Renewable Composite Interfaces: Strategies for Making Opposites Attract

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Renewable Composite

- Materials where one of the major constituents is derived from a renewable source
- Examples of renewable sources: wood, agricultural fibers, polymers derived from biomass (cellulose, hemicellulose, lignin), regenerated fibers (e.g. rayon), etc.
- Wood is bonded in over 70% of its applications
**Polymer Composites**

- Polymers are long chain molecules
- Polyethylene, polypropylene, PVC, polystyrene, ABS, bioplastics
- 45-75% wood or ag fiber (~0.150 mm in diameter)
- 25-55% polymer
- 1-25% other (lubricants, coupling agents, talc, biocides, fire retardants, etc.)

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**Why add natural fibers to plastic?**

- Reinforcement
  - 12GPa wood vs. 1 GPa PP
- Cost
  - $0.0125/lb wood vs. $0.90/lb PP
- Density (specific gravity)
  - 1.4 cell wall vs. .96 PP vs. 2.6 glass
- Durability - slows moisture diffusion
  - Biological deterioration requires water
Why is it important for composites?

- Wood is polar and very hydrophilic
- Most polymers are nonpolar and hydrophobic
- Wood and plastic have very little interaction
- Continuity of strain and the transfer of stress across an interface

Adhesion

The tendency of dissimilar molecules to cling together because of attractive forces impacts everyday life.
Ways to make things stick together

- Diffusion
- Chemical bonding
- Molecular interactions
- Adsorption
- Lifshitz-van der Waals interactions
- Mechanical interlock
- Electrostatic

Random Copolymers
A polar component to adsorb and/or react with the wood and a long chain to diffuse into the matrix

**Mechanical Properties**

Addition of 5% copolymer improved strength by more than 100% and elastic modulus by nearly 50%.


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**Molecular Velcro®**

Block Copolymers


Tingaud et al., Macromolecular Chemistry and Physics, 2008.
Copolymer architecture

Tingaut et al., Macromolecular Chemistry and Physics, 2008

Carbon Fibers

- Uses a low value byproduct of cellulosic
  Ethanol production as a Feedstock.
- Most lignin is burned for power generation.
- Current worth is ~ $0.02/lb.
- Current research aimed at adding value to
  lignin.
- Current price of medium grade carbon
  fiber ~> $8/lb.
- Current price of most plastics ~ $0.90/lb.
- Development of rural economies.
- Possible $4 billion industry that would
  increase worldwide carbon fiber production
  1500%.

Carbon fibers have the potential to reduce fuel consumption in transportation applications by reducing weight by up to 2/3.
Lignin Polymer Blends

- Lignin-synthetic blends as precursors for carbon fibers
- Melt extruded fibers
- Exploring copolymers as coupling agents
- Neutron reflectivity at the SNS showed decreasing in interfacial width

Self assembled structures

Bolaform amphiphilics: Hydrophilic headgroup/Hydrophobic core

Goal: Improve dispersion and interaction of lignocellulosics
Bolaforms offer a renewable source of surfactants
Hydrophilic reinforcement (cellulose) + Hydrophobic matrix (polypropylene) is used as a model system
Electron Beam Irradiated Composites

- Matrix for initial study was LDPE
- Irradiated at 80 kGy
- Formulated with di- and tri-functional acrylates and methacrylates

Toughness and creep

E-beam Composite Water Sorption

E-beam vs. No E-beam
Modification of the fiber surface

- Alternative process for wood acetylation (reaction with vinyl acetate)
- Strengthening of interfacial adhesion in wood-polymer composites:
  - Chain entanglement
  - Thermoplasticity
- Hydroxylation
- Crosslinking with AHS (Acrylonitrile-butadiene-styrene)
- Nanocellulosic fibers
- Photostabilization

Courtesy of Dr. Gilles Sève

Nanocellulosic fibers

- Nanocrystalline cellulose fiber (less than 100 nm in diameter)
- Produced by acid hydrolysis of cellulose pulp
- Tendency to aggregate and difficult to disperse
- Grafted hydrophobic vinyl acetate groups on the surface
- Dispersed grafted fiber in THF (tetrahydrofuran)

Photos courtesy of Dr. Nihat Çetin
Summary

- Renewable materials are of growing importance to for economy and stewardship of resources
- Interfaces between materials govern performance
- Strategies covered:
  - Controlled interfacial architecture
  - Coupling agents to bridge the surface and matrix
  - Modify the surface to look like matrix
  - Self assembly of adsorbed materials

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