Cellulose-based Composites: From Tunicates to Timber

Professor Steve Eichhorn
ACCIS/NCC Conference
21st November 2019

bristol.ac.uk/composites
Talk Overview

• What is cellulose?
• Where does it come from?
• Natural fibre composites
• Nanocellulose
• Project case studies
• Back to Timber
• Future perspectives

Anselme Payen (1795 – 1871)
Died on 13th May, 1871
Pete Eichhorn – built a VJ23 (Volmer Jensen design) from scratch and flew it for many years

Mainly made from wood
Leading edge – poplar plywood
Nose ribs – marine grade plywood
Wing spar cap strips and tail ribs - spruce
What is cellulose and where from?

Chlorophyll

$6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$

The most important equation on the planet!

Trafficking of the cellulose synthase complex in developing xylem vessels
Raymond Wightman, Simon Turner

Bicton Gardens, April 2018 (Spring!)
Natural Fibres

- Cotton
- Flax
- Jute
- Bluebell tunicate
- Wood
- Hemp
- Kenaf
- Nettle (Ramie)
- *Eichhornia crassipes*
Natural Fibre Composites

Henry Ford and the hemp/Soybean oil composite

George Washington Carver (1860s – 1943)

Mercedes A-200 using flax reinforced panels

Hemcrete – hemp fibre lime for insulation materials
### Nanocellulose

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g cm(^{-3}))</th>
<th>Modulus (GPa)</th>
<th>Specific modulus (GPa g(^{-1}) cm(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (crystal)</td>
<td>1.6</td>
<td>137</td>
<td>~86</td>
</tr>
<tr>
<td>Cellulose (fibril)</td>
<td>~1.5</td>
<td>39-65</td>
<td>~26-43</td>
</tr>
<tr>
<td>Cellulose (fibre)*</td>
<td>~1.5</td>
<td>Flax: 27.6</td>
<td>~18-85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jute: 26.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ramie: 61.4 – 128(!)</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>7.8</td>
<td>200</td>
<td>~26</td>
</tr>
<tr>
<td>Wood (pine)</td>
<td>0.5</td>
<td>9-16 (parallel to grain)</td>
<td>18-32</td>
</tr>
</tbody>
</table>

What if you were able to extract the crystalline properties of cellulose?
Nanocellulose

Native cellulose (microfibrilar)

Cellulose Nanocrystals

Wood

Cotton

Tunicin

Bacterial Cellulose

Tunicate cellulose nanocrystals

H_2SO_4
Nanocellulose Properties

Modulus of a single nano-whisker of tunicate cellulose is found to be 143 GPa by this Calculation. Expected high stiffness – potential exploitation


Modulus values of
150.7 ± 28.8 GPa (unmodified)
145.2 ± 31.3 GPa (TEMPO oxidated)

Strength values: Wood: 1.6 – 3 GPa; Tunicate : 3 – 6 GPa

Taking Waste from Paper Mill Sludge

Cellulose Nanofibre Composites

- FiberLean is a form “microfibrillated cellulose” (MFC) produced by mechanical disintegration of pulp.
- MFC is formed by interconnected and entangled flexible cellulose fibrils of different length and thickness which forms a complex networked morphology.
- MFC is naturally hydrophilic and incompatible with polyolefins.

Polarised light micrograph of Fiberlean

Confocal image of PPPE/Fiberlean

Tannic acid (natural extract from plants)

Tannic acid modified MFC + resin

EngD within the IDC in Composites Manufacturing

The Future – what is sustainable?

Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs (Bruntland 1987)

“The fact is that we live in a world that has been profoundly shaped by empire and its disparities. Differentials of power between and within nations are probably greater today than they have ever been. These differentials are, in turn, closely related to carbon emissions. The distribution of power in the world lies at the core of the climate crisis”


- Non-renewable
  - Oil
  - Coal
  - Natural Gas

- Renewable
  - Timber
  - Plants
  - Wool

- Replenishable
  - Water
  - Soil
  - Air


Solomon Islands
Flooding in India
Acknowledgements

Many thanks to the EPSRC and Royal Society for funding of the research.

Cynthia Adu
(Cranfield)

Caterina Palange
(Fiberlean/UoB)
Thankyou for listening!

Email.s.j.eichhorn@bristol.ac.uk