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Bacterial Cellulose Composites Opportunities and Challenges

(An important & exciting area that needs more public/private partnership)

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What is bacterial cellulose? Why is it unique?

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- Bacterial cellulose—a naturally occurring material:
  - Microbial Exo Poly Saccharides: Dextran, Xanthan, Gellan, Cellulose
  - *Gluconacetobacter, Agrobacterium, Achromobacter, Aerobacter, Azotobacter, Sarcina ventriculi, Salmonella, Escherichia and Rhizobium*
- Bacterial Cellulose—an attractive engineering material:
  - High Modulus (~100 GPa), High Strength (~2 GPa)
  - Low LCTE: (~1 x 10^{-7} K^{-1}), High Aspect Ratio (~50)
  - Nano-sized: Interesting Optical & Barrier Properties
- Bacterial Cellulose—a unique cellulosic material
  - Inherent Purity: free of hemicellulose, lignin, pectin, wax
  - Moldable in cultivation, May be produced directly as coating
  - Natural network structure, High Crystallinity: ~85%, High DP
  - High Carbon-to-Cellulose Conversion Efficiency

RUKA 2012

Production of Bacterial Cellulose

- Resources required for production
  - Carbon source & media (i.e. protein, yeast, agar, pH buffered)
  - Typical cell converts 108 glucose molecules to cellulose per hour
  - Cultured for days-to-weeks in static batch to produce pellicle
  - Alternates: shaking, stirred, air lift, rotating disk → continuous
- Carbon sources used for bacterial cellulose production
  - Glucose, fructose, sucrose, molasses, etc.
  - Sugar alcohols including glycerol
  - Corn steep liquor, potato effluent, grape pomace, whey lactose
  - Tea, guarana, coffee cherry, konjac powder, cacao, cola nut, mate
  - Saccharified food waste
  - >May require dilution and nutritional supplementation<
- Cellulose from Cyanobacteria
  - Nitrogen fixing? Saltwater tolerant?

Bacterial Cellulose in Polymer Composites

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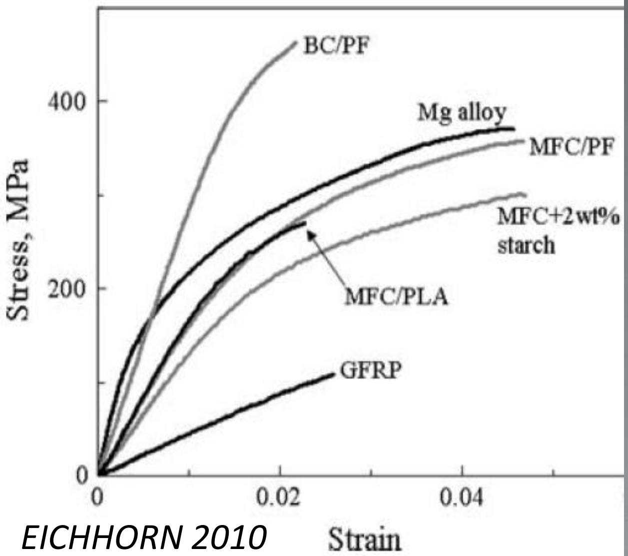
- Nano cellulose as high modulus filler
  - Improve modulus/strength, shear strength in FRPs
  - Lower density than ceramic/metal fillers
  - Adhesive filler for lap shear strength
- In-fiber filler for FRPs
- Hierarchical Composites
  - Low CTE natural fiber coating

  interfacial for NF reinforced composites
- Networked fiber structure
  - Reinforcing sheets, filters, supports
- H-Bonding hierarchical structure→ functional composites
- Challenges: high moisture absorption, aggregation, interfacing, enzyme degradability



EICHHORN 2010

Application Opportunities for BC Composites

- Current products:
  - High quality paper, High-fidelity speakers
  - Wound dressings, Dessert foods
- Vehicle light weighting
  - Structural/non-structural composites
- High performance reinforced composites
  - Wind energy, Civil infrastructure
  - Hydrokinetic energy, Marine infrastructure
- Barrier films and coatings
  - Food packaging
  - Organic electronics (PV, OLED)
  - Energy Storage
  - Building envelope: Vacuum insulation
- Transparent coatings/films/substrates
- Biomedical devices: bone growth, drug delivery
- Aerogels: insulation, sorbents
- Sensors, actuators

Public/Private Partnership Research and Development Needs

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- Issues related to polysaccharide production from bacteria
  - Pathogenicity? Production costs? Product quality/consistency?
  - Kinetics of bacterial cellulose (vs. plant cellulose) growth
  - Cellulose production may be difficult to transfer to other organisms
- Development Needs for Bacterial Cellulose
  - Alternate feedstocks, genetic engineering, process engineering
  - Low cost scaled-up production, isolation methods
  - Compatibilization chemistries, composite processing
- Key Opportunities
  - Industrial waste remediation (i.e. ag residue feedstocks)
  - Net shape fibrous reinforcement (i.e. cultivate in shape)
  - Organism engineering (i.e. cellulose from cyanobacteria)

Bacterial Cellulose for Composites
Conclusions

- Bacterial Cellulose is an attractive high performance natural nanomaterial that can compliment plant cellulose in US manufacturing

- Realization of the opportunities for this material in US manufacturing will require public and private investment to lower production cost and advance composite applications

Leo Fifield with Bacterial Cellulose isolated from Nata de Coco

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