Wettability and swelling of acetylated and furfurylated wood analyzed by a multicycle Wilhelmy plate method

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Why wettability study?

**Target Properties**
- Good wettability
  - Adhesion
  - Hydrophilicity
- Weak wettability
  - Hydrophobicity
  - Dimensional stability

**Examples**
- Adhesives, coatings
- Chemical modification
- Impregnation
- Performance
- Service life
BACKGROUND

multi-cycle Wilhelmy plate method

\[ F(h) = P_y \cos \theta - \rho Ahg + F_w(t) \]

BACKGROUND

multi-cycle Wilhelmy plate method

\[ F(h) = P \gamma \cos \theta - \rho Ahg + Fw(t) \]

\[ F_A = P \gamma \cos \theta_A \]

- Contact angle
- Dynamic sorption
- Dimensional stability
- Extractives dissolution
BACKGROUND

multi-cycle Wilhelmy plate method

\[ F(h) = Pγcosθ - ρAhg + Fw(t) \]

- Contact angle
- Dynamic sorption  \( \text{liquid mass} \% = \frac{F_{fn}}{W_o} \times 100 \)
- Dimensional stability
- Extractives dissolution

SP Technical Research Institute of Sweden
BACKGROUND

multi-cycle Wilhelmy plate method

\[ F(h) = P \gamma \cos \theta - \rho A h g + F w(t) \]

- Contact angle
- Dynamic sorption
- Dimensional stability
- Extractives dissolution


\[ P_n = P_{n-1} + (F_{f,n} - F_{f,n-1}) \frac{\Delta P}{\Delta F_f} \]

\[ P_n \ & P_{n-1} : \text{veneer parameters after cycle} \ n \ \text{and} \ (n-1) \]
\[ F_{f,n} \ & F_{f,n-1} : \text{final forces for cycle} \ n \ \text{and} \ (n-1) \]
\[ \Delta P = P_f - P_0 \]
\[ \Delta F_f: \text{total changes in final force} \]
BACKGROUND

multi-cycle Wilhelmy plate method

\[ F(h) = P \gamma \cos \theta - \rho A h g + F_w(t) \]

- Contact angle
- Dynamic sorption
- Dimensional stability
- Extractives dissolution
  - Measuring surface tension of water before and after a multicycle test

\[ \Delta \gamma = \gamma - \gamma_f \]
OBJECTIVES

• Applying multi-cycle Wilhelmy plate method on modified wood in order to study dynamic wetting and swelling, as well as dimensional stability

• Evaluating the effect of level and type of modification on capillary uptake and swelling rate of modified wood samples
MATERIALS AND METHODS

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Sample type</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS22.2</td>
<td>Acetylated SYP with 22.2% acetyl content</td>
</tr>
<tr>
<td>US22.2</td>
<td>Unmodified SYP matched to AS22.2</td>
</tr>
<tr>
<td>AS15.9</td>
<td>Acetylated SYP with 15.9% acetyl content</td>
</tr>
<tr>
<td>US15.9</td>
<td>Unmodified SYP matched to AS15.9</td>
</tr>
<tr>
<td>FS28</td>
<td>Furfurylated SYP with WPG of 28%</td>
</tr>
<tr>
<td>FS45</td>
<td>Furfurylated SYP with WPG of 45%</td>
</tr>
<tr>
<td>FS54</td>
<td>Furfurylated SYP with WPG of 54%</td>
</tr>
</tbody>
</table>

SYP: Southern Yellow Pine

- Thermally treated veneers at 104 °C for 1 h (MC=0%)
- Freshly cut veneers
MATERIALS AND METHODS

- Liquids
  - Water swelling liquid
  - Octane non-swelling liquid

- Multi-cycle Wilhelmy plate method
  - 20C for water and 10C for octane

- Perimeter determination by doing an octane immersion

- Dimensional stability – using the perimeter model
### RESULTS and DISCUSSION

#### Contact angle

<table>
<thead>
<tr>
<th>Sample name</th>
<th>( \text{CA}_{\text{app}} ^\circ ) thermally treated sample</th>
<th>( \text{CA}_{\text{app}} ^\circ ) fresh sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS15.9</td>
<td>81( \pm )5</td>
<td>72( \pm )1</td>
</tr>
<tr>
<td>US15.9</td>
<td>81( \pm )3</td>
<td>55( \pm )9</td>
</tr>
<tr>
<td>AS22.2</td>
<td>73( \pm )5</td>
<td>76( \pm )1</td>
</tr>
<tr>
<td>US22.2</td>
<td>63( \pm )5</td>
<td>58( \pm )3</td>
</tr>
<tr>
<td>FS28</td>
<td>63( \pm )5</td>
<td>54( \pm )7</td>
</tr>
<tr>
<td>FS45</td>
<td>87( \pm )4</td>
<td>70( \pm )3</td>
</tr>
<tr>
<td>FS54</td>
<td>65( \pm )7</td>
<td>58( \pm )3</td>
</tr>
</tbody>
</table>
RESULTS and DISCUSSION

Sorption - Furfurylated samples

- A fast regime with filling the voids and capillary action
- A slower regime with liquid up-take by diffusion/swelling
RESULTS and DISCUSSION

Sorption- Furfurylated samples

- Furfurylation decreases both the porosity and the degree of swelling
- Higher liquid repellency with higher level of modification
RESULTS and DISCUSSION

Sorption- Acetylated samples

- Lower rate and level of swelling for acetylated samples
- Lower liquid uptake for the sample having more latewood
Results and discussion - dimensional stability

Graphs showing the perimeter change (%) against cycle number for different materials:

- **Graph a)**
  - Materials: AC15.9, US15.9, AC22.2, US22.2
  - X-axis: Cycle No.
  - Y-axis: Perimeter change (%)

- **Graph b)**
  - Materials: FS28, FS45, US
  - X-axis: Cycle No.
  - Y-axis: Perimeter change (%)
RESULTS and DISCUSSION

Acetylation vs. Furfurylation

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Water up-take (F_{f20}) (%)</th>
<th>Octane up-take (F_{f10}) (%)</th>
<th>ΔP_{20} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS15.9</td>
<td>34.1±1.6</td>
<td>21.0±1.5</td>
<td>3.7±0.5</td>
</tr>
<tr>
<td>US15.9</td>
<td>54.3±1.5</td>
<td>28.0±2.9</td>
<td>12.2±5.6</td>
</tr>
<tr>
<td>AS22.2</td>
<td>41.9±3.7</td>
<td>34.8±6.2</td>
<td>2.5±0.3</td>
</tr>
<tr>
<td>US22.2</td>
<td>70.6±4.2</td>
<td>36.3±3.2</td>
<td>9.9±1.2</td>
</tr>
<tr>
<td>FS28</td>
<td>21.3±4.5</td>
<td>11.8±0.6</td>
<td>7.0±4.1</td>
</tr>
<tr>
<td>FS45</td>
<td>12.7±1.5</td>
<td>8.5±0.7</td>
<td>0.8±0.7</td>
</tr>
<tr>
<td>FS54</td>
<td>18.1±4.9</td>
<td>12.6±3.0</td>
<td>1.8±0.3</td>
</tr>
</tbody>
</table>

- Swelled cell wall due to chemical bonds for both type of modification
- Highly branched and cross-linked polymer in furfurylated samples
CONCLUSION

• Multicycle Wilhelmy plate method is a suitable technique for studying the dynamic wetting, swelling and liquid sorption behaviour of modified wood

• Lower contact angle for freshly cut veneers than thermally treated ones
• Acetylation makes the wood surface more hydrophobic
CONCLUSION

• Lower liquid (water and octane) uptake, lower swelling and higher
dimensional stability for furfurylated samples than acetylated ones

• Earlywood SYP shows higher liquid uptake/swelling than the latewood region

• By multicycle Wilhelmy in a swelling liquid (water) and non-swelling
liquid (octane), it is possible to study the capillary uptake and
swelling rate

• Acetylation mainly affects the swelling part of water uptake, while
furfurylation decreases both capillary uptake and swelling level
ACKNOWLEDGEMENTS

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Thanks for your attention!