BC experience

- Established 1989
- Original focus on wood based panels, pulp and paper, and novel products from agricultural residues
- Pilot plant for particleboard and MDF production
- Long natural fibres in non-woven mats for composites and insulation
- Resins from plant oils and extracts
- Bio-derived products in a wide range of applications
- New Technology Transfer Centre at Mona on Anglesey opened in 2006
Introduction

Green trends in construction:
• Awareness of green products and topics
  • e.g. green roofs, natural fibre insulation, solar panels, heat exchangers, geothermal heating, etc...
• Code for Sustainable Homes
  Zero Carbon by 2016
  (aspiration for 2011 in Wales)
• Energy efficiency and CO₂
• But also: water, materials, surface water run-off, waste, pollution, health and well-being, management, ecology

Introduction

Green trends in construction:
• Government “Strategy for Sustainable Construction”
  • The means:
    o Procurement
    o Design
    o Innovation
    o People
    o Better Regulation
  • The ends:
    o Climate change mitigation
    o Climate change adaptation
    o Water
    o Biodiversity
    o Waste
    o Materials

Construction Industry

• Natural materials have a long history of use in construction
• Timber frame housing has evolved from medieval cruck frames into a sophisticated set of techniques for fast assembly of sustainably sourced housing
• Move toward Modern Methods of Construction such as modular assembly and off-site construction
• Natural fibre composites could make an increasing contribution to the development of these systems

Introduction to Natural Fibre Composites

Why the interest in NFCs?
• “Green”
• Sustainable - natural fibres are renewable
• Lock-up CO₂
• Net negative greenhouse gas emissions
• Reduced reliance on fossil fuels
• Low embodied energy
• Improve the properties of plastics
• Cost

Natural Fibres

• Cellulose in fibres gives plants strength
• Good mechanical properties
• Low density
• Long fibres are available from the stems, leaves or fruit of many plants
  • e.g. Hemp, jute and flax;
  • Sisal, abaca and curauá;
  • Coir, kapok and cotton
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  - Coir, kapok and cotton
- There are many grades of fibre depending on the level of fibre separation, pulping or extraction method

Wood Plastic Composites

- Blends of 40 to 60% wood flour in PE, PP or PVC
- Wide range of profiles can be extruded for applications including decking, fencing and window frames
- Work now looking at improving the strength for higher value products
- Oriented surface layers can increase strength properties
- e.g. Short span bridges using o-WPC

Wood Plastic Composites and filled plastics

- Recent BC success
- Recycled MDF fibre for WPC decking
- Microrelease project
- System to generate recycled MDF fibre is now being commercialised
### Wood and WPC (40% fibre loading)

<table>
<thead>
<tr>
<th>Material</th>
<th>Flexural strength (MPa)</th>
<th>Flexural modulus (GPa)</th>
<th>Specific gravity</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak</td>
<td>96.0</td>
<td>11.3</td>
<td>0.61</td>
<td>38.9</td>
</tr>
<tr>
<td>Pine</td>
<td>76.0</td>
<td>11.2</td>
<td>0.46</td>
<td>70.5</td>
</tr>
<tr>
<td>PVC</td>
<td>42.0</td>
<td>5.2</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>HDPE</td>
<td>19.6</td>
<td>3.8</td>
<td>1.12</td>
<td>0.7</td>
</tr>
<tr>
<td>PP</td>
<td>47.9</td>
<td>3.3</td>
<td>1.05</td>
<td>1.1</td>
</tr>
</tbody>
</table>

### WPCs

- **What can we build?**
  - Decking
  - Short-span bridges
  - Pontoons and walkways

- **What can’t we build?**
  - Structural members of buildings
  - Long spans
  - Lightweight structures

- **Bending strength is a big challenge**

### Good compressive resistance

**WPCs for Marine Piling**
- Interest in the USA
- Large government funded project to investigate WPC for marine applications
- Large dimension extruded sections for use in sill plates and chock members

### Other Natural Fibre Composites

**Natural Fibre Composites**
- To better use the strength of the natural fibre the composite needs fibre lengths greater than the critical fibre length
- Initial work has looked at natural fibres as reinforcement in traditional matrices
- Non-woven mats
- Woven fabrics such as linen or hessian
- Flax or hemp sliver can give unidirectional composites

### Properties of NFCs with thermoset polyester matrices in comparison with glass fibre composites

<table>
<thead>
<tr>
<th>Property</th>
<th>E-glass</th>
<th>Flax Fibre</th>
<th>Hemp Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [µm]</td>
<td>8-14</td>
<td>5-40</td>
<td>10-50</td>
</tr>
<tr>
<td>Density [g/cm³]</td>
<td>2.56</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>E-modulus [GPa]</td>
<td>75</td>
<td>27.6</td>
<td>35</td>
</tr>
<tr>
<td>Tensile Strength [GPa]</td>
<td>1.4-3.5</td>
<td>0.6-1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Elongation to Fracture [%]</td>
<td>1.6-1.2</td>
<td>0.7-2.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Specific E-modulus [GPa/g/cm³]</td>
<td>30</td>
<td>18.4</td>
<td>25</td>
</tr>
<tr>
<td>Specific Tensile Strength [GPa/g/cm³]</td>
<td>0.9-1.3</td>
<td>0.4-1.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength</th>
<th>Modulus</th>
<th>Strain to break [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure polyester resin</td>
<td>25.8</td>
<td>3.1</td>
</tr>
<tr>
<td>44% Hemp non-woven mat</td>
<td>53.0</td>
<td>3.7</td>
</tr>
<tr>
<td>42% Glass fibre mat</td>
<td>43.0</td>
<td>3.9</td>
</tr>
</tbody>
</table>

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*WPC Chock members in Iraq, Port Hueneme, California. Source: Smith and Wolcott (2006) Forest Products Journal 56(3):4-11*
Natural Fibre Composites

- Many forms of "standard" composite manufacture process are possible:
  - e.g. hand lay up, vacuum bagging, resin transfer moulding
- Some interest in developing sheet moulding compound and pultrusion systems
- Data for model systems with unidirectional fibres is becoming more widely reported
- Factors affecting NFC performance include:
  - Porosity
  - Fibre quality and fibre preparation
  - Fibre surface and matrix effects
  - Fibre architecture

NFCs

- Applications in buildings?
- Limited examples so far
- Low cost roofing for tropical countries

Natural fibres

- Insulation products
- Many natural fibres
  - e.g. flax, straw, sheep's wool
- Supplied as a roll or as sheet

Natural fibre insulation

- Natural fibre insulation systems have been developed to allow offsite manufacture
- Modcell manufacture panels with straw bale insulation and timber structural components
- The panels can be dry-lined or rendered with a lime render
- Offsite production leads to rapid and reliable onsite assembly

Pre-fabricated cassettes for walls

- Structural Insulated Panels (SIPs) incorporating insulation, membranes, skins etc
- Timber frame construction
- Pre-fabricated product reduces variability by factory conditions during manufacture
- Reduced scope for moisture ingress into natural fibre or uptake by timber

Insulation

- With many forms of timber construction the U-values for the wall are good
- But not good enough for the new zero carbon homes standard of energy efficiency
- Thermal bridging effects
- Need to consider solutions, e.g. moving some of the insulation outside the structural wall to prevent bridging by the timber posts and studs
Hemp-lime mortar

• A natural fibre composite, with a mineral matrix not a polymer!
• Traditional building material with a modern twist

Traditional technologies

• Many timber products used in construction are “composites”
• Plywood
• OSB
• Glulam
• MDF

Newer technologies

• Some less well known timber composites for construction include
• Laminated veneer lumber (LVL)
• Parallam, Scrimber, Timberstrand and similar products
• Timber I-joists

Laminated veneer lumber

• Formed from veneers of wood
• Unlike plywood, the veneers are aligned in the same direction
• Forms very strong sections for joists and beams
• Dispersion of defects (e.g. knots) and guaranteed grain direction leads to superior performance compared to solid wood

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Parallel strand lumber

• Strands of wood, up to 1.5m long, are laid up uni-directionally
• Resin may be PF or PMDI
• Large posts, beams, headers, sole plates for timber frame construction
• Strength values are greater than solid wood
Parallel strand lumber

- System commonly used in North America

<table>
<thead>
<tr>
<th></th>
<th>Bending N/mm²</th>
<th>Tension N/mm²</th>
<th>Compression N/mm²</th>
<th>Mean E N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS redwood or whitewood</td>
<td>7.5</td>
<td>4.5</td>
<td>7.9</td>
<td>10500</td>
</tr>
<tr>
<td>Glulam LB whitewood</td>
<td>10.4</td>
<td>6.25</td>
<td>8.2</td>
<td>11025</td>
</tr>
<tr>
<td>Kerto-S LVL</td>
<td>13.9</td>
<td>12.3</td>
<td>15.7</td>
<td>12750</td>
</tr>
<tr>
<td>Microllam LVL, DF, grade 2.0E</td>
<td>15.7</td>
<td>15.3</td>
<td>14.3</td>
<td>12575</td>
</tr>
<tr>
<td>Parallam PSL</td>
<td>16.8</td>
<td>14.6</td>
<td>15.1</td>
<td>12750</td>
</tr>
</tbody>
</table>

Grade stresses for timber and structural composites (based on BS 5268)

Parallel strand lumber

- Life Cycle Analysis (LCA) by Weyerhaeuser showed net carbon storage for Parallam and Microllam

Timber I-joists

- Weight-saving option for joists
- Web is either plywood or OSB
- Flanges are either solid wood or LVL

Cross-laminated wood

- Panels formed with thin planks of wood
- Cross laminated to give orthotropic strength
Opportunities for other composite systems
• Novel Glulam constructions
• CF-Reinforced glulam beams
• Repairs to timber beams
  • e.g. modified flitch and upgrade using metal dowels and resins

Combining with other new technologies
• Acetylated timber bridge
• Acetylated wood has increased durability and decreased moisture movement
• Glulam structure with steel tensioning

Conclusions
Progress in natural fibre composites:
• Wood plastic composites are finding applications in low load situations
• Future challenges to improve the handling and processibility of long fibre composites, e.g. SMC options may lead to new applications
• Natural fibres are suitable for insulation
• Hemp-lime mortars have seen increased interest for green building
• Wood-based composites remain the main natural composite for construction

Acetylated timber bridge
Location: Motorway bridge, Netherlands
Conclusions

Timber composites in construction:

• Glulam is well established and seeing increased use in the UK
• Products such as LVL and Parallel Strand Lumber are being used in a greater range of building components
• New products have been developed suitable for Modern Methods of Construction, e.g. cross laminated panels, stressed skin panels and I-joists
• New technologies like acetylation can improve durability and expand the range of applications

Thank you for your attention!