FWF Seminar

September 24, 2007

Biobased Composite Materials from Macro to Nano Scale: Lessons from Nature and History

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Definition of Science

http://www.dictionary.com/

n.

a. The observation, identification, description, experimental investigation, and theoretical explanation of phenomena.
b. Such activities restricted to a class of natural phenomena.
c. Such activities applied to an object of inquiry or study.
d. Methodological activity, discipline, or study: *I've got packing a suitcase down to a science.*
e. An activity that appears to require study and method: *the science of purchasing.*
f. Knowledge, especially that gained through experience.
g. **Science** Christian Science.

Definition of Science

The science is to find out what have been done, what have not been done and to see what can be investigated.

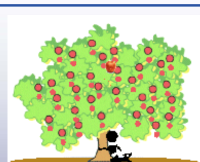
Top Journals

Science, Vol 300, Issue 5626, 13 June 2003

Top Journals

*General **George** S. **Patton***
"Who does not want to be a general will not be a good soldier"

Isaac Newton，1643 ~ 1727 : Universal gravitation



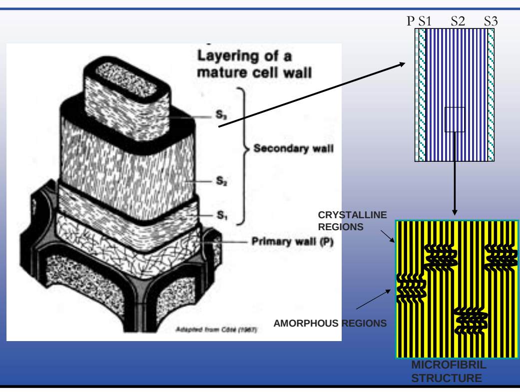
How Pine Cones Open

How Pine Cones Open

The scales of seed-bearing pine cones move in response to changes in relative humidity. The scales gape open when it is dry, releasing the cone's seeds[1]. When it is damp, the scales close up. The cells in a mature cone are dead, so the mechanism is passive: the structure of the scale and the walls of the cells composing the scale respond to changing relative humidity.

[1]. Eichholz, G. *Jb. Wiss. Bot.* 17, 543-588 (1886).

Wood Structure



How Pine Cones Open

Nature **390**, 668 (18 December 1997)

COLIN DAWSON[1], JULIAN F. V. VINCENT1 & ANNE-MARIE ROCCA[2]
[1] Centre for Biomimetics, University of Reading, Reading RG6 6AT, UK
[2] Defence Clothing and Textile Agency, Flagstaff Road, Colchester, Essex CO2 7SS, UK

Dissection of cones from the Monterey pine, *Pinus radiata*, revealed to us two types of scale growing from the main body of the cone — the ovuliferous scale and the bract scale. The larger ovuliferous scales respond to changes in relative humidity when removed from the body of the cone.

How Pine Cones Open

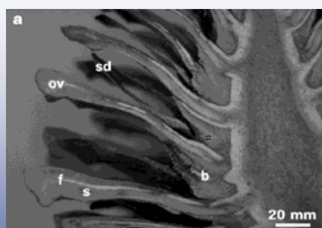
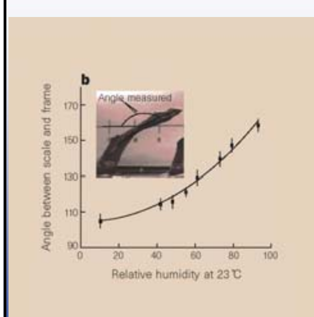


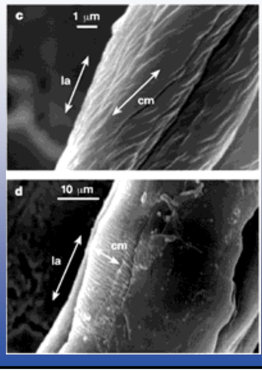
Figure 1. Morphology and behaviour of pine cone scales.
a, Median longitudinal section of female cone; **b**, bract scale; **sd**, seed; **ov**, ovuliferous scale with two-layer structure consisting of; **f**, fibres (white line within the scale) and **s**, sclerids.

How Pine Cones Open



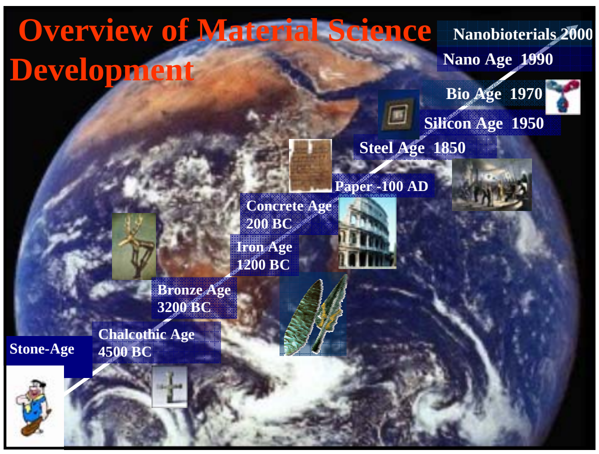
b. Graph plotting the angle a scale makes to the base of the experimental apparatus against relative humidity. Inset: experimental apparatus and measured angle. Five scales were used to calculate mean ± s.e.m.

How Pine Cones Open

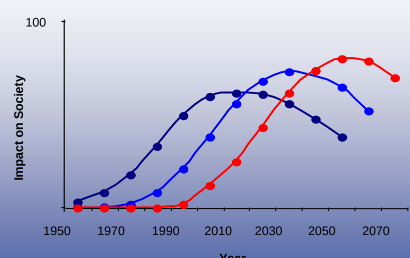


c, d, Scanning electron micrographs of fibres and sclerids, respectively. **θ**, the angle between the long axis (la) of the cell and the direction of winding of cellulose fibres (cm), is high in sclerids and low in fibres.

Overview of Material Science Development



Nanotechnology, "The Next Industrial Revolution"



Nanotechnology 1 to 100 nm

Source: ten Wold 1998

What is Nano???

What is Nano???

What is Nano???

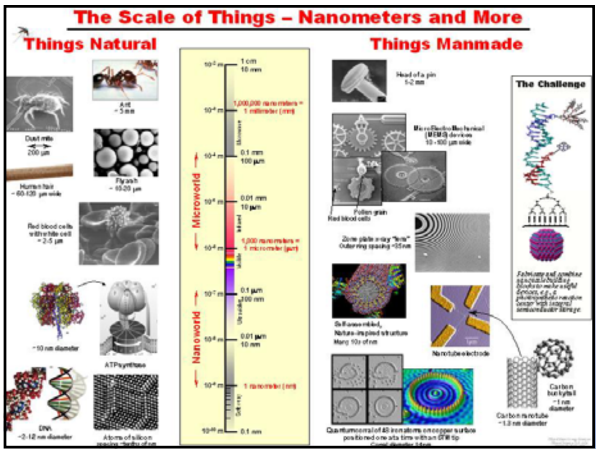
What is Nano???

What is Nano???

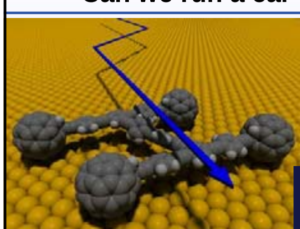
What is Nano??

Nanotechnologies are characterized by structural elements in the ~ 1 – 100 nanometer range

1 m = 1000 mm = 1, 000, 000 µm = 1, 000, 000, 000 nm

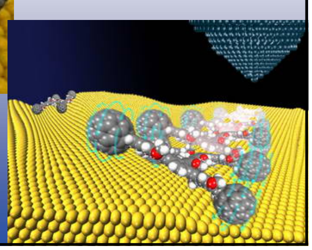


Can we run a car on a human hair?

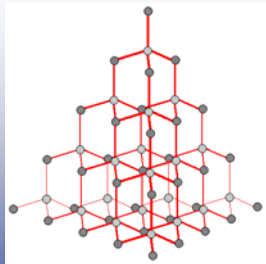


Scientists build world's first single-molecule car

Credit: T. Sasaki/Rice University



Natural Materials: Diamond



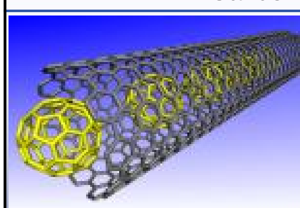
26.6 karats = $5.1 million
Hardness = 90-231 GPa
Modulus = 1141 GPa

At left is the diamond structure showing the carbon-carbon bonding. Bonds closer to the viewer are shown thicker.

Carbon Fiber for Composites

It is the first airplane to be built with more than half composites.

Carbon Nanotube



- Tensile strength 150 GPa, elastic modulus >1000 GPa
- $600/pound
- 100x stronger than steel, 1/6th the weight
- The best thermal conductor (10x greater than copper)

Some Applications for Carbon Nanotubes

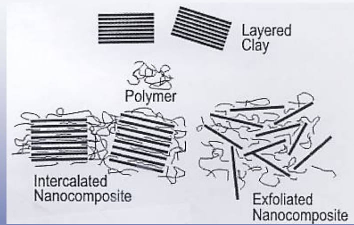
- Structural reinforcements in composites
- Field-emission flat-panel displays
- Conductive plastics
- High-performance fibres
- Chemical sensors
- Artificial muscles
- Portable X-ray machines
- Transistors
- Fuel cells
- Probe tips

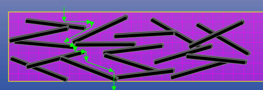
Polymer-nanoclay composites

The thickness of nanoclay in the composite is about 1nm; surface area 750 m^2/g

Barrier coating for food containers and paper packages

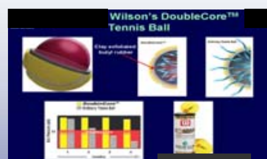
Water and vapor resistance, fatty and oil resistance, board strength

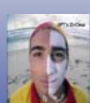




Nano - Application

Nano-Barriers





ZnO
Transparent at ~25 nm

NANO-CARE® fabric protection imparts superior wrinkle/stain resistant fabric

Biorenewable resources, also known biomass, are organic materials of recent biological origin

- Vast majority of the world's biorenewable resources: forest, prairies, mashes and fisheries
- Proteins, oils, and carbohydrates

Natural Materials: Silk fiber

- Nature's nylons- silk fiber from spiders
  - Common orb-weaving spiders spin as many as several different types of silk fibers, each critical to the spider's survival.
    - Strong, tough framework filaments that support the web
    - Elastic filaments that absorb the kinetic energy of insects striking the web
    - Accessory filaments are produced that wrap captured prey or provide cocoon materials.

Natural Materials: Silk fiber

- Nature's nylons- silk fiber from spiders
  - High-molecular-weight linear polymers
  - One of the best high-performance natural materials
    - Tensile strength two to three times greater than steel
    - Elongation-to-break ratio approaching 30 percent
  - Dragline filaments offer an attractive benchmark for next-generation materials because of their exemplary physical and mechanical properties and also because they are processed at ambient temperatures from aqueous media.

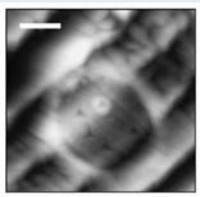
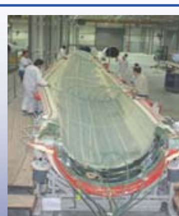


FIG. 2. Topography image of a transverse section of a dragline silk fiber illustrating accurate placement of indents in the fiber. The scale bar is 2 μm. Indents are visible as triangular imprints in the fiber.

J. Mater. Res. 21(8), 2006

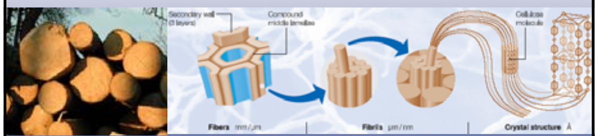
Wind Turbine Blade

MWT-1000A type with a rotor diameter of 180ft, Using the BALTEK balsa core materials for these blades



Cellulose micro/nanofibril

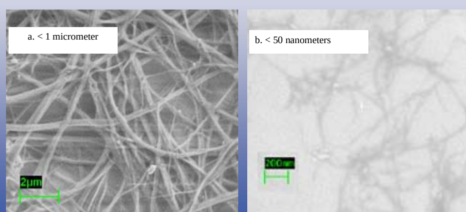
- Cellulose microfibril (CMF), a lightweight, high strength, and tremendous natural resource, is becoming a more and more attractive reinforcing material for composites to researchers. Wood combines high strength and elasticity, which are from the composite structure of its cell walls.
- Perfect natural composite: cellulose fibrils embed in lignin matrix.
- Possibility: Isolate cellulose fibrils and embed them in a polymer matrix.



	Wood	Fibers	Nanocrystal
Modulus of elasticity	10GPa	40-70GPa	130-250GPa
Tensile strength	100MPa	130-250MPa	800-10000MPa

Nanostrutural composites with cellulose nanocrystals

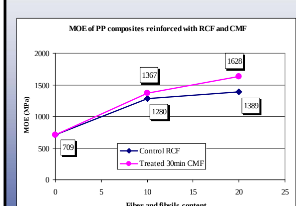
- Nanomaterials are nanoscale materials with structural feature of at least one dimension in range 1-100 nm.
- Cellulose nanocrystals could be prepared by acid hydrolysis of various wood-based materials or no-wood cellulose materials.

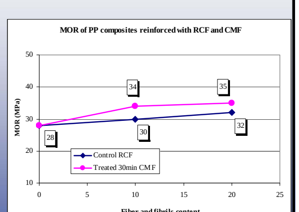


SEM images of cellulose microfibrils liberated from regenerated cellulose fiber

Micro/nanofibril reinforced composites

Tensile properties (Modulus and strength):
Composite from PP and CMF by filtration system followed by compressive molding (Mat):





Control: MOE increased 81 & 96%. MOR increased 7 &14%.
Treated: MOE increased 93 & 130%. MOR increased 21 & 25%.

Cheng et al. Cellulose (in print)

Why forest products industry sector?

- **Lignocellulose is among Nature's most abundant self–assembling materials and its use and functionality for nanomaterials is largely unexplored**
- **The Forest Products Industry Sector is largely a mature commodity industry and would greatly benefit from revitalization**
- **Applications for nanomaterial use abound through out forest products processing and products**

Why forest products industry sector?

- Most wood products (70%) go to residential markets

Sources: Al Schuler, USDA Forest Service

Why forest products industry sector?

- Wood-plastic composite is a very promising material to achieve durability without using toxic chemicals.

Deck and fence

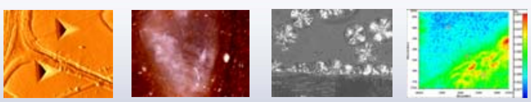
Pool and docks

Door panel (Audi A2)

Source from Nexwood website

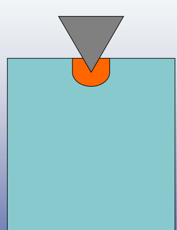
Composite Research Group at TFPC

Raw Materials Characterization…

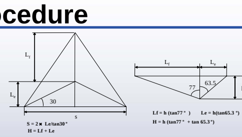


- Statics and kinetics of water vapor sorption of loblolly pine
- Measurement of cell wall mechanical properties by micro column compression test
- Nano-mechanical properties of lignocellulosic materials
- Partners: ORNL, UT-Chem, UT-MatSci

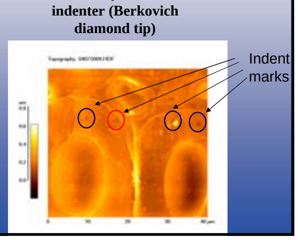
Nanoindentation Instrument and Indentation Procedure



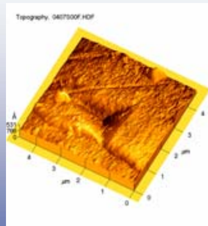
Schematic of the NANO II Indenter

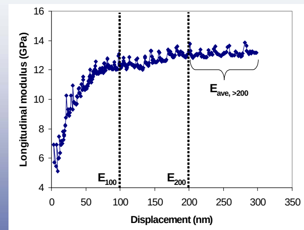


Geometry of nano-indenter (Berkovich diamond tip)



Wood Cell Wall: Loblolly Pine





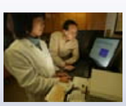
Depth-dependent longitudinal stiffness

Wood properties of ten hardwoods

Species	D_O (g/cm³)	D_S (g/cm³)	E_N (GPa)	E_S (GPa)	E_B (GPa)	H (GPa)	MFA (degree)
Poplar	0.305	0.409	16.9 (1.9)	9.29 (1.9)	8.1	0.49 (0.047)	18.1 (1.69)
Manchurian Ash	0.503	0.584	18.5 (1.9)	12.1 (1.7)	12.9	0.48 (0.048)	12.7 (0.62)
Alder Birch	0.650	0.760	19.7 (1.1)	20.3 (2.1)	12.9	0.49 (0.032)	12.9 (1.42)
Asian White Birch	0.610	0.700	17.5 (2.1)	16.0 (2.3)	11.2	0.45 (0.033)	13.4 (1.33)
Red Oak	0.680	0.718	22.6 (1.5)	16.3 (1.6)	12.6	0.55 (0.037)	10.8 (1.08)
White Oak	0.650	0.730	19.5 (1.8)	13.4 (2.4)	12.3	0.49 (0.028)	15.0 (4.88)
Mongolian Oak	0.679	0.866	18.4 (2.0)	20.6 (4.3)	13.2	0.44 (0.047)	12.0 (0.94)
Iroko	0.706	0.735	22.9 (2.5)	15.3 (1.9)	9.4	0.51 (0.040)	8.75 (1.31)
Kwila	0.839	0.902	21.2 (1.5)	24.3 (2.7)	16.0	0.56 (0.031)	4.17 (4.36)
Keranji	1.135	1.177	24.6 (2.0)	32.9 (7.4)	21.1	0.54 (0.022)	6.30 (1.48)

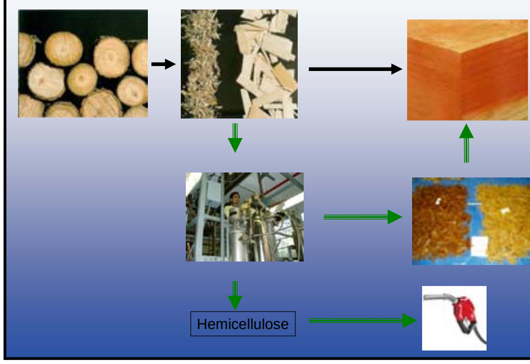
Note: D_o: oven-dry density, D_s: SilviScan density, E_N: elastic modulus from nanoindentation, E_s: elastic modulus from SilviScan, E_B: Bending elastic modulus from references (Alden 1995; Cheng et al. 1992), H: hardness, MFA: microfibril angle.

Composite material developing and processing…



- Interphase investigation in natural fiber reinforced polymer composites via advanced instruments
- Production of improved oriented strandboard using the extracted flakes
- Manufacturing OSB using less-desirable, low-quality and high density hardwood species
- Partners: ORNL, UT-MatSci, L-P Corp.

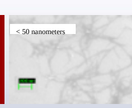
Production of improved oriented strandboard using the extracted flakes



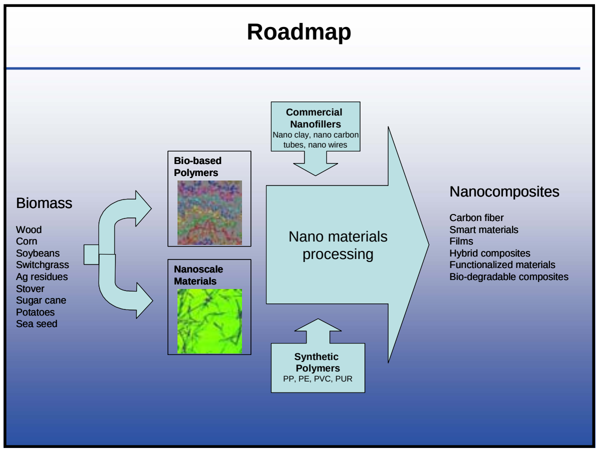
New Invention to Make Structural Engineered Products More Profitable and Stronger

We have invented a nanotechnology based technique to allow mills to produce light weight wood engineered products such as OSB and OSL using existing wood species or using less-desirable and high density hardwood species such as oak. Total saving per year per mill ranges from 2.4 million dollars to 9.7 million dollars if they adopt this technique. This invention could be applied to other wood composites production, such as particleboard and fiberboard as well. The UT Research Foundation is filing a patent application on this invention.

Advanced materials…



- Multifunctional composites
- Nanostructural composites with cellulose nanocrystals
- Sustainable, biodegradable and renewable composites
- Partners: ORNL, UT-MatSci, international partners…


Roadmap
Commercial Nanofillers
Nano clay, nano carbon tubes, nano wires
Bio-based Polymers
Biomass
Wood
Corn
Soybeans
Switchgrass
Ag residues
Stover
Sugar cane
Potatoes
Sea seed
Nanoscale Materials
Nano materials processing
Synthetic Polymers
PP, PE, PVC, PUR
Nanocomposites
Carbon fiber
Smart materials
Films
Hybrid composites
Functionalized materials
Bio-degradable composites


Thank You
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