Notes on Projects and Advanced Materials

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The Plan for Today

- Projects
- Advanced Materials
Grading Policy

• Assignments and Labs: 45%
  - 4 assignments (must be completed individually)
  - 4 labs (done in groups)

• Project: 45%
  - Project proposal: 10%
  - Mid-point presentation: 10%
  - Final presentation and report: 25%

• Nanoquizes: 10%
  - At the beginning of most lectures
  - Lowest 3 scores dropped

• No midterm/final
Projects

• Project proposals and presentations (10%)
  - due April 1\textsuperscript{st}

• Mid-point project presentations (10%)
  - due April 24\textsuperscript{th}

• Final project presentations (10%)
  - due May 15\textsuperscript{th}

• Project report (15%)
  - due May 15\textsuperscript{th}
Project Proposals

- Problem and motivation
- Background (include previous work)
- Proposed technical method
- Expected results
Project Proposal Presentations

- In-class on April 1st
- 5 minutes/group including questions
- Slides (PDF or PPT)
  - Problem and motivation (1 slide)
  - Background and Tools (1 slide)
  - Proposed technical method (1-2 slides)
  - Expected results (1 slide)
- Send us slides at least 1 hour before the lecture
Projects

- Find a partner (now)!
- Meet with us early to discuss project ideas (now)!
  - Or send email
- Projects should have a substantial computational component
- Projects should have some connection to the real world
Project Resources

- MakerBot Replicators
- Laser cutter
- MS Kinects
- Code from assignments

If you need anything else, we will try to make it happen!
Project Ideas

- Extend one of the programming assignments or labs
- Create a tool that automates 3D printing
- Create an interactive tool for customizable design and fabrication
- Design a new object or material structure and characterize it
Project Ideas

• An extension to Assignment 1
  - Voxelization and slicing for FDM that handles imperfect geometry
Project Ideas

• New types of support structures for FDM
Project Ideas

- Automated surface orientation for FDM
Project Ideas

- Make a stand
Project Ideas

• Make it float
Project Ideas

- An extension to Assignment 3 and Lab 3
  - An interactive tool for designing and fabricating mechanisms
Project Ideas

- An extension to Assignment 4
  - Extend to 3D in C++
  - Visualize stress
Project Ideas

- Printable puzzle creator
Project Ideas

- Printable, parametric music box

http://www.thingiverse.com/thing:53235
Project Ideas

- Printable, parametric music box

http://www.thingiverse.com/thing:53235
Project Ideas

- Printable, parameterized flute

http://www.thingiverse.com/thing:12301
Project Ideas

- Printable, parameterized flute

http://www.thingiverse.com/thing:12301
Project Ideas

- Printable, parameterized mechanical components
  - Joints
  - Gears
Project Ideas

- Geometry processing
- Automated hole filling for scanned meshes
Project Ideas

• Using MS Kinect to create blend shapes
  - 3D print an animation
The Plan for Today

- Projects
- Advanced Materials
Simple Materials
Advanced Materials

- Cellular materials
  - Metamaterials
- Composite materials
  - Functionally graded materials
- Biomimetic/bio-inspired materials
- Materials with structural hierarchy
Cellular Materials

- Regular
  - Lattice truss structures
- Irregular
  - Foam
    - Open-cell
    - Closed-cell
- Properties governed by:
  - Topology
  - Fraction of cell occupied by material
  - Properties of constituent material
Topologies of Cellular Lattices

(a) Honeycomb (square)  
(b) Corrugation  
(c) Pyramidal  

(d) Tetrahedral  
(e) 3D-Kagomé  
(f) Diamond textile  

(g) Square Textile  
(h) Diamond collinear  
(i) Square collinear

http://www.virginia.edu/ms/research/wadley/cellular-materials.html
Topologies of Cellular Lattices

http://www.virginia.edu/ms/research/wadley/celluar-materials.html
Topologies of Cellular Lattices

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Solid Foams

- Open-cell foams (*reticulated foams*)
  - Lighter, softer
- Closed-cell foams
  - Heavier, harder
Mechanical Properties

http://www.virginia.edu/ms/research/wadley/celluar-materials.html
Applications

http://www.virginia.edu/ms/research/wadley/celluar-materials.html
Applications

CETEX System 3, a PEI thermoplastic-core sandwich material used in Airbus A340-500/600 aircraft

Nomex honeycomb in ATEC 212 SOLO

A Nomex honeycomb core was used to build this boat (NEB)

Nomex honeycomb cores

http://www.virginia.edu/ms/research/wadley/celluar-materials.html
Applications

Microcellular Foams and Elastomers
- 800 kg/m³

High Density Foams
- 400 kg/m³

Low Density Foams
- 6 kg/m³

density
stiffness

fabric coatings and synthetic fibers
vehicle facia and other exterior parts
structural foam

footwear outsoles
footwear midsoles
integral skin foam for vehicle interiors

high resiliency foam for bedding and upholstery

packaging foam

flexible
semi-rigid
rigid

simulated wood

insulation foam
Cellular Materials in Nature

http://www.virginia.edu/ms/research/wadley/cellular-materials.html
3D Printing Cellular Materials

- Many structures can be printed using FDM
- Closed-cell foams are difficult to print
Mechanical Metamaterials

- Periodic cellular structures made of polymers, ceramics, or metals

- Mechanical properties can be designed to have values which cannot be found in nature
Negative Poisson’s Ratio
Negative Poisson’s Ratio
Negative Poisson’s Ratio
Pentamode Metamaterials (Meta-fluids)

- Solid that behaves like a fluid
- Hard to compress, easy to deform
Composite Materials

- Made from two or more constituent materials
  - At least one matrix and one reinforcement material e.g., polymer + fiber
Matrices

- Polymer
  - Thermosets (Epoxy, Polyester)
  - Thermoplastics (Polystyrene, Nylons)

- Metal
  - Alloys (Steels, Aluminiums)

- Ceramic
  - Glass
  - Ceramics (Semi conductors, Cermets)
  - Cements

- Carbon and Graphite
Composite Materials: Boeing 787 Dreamliner

Materials used in 787 body:
- Fiberglass
- Carbon laminate composite
- Carbon sandwich composite
- Aluminum/steel/titanium

Total materials used by weight:
- Composites 50%
- Aluminum 20%
- Titanium 15%
- Steel 10%
- Other 5%

By comparison, the 777 uses 12 percent composites and 50 percent aluminum.
Mechanical Properties

![Graph showing the relationship between Young's Modulus (E) and Density (ρ) for various materials. Each material is represented by a dot or ellipse on the graph. Key materials include carbon fibres, Kevlar fibre, carbon fibre composites (parallel to fibres), carbon fibre composites (perpendicular to fibres), fibreglass composites, steels, aluminium, titanium, glass, polymer resins, and wood (parallel to grain and perpendicular to grain).]
Why Composite Materials

• Advantages
  - Lower density (20 to 40%)
  - Higher directional mechanical properties
  - Strength (ratio of material strength to density)
    • 4 times greater than that of steel and aluminum
  - Higher fatigue endurance
  - Higher toughness than ceramics and glasses
  - Versatility and tailoring by design
  - Easy to machine
  - Can combine other properties (damping, corrosion)
  - Cost
Why Not Composite Materials

• Disadvantages
  - Not often environmentally friendly
  - Low recyclability
  - Can be damaged
  - Anisotropic properties
  - Matrix degrades
  - Low reusability
Functionally Graded Materials (FGMs)

- A special case of composite materials
- Composition and structure of the constituent materials can gradually change
Functionally Graded Materials (FGMs)
FGM Origin

• The “first” FGM developed in Japan in 1984-85
• Many FGM materials have existed for decades
• Some FGM also occur naturally
  - Bones and teeth
  - Seashells
FGM Motivation

- FGMs allow better customization and tailoring of materials for specific tasks

Stiffer at clamped end

Softer at clamped end

More variety in material selection for engineering design
FGM Classification

- Gradation
  - Continuous vs. Stepped
3D Printing FGMs

- FGMs can be printed using inkjet-based 3D printers
  - Mix before UV-curing
3D Printing FGMs

- FGMs can be printed using inkjet-based 3D printers
  - Input volume is dithered
Halftoning in 3D
Applications: Aerospace

- Ceramic-metal FGMs are particularly suited for thermal barriers in space vehicles
  - Metal side can be bolted onto the airframe rather than bonded as are the ceramic tiles used in the Orbiter
Applications: Fuel Cells

- Creating a porosity gradient in the electrodes - the efficiency of the reaction can be maximized
Applications: GRIN Optics

- GRIN = Graded Refractive Index

Traditional Lens

GRIN Lens
Applications: GRIN Optics

- GRIN = Graded Refractive Index

http://www.laurawaller.com/opticsfun/sugarGRINlens.htm
FGMs: Advantages and Challenges

• Advantages
  - Multiple functions
    • benefits of different materials e.g., ceramics and metals
  - Control of deformation, dynamic response, wear, corrosion
  - Design for different complex environments
  - Removing stress concentrations

• Challenges:
  - Mass production
  - Quality control
  - Cost
Biomimetic/Bio-inspired Materials

Plant: the energy reservoir
www.gardeningoncloud9.com

Spider silk: tough materials
www.tehrantimes.com

Bird: the natural airplane
http://www.guidetobelize.info

Flagellum: the mechanical motor
http://creationrevolution.co

Lotus leaf: hydrophobic surface
http://sustainabledesignupdate.com

Eye: nature’s best camera
www.photoshopstar.com

Brain: the super computer
www.healthguide.howstuffworks.com

Termites mound the natural cooler
www.animals.howstuffworks.com

Dolphins the best ship
www.fishnature.org
Biomimetic Materials: Gecko Tape

The example of Gecko

setae

spatulae

Scanning electron microscope image of a 1cm² section of the Gecko-sticky tape made of polyimide fibers
Biomimetic Materials: Gecko Tape
Biomimetic Materials: Spider Silk

Connected together, these blocks make the silk fiber.
Biomimetic Materials: Swim Faster

- The structure of shark skin reduces drag in the water leading to more energy efficient locomotion.
Biomimetic Materials: Swimming Faster

- This was big news for the 2008 Summer Olympics
Biomimetic Materials: Strong Materials

- Mollusc Teeth
Biomimetic Materials: Velcro

- Inspired by Burrs
Biomimetic Materials: Velcro

- Detachable adhesive
Biomimetic Materials: Velcro
Biomimetic Materials: Velcro in Action
Materials with Varying Stiffness

- Inspired by sea cucumbers which can alter the stiffness of their dermis (outer skin layer)
- Change the structure of collagen fibers embedded in low stiffness matrix
Materials with Varying Stiffness
Transparent Construction Materials

- Inspired by skeletons of undersea sponges made of glass and Venus Flower Basket
Transparent Construction Materials

- Glass sponge
Mussel Superglue

- Mussels can stay attached to rocks in very strong tides
- They emit a slime that forms a thread-like, ultra-strong, water resistant adhesive on contact with water
Mussel Adhesive in Action
Hydrophobic Materials: Lotus Leaf

- Lotus leaves have a bumpy structure that causes water to bead and roll off

http://en.wikipedia.org/wiki/Lotus_effect
Hydrophobic Materials

Ultra-Ever Dry®
Structural Coloration

The diagram illustrates the principle of structural coloration. Incident light enters from the left, interacts with a thin layer of material, and is reflected back as shown. The angles $\theta_1$ and $\theta_2$ are critical in determining the color seen. The thickness $d$ of the layer also plays a significant role in the color production. The images on the right show examples of structural coloration in nature.
Materials with Structural Hierarchy

- Both man-made and natural
- Structure at more than one scale
- Structural hierarchy can result in improved mechanical properties
- Examples:
  - Bones
  - Livers
That’s all for today!