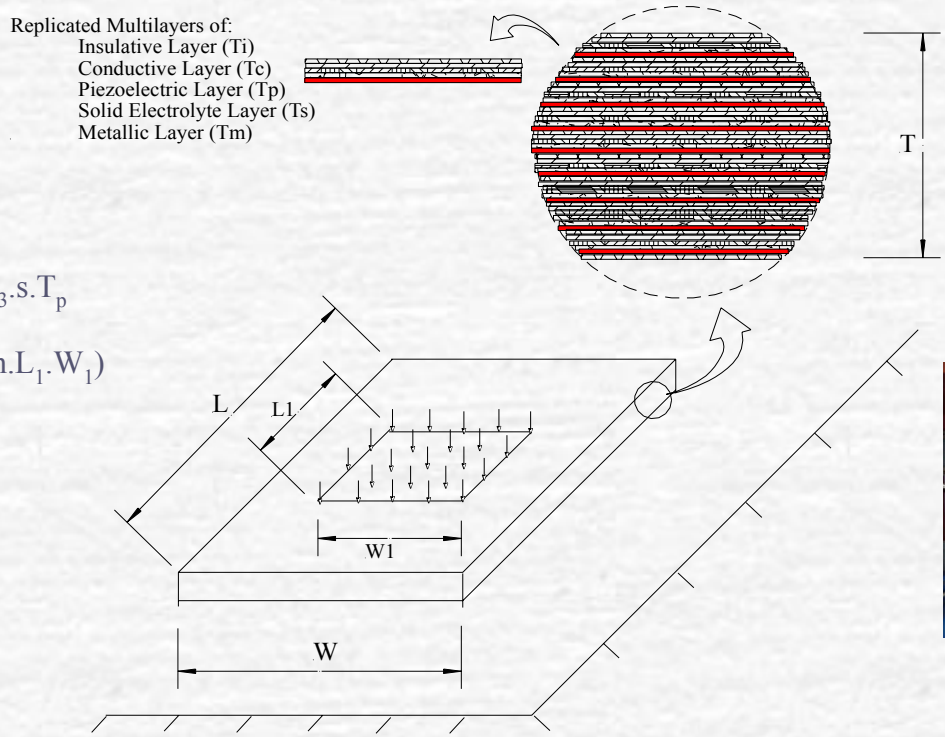
- Modeling and Validation of Structural Principles

Designs and Validation of a Basic System



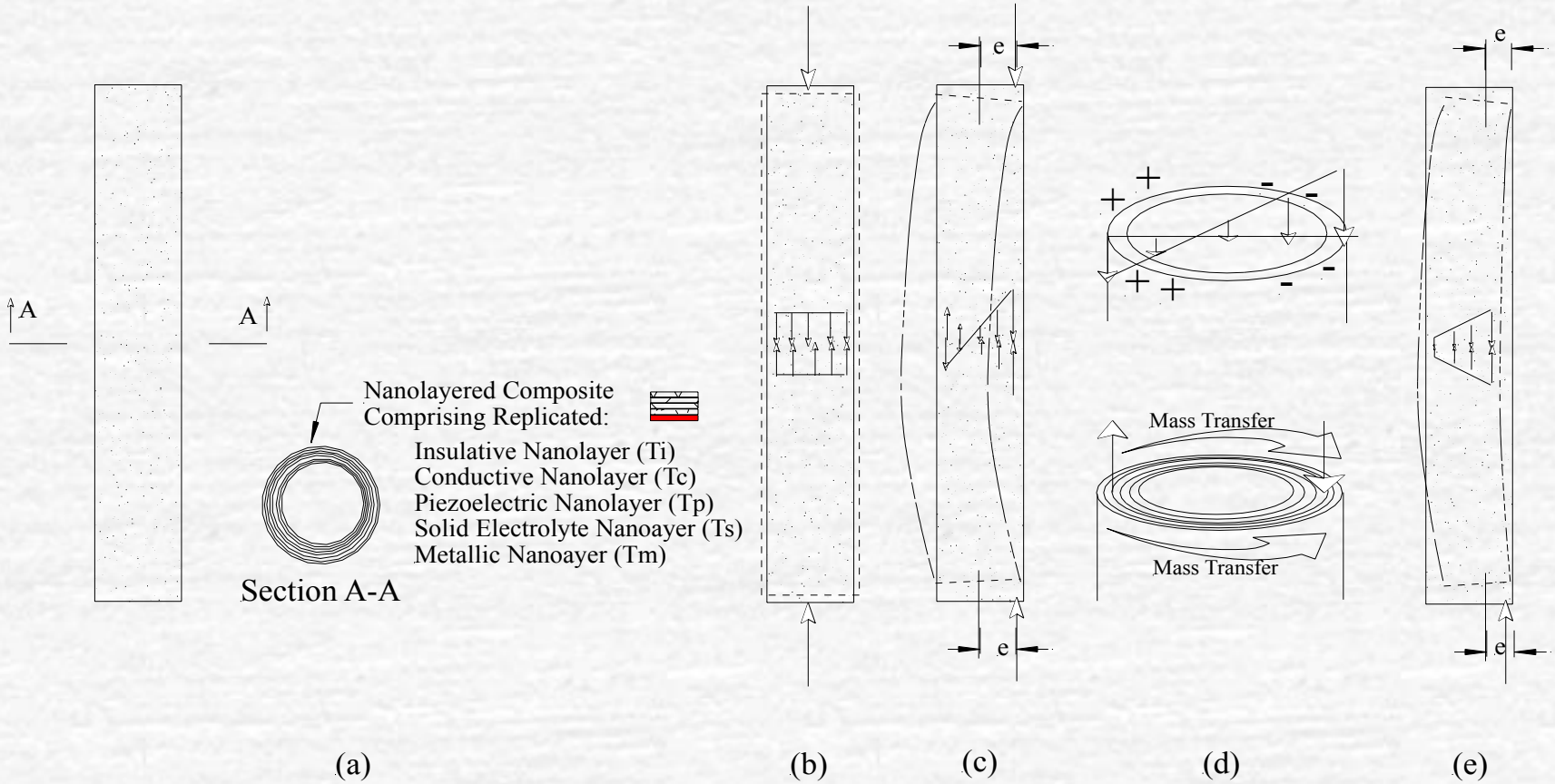
Schematic Presentation

Processing and Test Set-Ups

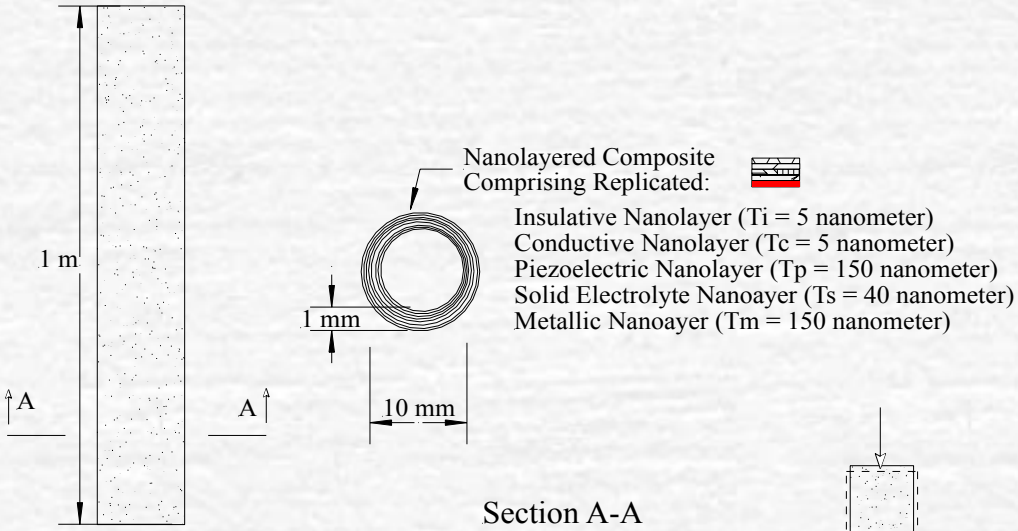
System	T_i	T_c	T_p	T_s	T_m
I (conventional)	50 µm	50 µm	50 µm	50 µm	50 µm
II (nanocomposite)	5 nm	5 nm	50 nm	40 nm	40 nm

Alternative Designs

An Elaborate Adaptive Element

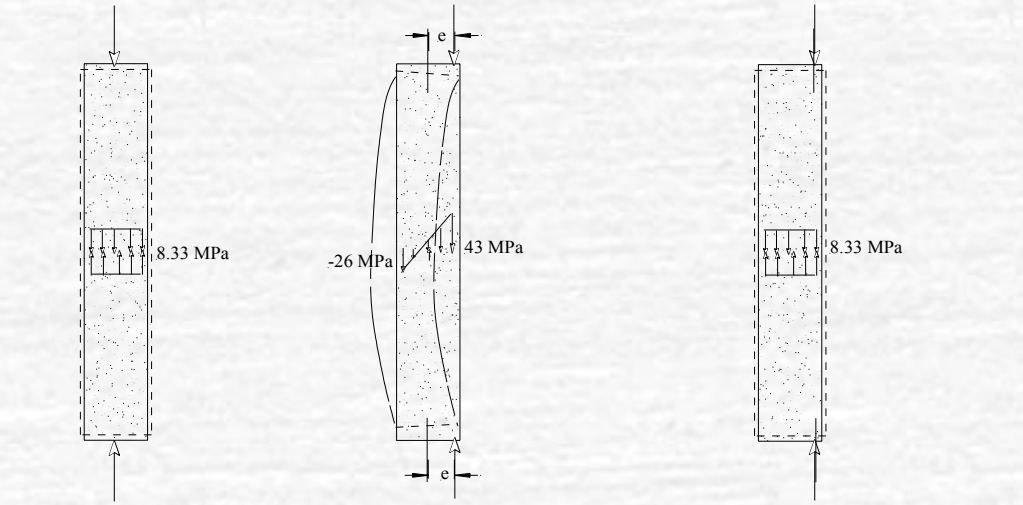


Detailed System Design and Analysis



Section A-A

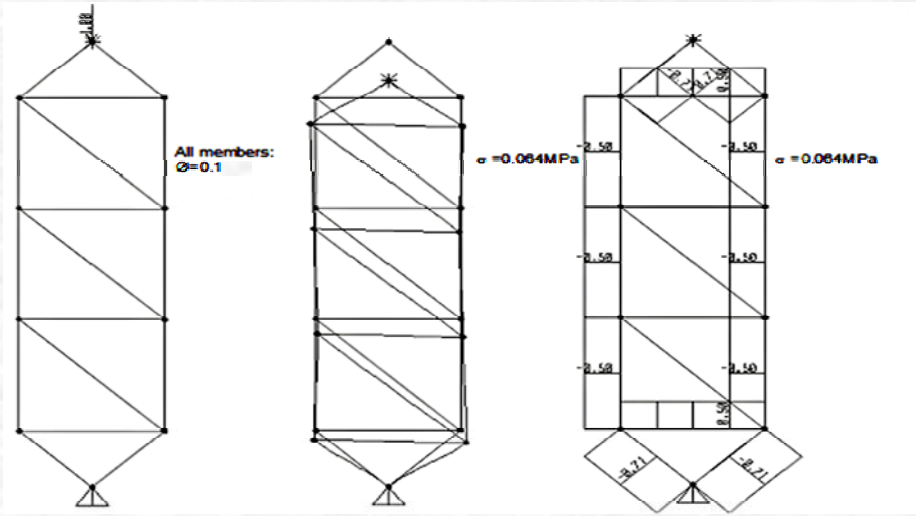
System Design

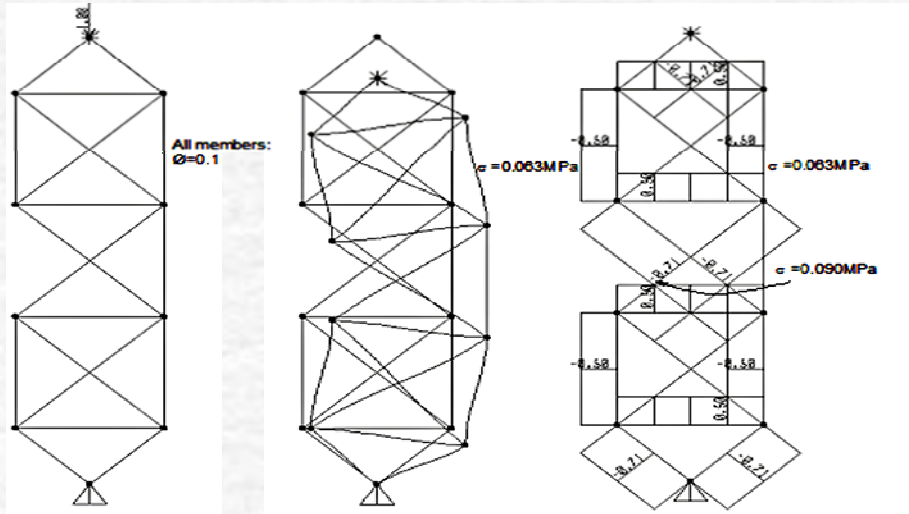


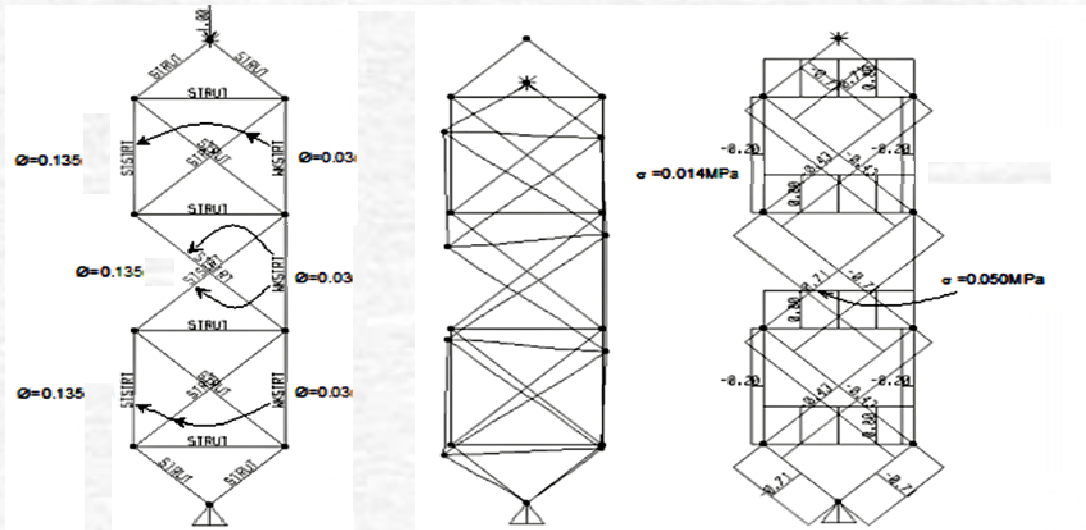
(a) Concentric Loading (b) Eccentric Loading (c) Concentricity Restored by Self-Adaptation

Structural & Adaptive Analysis

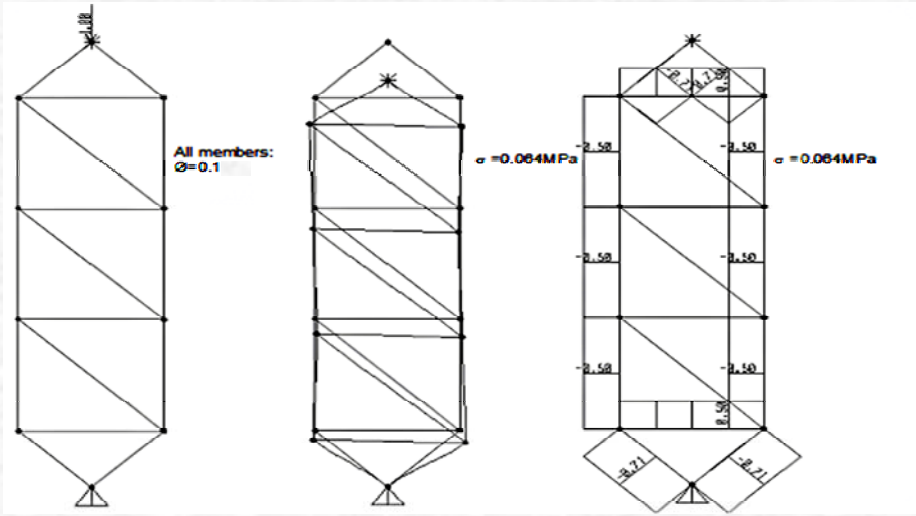
Preliminary Assessment of Structural Implications

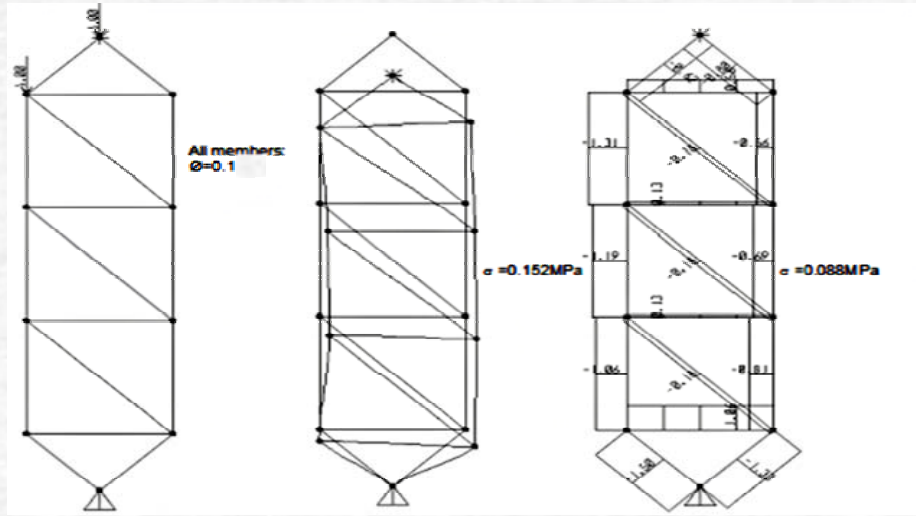


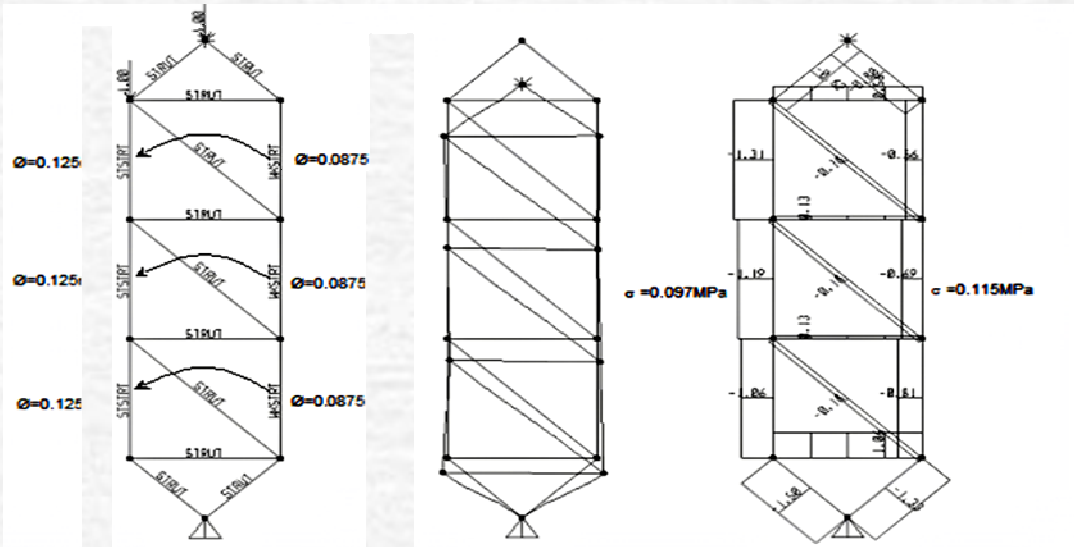




Preliminary Assessment of Structural Implications







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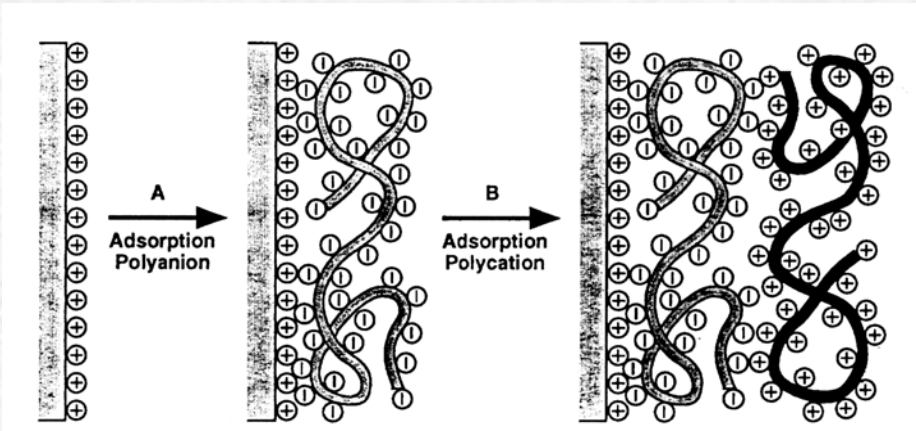
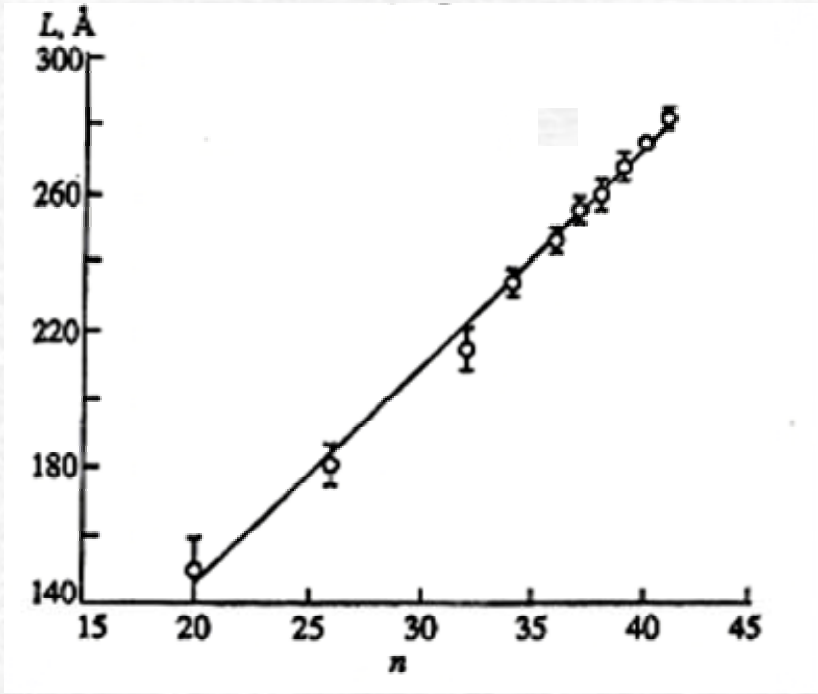
Ionic Self-Assembly: Basic Principles

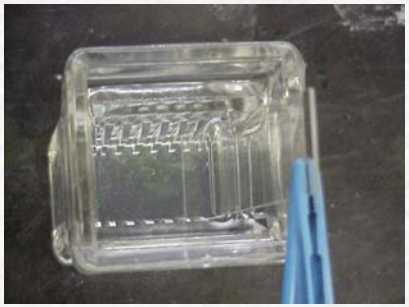


Mechanism of Self-Assembly

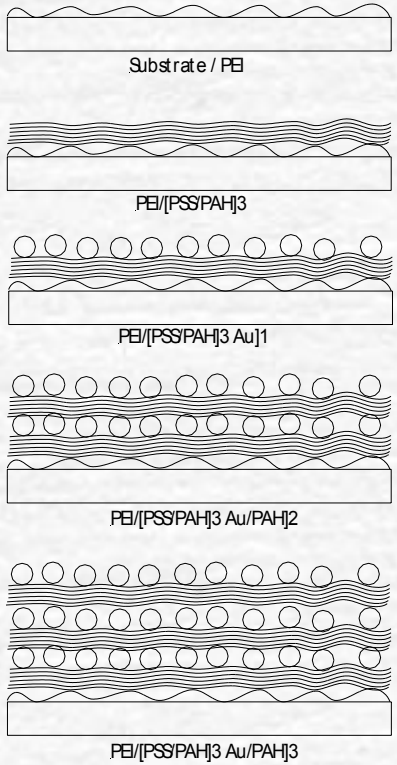


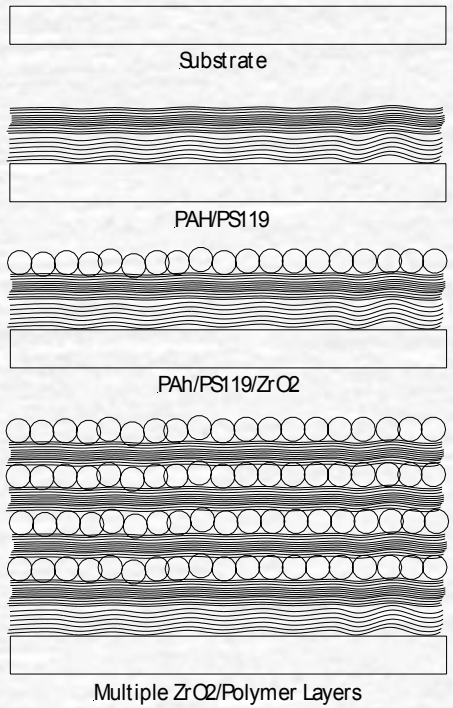
Build-Up of Nanolayers

Adaptation of Ionic Self-Assembly



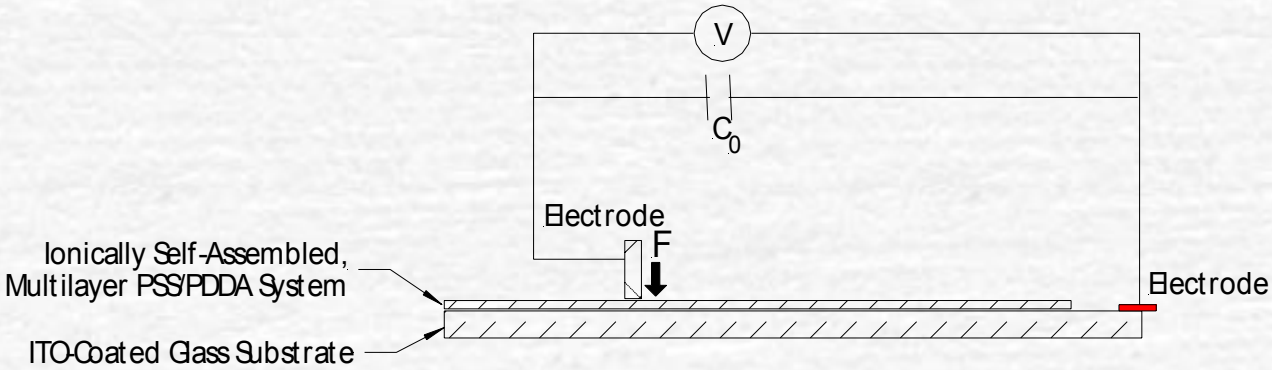
Manual and Automated Processing

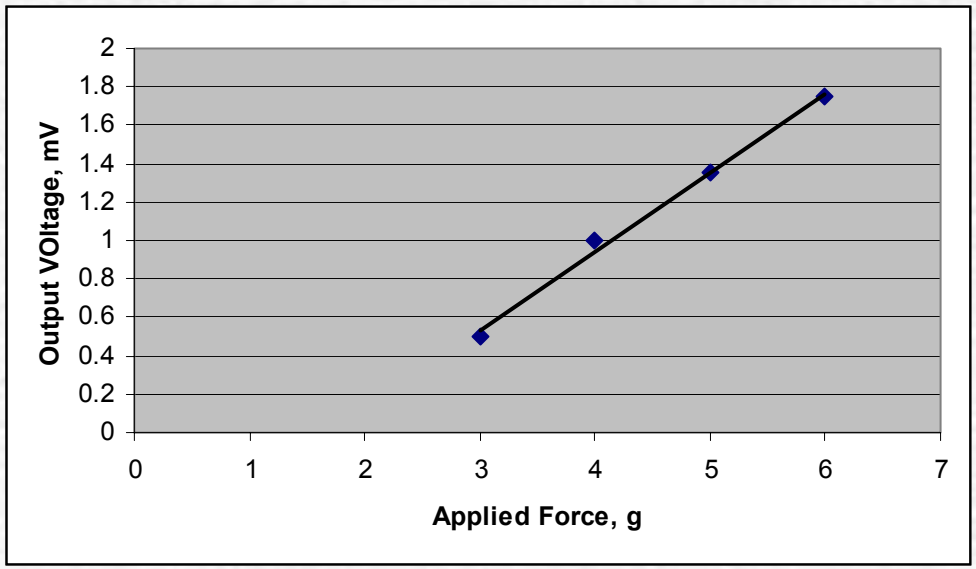




Self-Assembly of Colloidal Nanoparticles

Self-Assembly of Piezoelectric and Conducting Nanolayers





Outline of the Presentation

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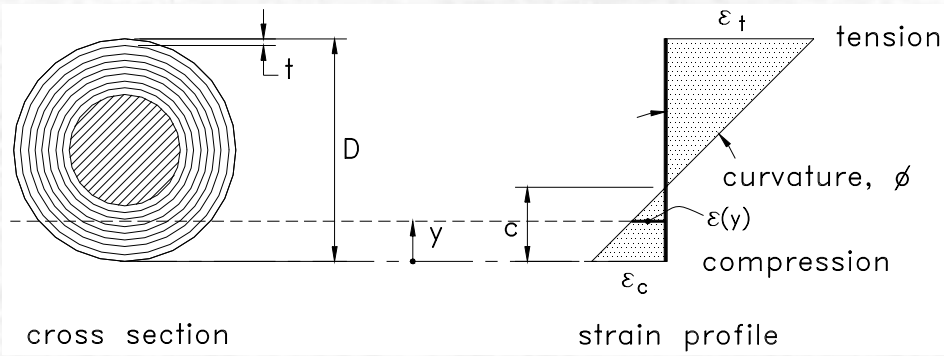
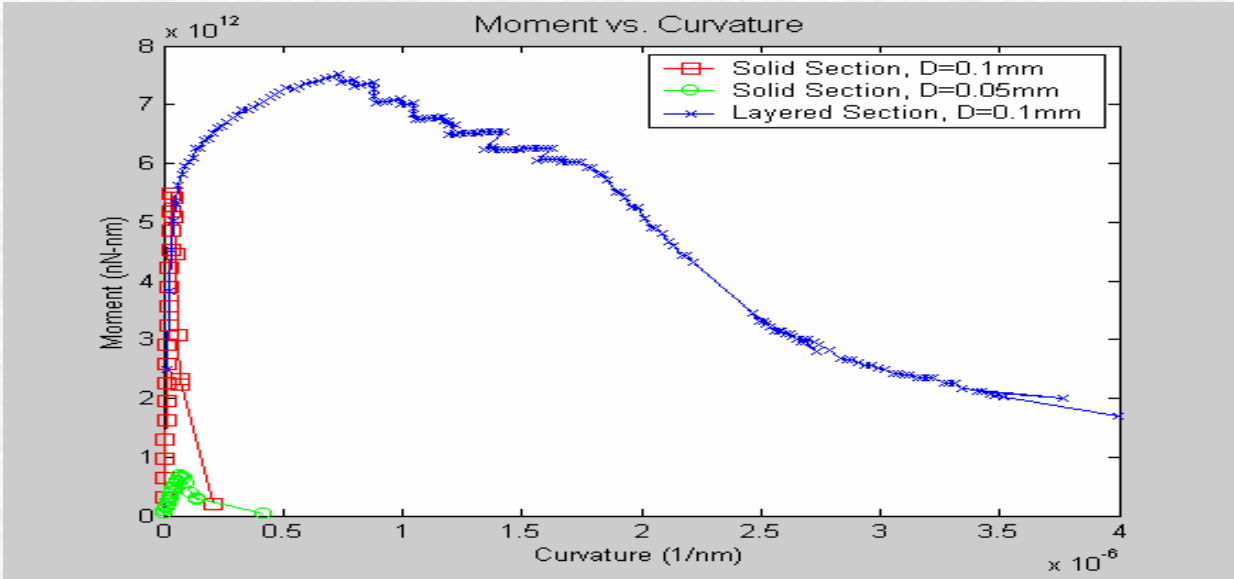
Section-Level Structural Modeling



$$\int_{A_c} f_c dA_c + \int_{A_l} f_l dA_l = N$$

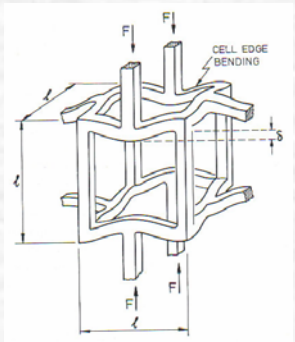
$$\int_{A_c} f_c y dA_c + \int_{A_l} f_l y dA_l = M$$

Modeling Principles

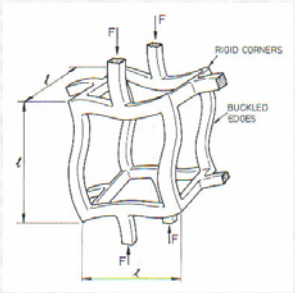


Effect of Hybrid Nanolayer Build-Up on RVC Section Behavior

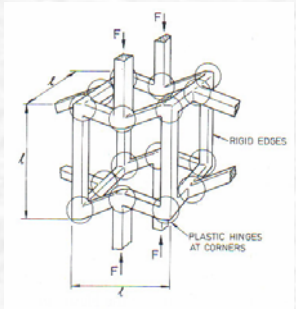
Preliminary System-Level Analysis



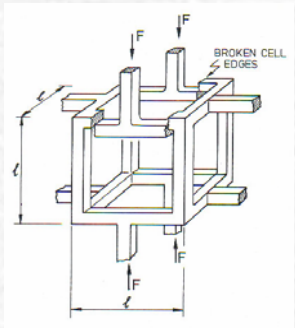
(a) Bending



(b) Buckling



(c) Yielding



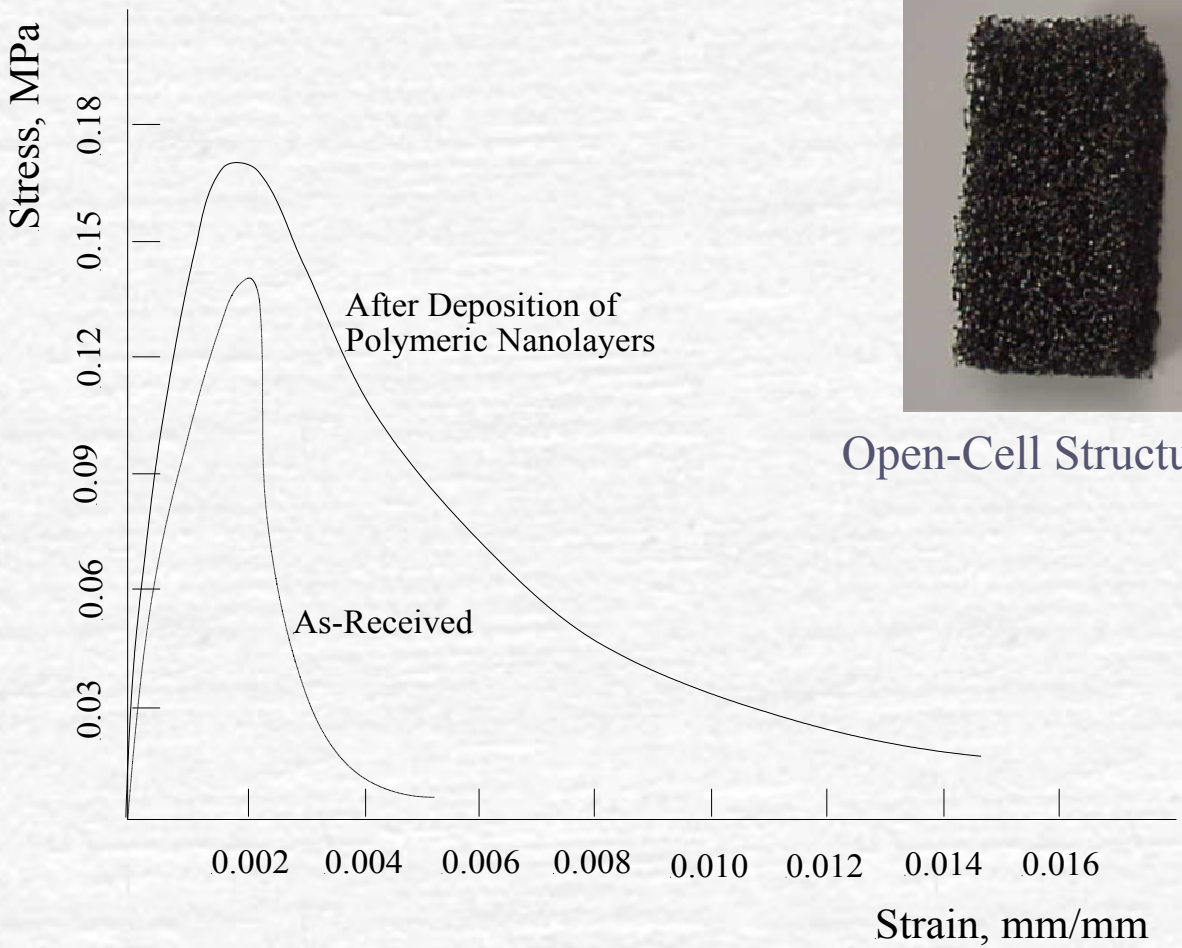
(d) Fracture

Failure Modes

Effect of Multi-Layer Polymer/Ceramic/Metal Build-Up on Bulk Properties of RVC Open-Cell System

Property	Composite/Base Ratio
Density	3.9
Elastic Modulus	21
Tensile Strength	11

Preliminary Structural Evaluation



Effect of Polymer Nanolayers on Tensile Behavior of Open-Cell Structure

Open-Cell Structure and Tension Test Set-Up

Summary & Conclusions

- Selection of adaptive system constituents and viable architectures
- Modeling, design and experimental validation of adaptive structures
- Implementation of nanocomposite processing techniques
- Modeling and validation of structural principles