Improved properties for wood by thermomechanical modification?
Background

• In general, Finnish wood species have relatively low density
• This restricts their use in applications which require hardness, durability and abrasion resistance
  – Furniture, floor materials, etc.
• Need for a substitute for tropical hardwood
• Only a few wood modification technologies have been commercialized in Europe
• Combined use of temperature, moisture and mechanical action (THM) is a promising technology for wood modification

Boards before and after the compression and thermal modification.
Viscoelastic behaviour of wood

• The mechanical properties of wood depend on temperature and moisture it is subjected to.
• At long periods of high temperatures and high moisture content wood exhibits rubbery elastic behavior.
• At the glass transition temperature ($T_g$) stiffness of wood decreases rapidly.

Figure: Length 1999
Glass transition temperature

- Different polymers (lignin, hemicellulose and semi-crystallized cellulose) have unique glass transition temperatures ($T_g$)
- High moisture content reduces $T_g$
- At high moisture content lignin determines the minimum temperature of THM processing

Figure: Salmén 1982
Set-recovery effect

- Compressed wood springs-back without further treatment because of its internal stresses.
- These stresses can be relaxed at high temperatures in a saturated steam environment.
- Set-recovery can be almost totally eliminated at temperature of 180–200°C under humid conditions.

Wood compression and methods of fixation at the cell level. Figure: Sandberg et al. 2013.
Target

• The main target of the study is to examine structural changes caused by the THM modification

• Utility of the results
  – New applications for modified wood
  – Boost to the wood product industries in their product development
  – Technology development in the engineering industry
Research Material

- Scots pine and Norway spruce logs from Juankoski, Finland
- Each board (280 pc.) had a nominal cross-cut dimension of 40 mm × 100 mm and length of 2700 mm
Process

• The modification processes were executed in the industrial-sized pilot kiln, owned by Nextimber Ltd.
• Kiln allows drying, compression and thermal modification at the same unit
• Air was circulated through the holes of the perforated aluminium plates to enhance the evaporation of moisture from the wood surface
• The boards were compressed using hydraulic press
## Treatments

<table>
<thead>
<tr>
<th>Batch</th>
<th>N</th>
<th>Initial moisture content</th>
<th>Compression target</th>
<th>Actual compression degree</th>
<th>Thermal treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine, reference</td>
<td>28</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pine, G</td>
<td>28</td>
<td>Green</td>
<td>30%</td>
<td>31%</td>
<td>–</td>
</tr>
<tr>
<td>Pine, G + TM</td>
<td>28</td>
<td>Green</td>
<td>30%</td>
<td>31%</td>
<td>3 h, 190 °C</td>
</tr>
<tr>
<td>Pine, MC20</td>
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<td>30%</td>
<td>15%</td>
<td>–</td>
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Preliminary results – mechanical properties
Modulus of elasticity, Scots pine

ISO 13061-4:2014

Columns not sharing the same letter show significant difference (P<0.05)
Modulus of elasticity, Norway spruce

ISO 13061-4:2014

Reference
G
G + TM
MC20
MC20 + TM

\[ \text{MPa} \]

Juhani Marttila 25 April 2017
Modulus of rupture, Scots pine

ISO 13061-3:2014

![Graph showing the modulus of rupture for different treatments of Scots pine.](image)
Modulus of rupture, Norway spruce

ISO 13061-3:2014

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Brinell hardness, Scots pine

EN 1534:2010

![Bar chart showing Brinell hardness values for different conditions.](image-url)
Brinell hardness, Norway spruce

EN 1534:2010
Case hardening, Scots pine

CEN/TS 14464:2010

Reference G G+TM MC20 MC 20+TM

![Graph showing case hardening results with error bars]

![Image of Scots pine sample with text "102 CH4"]
Case hardening, Norway spruce

CEN/TS 14464:2010

![Graph showing measurements in millimeters for different treatments: Reference, G, G+TM, MC20, MC20+TM.]

![Image of a wood sample with measurements marked.]

Juhani Marttila 25 April 2017
Conclusions

• Thermal modification reduces MOR at 12% MC (presumed in ISO 13061-3) but...

• In normal operating conditions this is effectively compensated by lower equilibrium moisture content of the TM boards (moisture content and MOR correlate negatively)

• Brinell hardness of pine substantially increases in densification but there was no significant difference in spruce between the reference and G+TM treated boards

• Densification causes case hardening but subsequent thermal modification eliminates it – a promising result for further processing
Thank you!