Mechanical, physical and chemical properties of wood, heat-treated with the vacuum-press-dewatering method

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1 Introduction

Trends:
- Intensified use of renewable primary products
- Growing ecological awareness tends to result in using fewer chemical preservatives

Advantages:
- Increasing durability
- Increasing dimensional stability

➢ Heat-treated wood gains in importance
➢ Different methods to produce heat-treated wood are developed
2 Vacuum-press-dewatering – Vacu³

- Technology
  - Conductive heat transfer with heating platens
  - Vacuum up to 150mbar
  - Airbag-system applies a pressure up to 70tons
  - Condensation water is exhausted during the entire treatment
### Investigated industrial treated hardwood

<table>
<thead>
<tr>
<th>Properties</th>
<th>untreated (u)</th>
<th>medium (m)</th>
<th>high (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mechanical and physical</td>
<td>beech</td>
<td>beech</td>
<td>beech</td>
</tr>
<tr>
<td></td>
<td>ash</td>
<td>ash</td>
<td>ash</td>
</tr>
<tr>
<td></td>
<td>poplar</td>
<td>poplar</td>
<td>poplar</td>
</tr>
<tr>
<td>chemical</td>
<td>beech ash oak</td>
<td>beech ash oak</td>
<td>beech ash oak</td>
</tr>
</tbody>
</table>

*The treatment temperatures of the samples which were investigated of mechanical/physical and chemical properties are the same, but the process management was different.*
4 Properties of heat-treated wood
4.1 Physical and mechanical properties

- Colour changes
- Density
- Brinell hardness
- Bending strength
- EMC and Swelling
4.1 Physical and mechanical properties

4.1.1 Colour changes $\Delta E_{ab}$

in relation to untreated wood

$\Delta E_{ab}$ [-]

rad | tang | rad | tang | rad | tang | rad | tang | rad | tang
m   | h    | m   | h    | m   | h    |     |      | h   |
beech| ash  |      |      |      |      |      |      |      |      |

* m: medium; h: high; rad: radial; tang: tangential
4.1 Physical and mechanical properties

4.1.1 Colour changes in relation to untreated wood

- Unequal colour distribution caused by red heartwood
- Treated with high temperature
4.1 Physical and mechanical properties

4.1.1 Colour changes in relation to untreated wood

- Colour changes effect by a treatment with Vacu$^3$ is low compared to a treatment in an autoclave
4.1 Physical and mechanical properties

4.1.2 Density

\[ \rho \ [\text{kg/m}^3] \]

\begin{tabular}{c|c|c}
<table>
<thead>
<tr>
<th></th>
<th>untreated</th>
<th>medium</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>beech</td>
<td>250</td>
<td>350</td>
<td>450</td>
</tr>
<tr>
<td>ash</td>
<td>550</td>
<td>650</td>
<td>750</td>
</tr>
<tr>
<td>poplar</td>
<td>950</td>
<td>850</td>
<td>950</td>
</tr>
</tbody>
</table>
\end{tabular}
4.1 Physical and mechanical properties

4.1.3 Brinell hardness

![Graph showing Brinell hardness for beech, ash, and poplar woods with different orientations and levels of hardness. The graph indicates that beech wood has the highest hardness, followed by ash, and then poplar. The annotations include notes on medium (m) and high (h) levels, and radial (rad) and tangential (tang) orientations.](image-url)
4.1 Physical and mechanical properties

4.1.4 Bending strength

\[
\sigma \text{ [N/mm}^2]\]

- u: untreated
- m: medium
- h: high

<table>
<thead>
<tr>
<th>Material</th>
<th>u</th>
<th>m</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.1 Physical and mechanical properties
4.1.6 Equilibrium moisture content (EMC)

![Graph showing equilibrium moisture content (EMC) for different types of wood.](image-url)
4.1 Physical and mechanical properties

4.1.7 Swelling tangential and radial
4.2 Chemical Properties
by T. Hofmann and T. Rétfalvi, Sopron, University of West Hungary

- pH-value
- Total Phenol content
- Loss of VOCs (volatile organic compounds)
  - acetic acid
  - formic acid
  - furfural
- Complex investigation of condensation water exhausted during heat-treatment
4.2 Chemical Properties

4.2.1 pH-value

![pH-value diagram]

- **pH** value:
  - *u*: untreated
  - *m*: medium
  - *h*: high

- **Materials**:
  - beech
  - ash
  - oak
4.2 Chemical Properties

4.2.2 Total phenol content

[mmol Quercetin/100g dry wood]

- u: untreated
- m: medium
- h: high
### 4.2 Chemical Properties

#### 4.2.3 Volatile organic compounds (VOC)

<table>
<thead>
<tr>
<th>sample</th>
<th>formic acid*</th>
<th>acetic acid*</th>
<th>furfural*</th>
</tr>
</thead>
<tbody>
<tr>
<td>beech</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>untreated</td>
<td>1.53 ± 0.84</td>
<td>33.26 ± 7.31</td>
<td>0.60 ± 0.27</td>
</tr>
<tr>
<td>medium</td>
<td>2.19 ± 1.48</td>
<td>53.44 ± 33.12</td>
<td>4.84 ± 4.43</td>
</tr>
<tr>
<td>high</td>
<td>3.32 ± 1.61</td>
<td>48.62 ± 13.44</td>
<td>2.86 ± 1.17</td>
</tr>
<tr>
<td>ash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>untreated</td>
<td>1.44 ± 0.84</td>
<td>6.43 ± 1.23</td>
<td>not detectable</td>
</tr>
<tr>
<td>medium</td>
<td>4.89 ± 2.61</td>
<td>94.25 ± 58.07</td>
<td>4.61 ± 2.26</td>
</tr>
<tr>
<td>high</td>
<td>3.43 ± 1.59</td>
<td>60.21 ± 26.41</td>
<td>2.52 ± 1.41</td>
</tr>
<tr>
<td>oak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>untreated</td>
<td>3.06 ± 0.34</td>
<td>141.89 ± 36.94</td>
<td>2.58 ± 0.68</td>
</tr>
<tr>
<td>medium</td>
<td>2.76 ± 0.31</td>
<td>75.57 ± 32.34</td>
<td>27.36 ± 8.28</td>
</tr>
<tr>
<td>high</td>
<td>2.58 ± 0.42</td>
<td>27.32 ± 8.34</td>
<td>7.35 ± 0.74</td>
</tr>
</tbody>
</table>

* in mg /100g dry wood; reviewed by the flask method (40°C, 24h); mean value ± 95% confidence
4.2 Chemical Properties
4.2.4 VOC time course – beech medium

<table>
<thead>
<tr>
<th>time after treatment</th>
<th>formic acid*</th>
<th>acetic acid*</th>
<th>furfural*</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 weeks</td>
<td>2.19 ± 1.48</td>
<td>53.44 ± 33.12</td>
<td>4.84 ± 4.43</td>
</tr>
<tr>
<td>20 weeks</td>
<td>4.26 ± 0.55</td>
<td>36.79 ± 9.83</td>
<td>2.26 ± 0.77</td>
</tr>
<tr>
<td>40 weeks</td>
<td>3.25 ± 1.52</td>
<td>43.14 ± 22.75</td>
<td>3.45 ± 2.13</td>
</tr>
<tr>
<td>52 weeks</td>
<td>3.35 ± 1.95</td>
<td>47.90 ± 37.70</td>
<td>4.55 ± 3.88</td>
</tr>
</tbody>
</table>

*in mg /100g dry wood; mean value ± 95% confidence

**Trends** of mean values:
- formic acid at the highest after 20 weeks
- acetic acid and furfural decrease after 20 weeks and rise again to 52 weeks
4.2 Chemical Properties
4.2.5 Compounds in condensation waters

- Absolute concentration [g/l] of the most VOC compounds in condensation waters

<table>
<thead>
<tr>
<th>Source</th>
<th>Furfural</th>
<th>Acetic acid</th>
<th>Formic acid</th>
<th>5-methyl-Furfural</th>
<th>Guaiacol</th>
<th>2,6-dimethoxy-phenol</th>
<th>Vanillin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ash</td>
<td>1.81</td>
<td>49.6</td>
<td>7.0</td>
<td>2.34</td>
<td>0.660</td>
<td>0.059</td>
<td>0.217</td>
</tr>
<tr>
<td>oak</td>
<td>25.53</td>
<td>108.1</td>
<td>13.6</td>
<td>6.46</td>
<td>0.115</td>
<td>0.166</td>
<td>0.416</td>
</tr>
</tbody>
</table>

- High concentration of VOCs (composition depends on wood species) have technological aspects and raise waste handling and environmental issues
- Application fields for the valuable compounds amongst others in chemical industry or in food industry
- Alternatively the utilization of the mixture as a whole could be considered
5 Summary

- Vacu³ method is an effective wood modification process
- Vacu³ effects lower colour changes as other treatment processes
  - unequal colour distribution for heat-treated beech samples with red heartwood
- Strength decrease for all samples except for ash medium
- Swelling decrease with increasing treatment temperature up to 61% compared to untreated wood
- The produced wood is characterised by low VOC emissions
- Condensation waters are highly acidic and concentrated, containing valuable compounds
Thank you for your attention