New Uses for Plant Fibers: Biocomposites

C.A. Ulven, Assistant Professor
Mechanical Engineering Department
North Dakota State University (NDSU)

Collaborators:
V. Chevali, S. Pryor, I. Akatov, D. Wiesenborn, & C. Gustafson
- North Dakota State University (NDSU)
S. McKay & M. Alcock - Composite Innovation Centre (CIC)
B. Tande & W. Seames - Univ. of North Dakota (UND)
D. Huotari & S. Geiger - SpaceAge Synthetics, Inc. (SAS)
J. Dworshak - Steinwall, Inc.

Current NDSU Students:
M. Fuqua, S. Huo, L. Gibbon, J. Lattimer, B. Nerenz, B. Bakke, & J. Flynn
Natural fibers have been used as reinforcement in base materials globally long before the term "composite material" was ever coined.

- Straw and horsehair used to reinforce clay bricks
- Composite materials R&D began only in the mid 1960s
- Majority of R&D has focused on synthetic fibers in composite materials
Motivation for Biocomposites Research

Biocomposite materials will emerge as an important engineering material as the technology evolves through strong collaboration by several facets of the entire production process:

- Farmers & Processors
- University & Industry Researchers
- Commodity Groups
- Plastics & Composite Manufacturers
A multidisciplinary team has been assembled focused on improving the growth, harvesting, treatments, and development of new agri-based precursors for processing structural biocomposites in local and regional composite manufacturing facilities for use in a wide range of applications.
Role of Natural Fibers in Biocomposites

- Lighter weight
- Low dermal abrasion
- Reduction in energy consumption
- Better vibration dampening capabilities
- Better insulation and sound absorption properties
- Better degradation when service-life is exhausted
- Reduction in the dependence on petroleum based products

Candidate Natural Fibers in ND
Fibers: Flax, Corn, Sunflower, Sugar Beat, Switch Grass, etc.
## Natural Fiber Properties

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Density (g/cm³)</th>
<th>Elastic Modulus (GPa)</th>
<th>Specific Modulus (GPa/g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-glass</td>
<td>2.55</td>
<td>73</td>
<td>29</td>
</tr>
<tr>
<td>Hemp</td>
<td>1.48</td>
<td>70</td>
<td>47</td>
</tr>
<tr>
<td>Flax</td>
<td>1.4</td>
<td>60-80</td>
<td>43-57</td>
</tr>
<tr>
<td>Jute</td>
<td>1.46</td>
<td>10-30</td>
<td>7-21</td>
</tr>
<tr>
<td>Sisal</td>
<td>1.33</td>
<td>38</td>
<td>29</td>
</tr>
<tr>
<td>Cotton</td>
<td>1.51</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>
Natural Fiber Processing Challenges

Manufacturing challenges:
- Flow is poor due to a rough surface and low bulk density
- Uneven fiber quality
- Limited length, limited processes
- Low degradation temperature

Preparation after harvesting:
- Washed to remove dirt and core material
- Dried to decrease the moisture content
- Chopped to short lengths or left to length

Composite processing techniques: film stacking, compression molding, pultrusion, injection molding, extrusion, vacuum bagging, resin transfer molding, thermoforming, and stamping
Natural Fiber Biocomposite Project Areas

Short Fiber Research

✓ Utilization of “waste” cellulose fiber
✓ DDGS, Sunflower Hull, Sugar Beet Pulp, Oat Hull, etc.

Long Fiber Research

✓ Utilization of residual flax, hemp, grasses, etc.
✓ Aspect Ratios (L/D) >2000
Biocomposites To-Date

*Fibers:*
flax, flax shive, hemp, sugar beet pulp, sunflower hull, DDGS, corn chaff, corn cob, oat hull, etc.

*Polymers:*
polypropylene, polyethylene, acrylonitrile butadiene styrene, polymethyl methacrylate, vinyl ester, epoxy, etc.

*Fiber volume fractions from 5-50%*

*Multitude of chemical treatments*
Untreated natural fibers

- Consist of crystalline cellulose, amorphous hemicellulose, lignin, waxes, proteins, and pectin
- Cellulose nanostructure has strong hydrogen bonding through hydroxyl groups, yielding high strength
Natural Fiber Surface Treatments

The improvement of natural fiber composite properties can be accomplished by modifying the natural reinforcing fibers using physical and chemical methods.

- **Physical methods**: stretching, calendaring, thermo-treatment, electronic discharge, and the production of hybrid yarns.
- **Chemical methods**: mercerization, latex coating, gamma radiation treatment, silane treatment, toluene diisocyanate (TDIC) treatment, acetylation, and peroxide treatment.

- Treatments decrease the diffusion coefficient, sorption coefficient, and permeability coefficient of the fiber.
- Treatments can also adversely affect the mechanical properties.
Grinding into Particulates for Short Fiber Biocomposites

<table>
<thead>
<tr>
<th></th>
<th>$l$ (µm)</th>
<th>$d$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>94</td>
<td>44</td>
</tr>
<tr>
<td>Max</td>
<td>863</td>
<td>320</td>
</tr>
<tr>
<td>Std. dev</td>
<td>101</td>
<td>39</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>$l/d$</td>
<td>2.11</td>
</tr>
</tbody>
</table>
Short Fiber Biocomposite Processing Strategy

Neat Plastic Pellets
Natural Fiber Filler
Reinforced Plastic Pellets

Compression Molding
Injection Molding

Twin Screw Extrusion
Short Fiber Biocomposite Results

Injection Molded Polypropylene (PP) w/ 10 wt% fiber loading

*Other fibers investigated include: hemp, flax shive, oat hull, pea hull, soybean hull, etc.
Short Fiber Biocomposite
Results Cont.

Coefficient of Linear Thermal Expansion – Polypropylene (PP)

*Other properties investigated include: impact, heat distortion temp., UV resistance, moisture absorption, etc.
Polymethyl methacrylate (PMMA) reinforced with 10 wt% Sunflower Hull fiber increases both strength and stiffness.

*Other polymers investigated include: acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and post-industrial recycled polyolefins (LDPE, HDPE, PP, etc.)
Natural Fiber Filler Performance in Recycled Polymers

- Virgin HDPE sees greater effects of corn cob inclusion on tensile strength
- Fiber without modifier causes strength decrease
- MAPE addition leads to improved strength,

- Virgin and recycled HDPE sees similar elastic modulus performance
- Compatibilizer loading plays no significant role
Biocomposite materials from NDSU are being/have been evaluated by different molding facilities throughout the U.S.

- Great Plains Plastic Molding, Fargo, ND
- Steinwall, Inc., Coon Rapids, MN
- Advanced Tooling Concepts, Longmont, CO
- Molded Materials, Inc., Plymouth, MI

*Trial structural step parts produced with NDSU biocomposite material by Great Plains Plastic Molding
John Deere Company
Moline, IL

- Developing biocomposite injection molded parts for John Deere tractor equipment
- Steinwall, Inc. is the molder for several John Deere parts
New partnership with MCG BioComposites, LLC based in Cedar Rapids, Iowa, to provide technical assistance in developing biocomposite materials for industrial and commercial applications…

“The partnering with Dr. Chad Ulven and his research group in the Mechanical Engineering Department at NDSU will help our company with the numerous applications for new materials we have indentified.” according to Sam McCord, President & CEO of MCG BioComposites, LLC.
• Polyvinyl chloride (PVC) is a high volume engineered plastic with a wide range of applications
• PVC is an attractive polymer for adding natural fiber reinforcement in order to tailor desired strength and stiffness
Long Fiber Biocomposite Results

- Flax and hemp fibers have been investigated using a multitude of chemical surface treatments
- Results show tensile, flexure, & interfacial strength to increase but stiffness to decrease as a result of chemical treatment
- Results indicate flax and hemp can compete with fiberglass in composite applications
• ND flax fiber collected from flax seed production to make horticultural products such as mulch mats for gardens and trees and hanging basket liners
• Shive content ~ 40% by weight
• Fiber length ~ 2 cm to 6 cm
• Fiber aspect ratio of over 2000
• Moisture content ~ 8 to 10 wt%
Randomly orientated flax fiber mat / polyester composite protective cover for a hydrogen tank mounted on the front end of an experimental hydrogen assisted diesel tractor at NDSU.

Protection from impact, environmental degradation, etc. provided for tank.
Development of lightweight sprayer booms

- Less Soil Compaction
- Improved Fuel Economy
- Longer Spans
- Corrosion Resistant

Sprayer Boom Tip Prototypes

10 ft Composite Boom
10 ft Steel Boom

30’ Boom Design in FEA
SpaceAge Synthetics, Inc. manufactures rigid polyurethane (PU) foam reinforced with E-glass composites (Thermo-Lite Board®) for replacing traditional applications of plywood.
Applications of Thermo-Lite Board® Composites
Biocomposites Research Funding To-Date

Funding To-Date (4 yrs, over $600k):
- AGCO Corporation
- Composites Innovation Centre (CIC)
- ND Corn Council
- US DoE / ND EPSCoR – SUNRISE
- NSF / ND EPSCoR – Startup & AURA Program
- USDA / CSREES National Research Initiative Competitive Grants Program
- National Canola Growers Association

Funding Next 2 yrs (over $250k):
- ND Centers of Excellence – SUNRISE Bioproducts
- Composites Innovation Centre (CIC)
- AGCO Corporation
- MCG Biocomposites, LLC

Students:
Graduate - M. Fuqua, M. Hanson, S. Huo, D. Huotari, S. Mekic, W. Manamperi, J.D. Espinoza-Perez, M. Tatleri & A. Thapa
Undergraduate - B. Aakre, L. Gibbon, E. Hall, E. Kerr-Anderson, B. Miller, A. Reich, N. Sailer, L. Dionne, & Several ME Senior Design Teams