Biomaterials Research in MSE at Georgia Tech

Naresh Thadhani, Chair MSE

Advances in Lignocellulosic Processes and Products: A Cross-Disciplinary, Multi-Industry Symposium

October 1-2, 2014

www.mse.gatech.edu
MSE: Enabling discipline that combines “science” and “engineering” in its designation and focuses on the paradigm of process-structure-property-performance correlation.

Manufacturing methods used for processing traditional materials usually employ extreme conditions such as pyro-, or hydro-, or electro-, or pressure-based processes.
Nature’s method of making renewable bio-products relies on aqueous processes employing sunlight, CO$_2$, water, minerals.

**Wood based bio-products - Forests are sustainable, renewable, environmentally-friendly manufacturing factories**

Bio-products are “Building Blocks” for creating designer materials with hierarchical structure for unique functionalities.

Cellulose – most abundant polymer; nanofibrils/nanocrystals can be used as reinforcing agents in composites for many exotic applications, from smart/responsive/fireproof paper to armor.

Bio-products and other natural species are also “Templates” – there is lot that we can learn from nature.

Wagner, Ireland, and Jones, in “Production and Applications of Cellulose Nanomaterials, Eds. Postek, Moon, Rudie, and Bilodeau, TAPPI Press, 2013
Bio-products - Templates of Hierarchical Structure

Mechanical Properties of Plant Materials

<table>
<thead>
<tr>
<th>strength–density</th>
<th>for woods</th>
</tr>
</thead>
<tbody>
<tr>
<td>cellulose</td>
<td>$\sigma_s = 750–1080 \text{ MPa}$</td>
</tr>
<tr>
<td>woods, parallel to grain</td>
<td></td>
</tr>
<tr>
<td>slope 1</td>
<td></td>
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<tr>
<td>wood cell wall</td>
<td></td>
</tr>
<tr>
<td>slope 2</td>
<td></td>
</tr>
<tr>
<td>balsa, perpendicular to grain</td>
<td></td>
</tr>
<tr>
<td>oak</td>
<td></td>
</tr>
<tr>
<td>pine</td>
<td></td>
</tr>
<tr>
<td>spruce</td>
<td></td>
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<tr>
<td>slope 3</td>
<td></td>
</tr>
<tr>
<td>strength, $\sigma$ (MPa)</td>
<td></td>
</tr>
<tr>
<td>density, $\rho$ (Mg m$^{-3}$)</td>
<td></td>
</tr>
</tbody>
</table>

Cellulosic building block of hierarchical structure

CH group, OH group, CH$_2$OH

- CH group
- OH group
- CH$_2$OH

Cellulose molecule, acidic pectin, glycoprotein

- Cellulose molecule
- Acidic pectin
- Glycoprotein

Hemicellulose molecule, microfibril, section of primary wall

- Hemicellulose molecule
- Microfibril
- Section of primary wall

Primary wall, outer layer (S1), middle layer (S2), inner layer (S3)

- Primary wall
- Outer layer (S1)
- Middle layer (S2)
- Inner layer (S3)

20–40 μm

non-crystalline regions, crystallites ~20 nm, 10–25 nm macrofibril

- Non-crystalline regions
- Crystallites ~20 nm
- 10–25 nm macrofibril

Mechanical properties of plant materials, strength–density relationship.
Satish Kumar, Professor

RESEARCH AREAS OF INTEREST
Nano-structured Polymers, Fibers, and Nano-composites, Biomedical Applications of Polymers, Functional Polymers and Systems, Polymer Processing, Advanced Techniques for Characterization of Polymer Structure and Properties
RESEARCH AREAS OF INTEREST

Polymers inspired by animal or plant viruses and diseases, cellulose derivatives and aromatic backbone materials; Biological and synthetic polymers in dilute and concentrated solutions, gels, liquid crystals and dispersions. Micro-rheology, transport, X-ray and light scattering, chromatography and fluorescence photobleaching recovery.

Encapsulation of light-absorbing polymer in solution by hydrophobic protein membrane

Colloidal crystals made from composite silica-polypeptide hybrid particles
RESEARCH AREAS OF INTEREST
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Bio-enabled and near net-shape reaction processing of micro/nano-structured inorganic and composite materials;
High-temperature oxidation & corrosion

Exchange reactions enable replication of nano-scale structure

Examples: Conversion of Diatom (Algae) 3-D SiO₂ Frustules into Porous Si, Porous C/Pt, or Porous TiO₂

Highly Porous Nanocrystalline 3-D Microparticles of:
- Si for Anodes in Li-Ion Batteries
- C/Pt for Anodes in PEM Fuel Cells
- TiO₂ for Pesticide Destruction in Water
Vladimir Tsukruk, Professor

RESEARCH AREAS OF INTEREST

Biomedical Applications of Polymers, Functional Polymers and Systems, Nano-structured Polymers, Nanocomposites, Polymer Structure/Properties, Responsive/Sensing Matls

Mechanotransducing Biological Sensors

Responsive behavior of (PSS/PMETAI$_{18}$)$_n$ microcapsules to light irradiation

Vibration detection by lamellar structure of cuticular pad on spider leg
Mohan Srinivasarao,

RESEARCH AREAS OF INTEREST
Physical chemistry of polymers, optics and physics of nematic liquid crystals, rheology/rheo-optics of polymeric fluids and liquid crystals, polymer/liquid crystal dispersions, confocal microscopy, photon tunneling microscopy, color science, nano-optics in biological world.
RESEARCH AREAS OF INTEREST
Shape memory alloys and polymers, biomedical implants, mechanical properties

Shape-Memory Polymers can deform up to 400% and still recover shape without loss of mechanical integrity

Deployment of Shape-Memory Polymer Device in Body Temperature Bath

MEDSHAPE INC.: Shape-Memory Alloys and Bio-Polymers as self-adapting implants for joint fusion and fracture repair
RESEARCH AREAS OF INTEREST
Probing physical, chemical, mechanical changes under extreme conditions of high-pressure shock loading and high-strain-rate deformation, for structural, energetic, functional applications

Laser-activation of Carbon nanoparticles for efficacious intracellular drug delivery*

*Collaborative research with Professor Mark Prausnitz, ChBE
Thank You