THERMAL MODIFICATION OF BIRCH USING SATURATED AND SUPERHEATED STEAM

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ABSTRACT

During the thermal modification, wood is normally exposed to temperatures between 160 - 220°C. As a result physical and chemical changes are taking place and some of the wood properties are changed. Dimensional stability and weather resistance are improved. On the other hand the mechanical strength properties are usually negatively affected by the treatment. The visual appearance is also changed. There were two different types of thermal modification processes used in this study. One of them was using saturated steam and the other one superheated steam. Treatment temperature was 160°C in saturated steam process and 185°C in superheated steam. The wood species used in this study was Silver birch (Betula pendula). In the chemistry part the acid content was investigated. Despite the 25°C lower treatment temperature, birch modified in saturated steam was more acidic compared to birch modified in superheated steam. Some differences in equilibrium moisture content (EMC) and dimensional stability were found mainly in the environment T=20°C and RH=85%. The colour of birch treated in saturated steam at 160°C was darker than the colour of birch treated in superheated steam at temperature 185°C.

Key words: Saturated steam, Superheated steam, Thermal modification, Heat treatment

INTRODUCTION

Environmental aspects have increased interest to develop new, alternative wood modification methods. Thermal modification using adjustable treatment parameters is one of them. Thermal modification of wood causes both chemical and physical changes. The changes depend on different factors such as process, treatment parameters, wood species, moisture content and sometimes even on dimension of treated wood. Usually the thinner, having smaller cross-section samples are easier to treat. The major part of property changes during the treatment process are caused by chemical reactions taking place in the wood cell structure. It is well known that hemicelluloses are degrading during thermal modification process (Stamm 1956, Kollman and Fengel 1965, Tjeerdema et al 1998, Sivonen et al. 2002). Acetyl groups of hemicelluloses are split of during heating and as a result acetic acid is formed (Kollman and Fengel 1965). In hardwoods, acetic acid formation is mainly due to the degradation of the hemicellulose glucuronoxylan (Theander and Nelson 1998). Low- molecular organic aids such as acetic and, especially, formic acid are volatile and are difficult to collect and analyse (Sundqvist et al. 2006). Dimensional stability of heat treated wood is related to

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degradation of polysaccharides and hemicelluloses as they can bond water in cell wall and are greatly influenced by the process. This degradation process leads to formation of products that interact less with water but also to evaporation and leaching during the heat treatment. It is well known that cellulose in wood contributes considerably to its mechanical properties. Sundqvist et al. (2006) found that treatments for birch at 180°C for 1 to 2.5 hours reduced strength and hardness significantly. Losses in mechanical properties can be linked to the mass loss and increase in formic and acetic acid concentrations. Time and especially the heat-treatment temperature have a significant influence on changes in colour. It has been shown that hygrothermally treated birch has a rapid decrease in lightness early in the heat treatment process and at fairly low temperature between 160°C and 180°C.

MATERIAL AND METHODS

Raw material and processes

Wood species used in this study was Silver Birch (Betula pendula) from Eastern part of Finland. Birch was through and through sawn and seasonally dried and then further kiln dried in vacuum to moisture content approximately 12%. The drying temperature was kept fairly low in order to avoid any type of discoloration. After kiln drying the 4 – 4.5 meter long and 32 mm thick boards were cut into three parts. One part was used as a reference, second and third parts were thermally modified in superheated and saturated steam respectively. Number of boards in each batch was 20. Density of untreated wood was 543 kg/m³ as an absolute dry. Superheated modification was carried out in a typical kiln drying chamber. The process is commonly known as a Thermowood® process. The process is using steam as a heat transfer medium and an inert blanket to limit oxidative processes. Normally in Thermowood process the treatment temperatures are varying between 180°C-215°C. Treatment temperature used in this study was 185°C having two hours duration in maximum temperature. These treatment parameters meet the requirements set for class Thermo-S. The process using saturated steam is carried out in a pressurized (5-8 bar) autoclave cylinder while the process using superheated steam is operating all the time at normal atmosphere in a typical drying chamber. There is not any particular, intensive drying phase during the process. Process is semi-closed having a possibility to release pressure if necessary. Treatment temperature used in this process was 160°C having one hour duration in maximum temperature.

Test methods

Colour measurement

The colour of wood was measured from planed and defect free surface. There were three measurement points in each sample, taken into consideration the whole width of the board. The shown value is the average from these measurements. The colour measurement device used was Minolta Chroma Meter CR210. It measures the colour in a three dimensional colour space according to CIE L*a*b* system and standard. L*a*b* colour space uses rectangular coordinates. In this colour space, L* indicates lightness varying between L*= 0 (black)...L*=100 (white), a* and b* are the chromaticity coordinates. In chromaticity diagram a* and b* indicate colour directions: +a* (red) direction, -a* (green) direction, +b* (yellow) direction, and -b* (blue) direction.
**Equilibrium moisture content (EMC)**

EMC was determined in conditioning chamber with constant 20°C temperature and three different relative humidity (RH) settings; RH 35 %, / RH 65 % / RH 85 %. Size of the samples was 200 (l) x 100 (w) x 20 (t) mm. All the tested batches had 22 samples. The final moisture content was determined by using oven dry method.

**Dimensional stability**

Dimensional stability was determined in same conditions as EMC tests. Dimensions of the samples were measured in longitudinal, tangential and radial direction. The results are expressed as a swelling percentage (%) and then compared to absolute dry (0%) dimensions.

**Acidity (pH)**

The samples for the tests were milled from defect free boards. The saw dust (1g) was mixed with 20 ml water solution with 3% NaCl and put in ultrasonic bath for 120 minutes. The pH was measured with pH meter Metrohm 744. Titration of acid equivalents in the solutions was performed with sodium hydroxide (NaOH) 0.01002M. Measurements were repeated after 24 and 96 hours before the solutions were finally neutralized.

**RESULTS**

**Colour measurements (L*a*b*)**

The colour measurements showed that both the treatments result in significant L*-value decrease (Fig. 1). The average L*-value of saturated steam treated birch was 52.7. The L*-value of birch treated in superheated process was 2.8 L*-units lighter even though process temperature was 25°C higher. No colour difference was observed when outer and inner surfaces from each sample were measured. Difference in a*-value between the treatments was 1.6 units, indicating slightly more redness after process in saturated steam. Difference less than 0.2 units in b*-value was observed.

| Table 1. The average colour L*a*b*-values and standard deviation (std). |
|-----------------|--------|--------|--------|--------|
| L*   | std   | a*     | std   | b*     | std   |
| Reference       | 80.92  | 0.97   | 4.41   | 0.39   | 17.01  | 1.1   |
| Superheated 185°C | 55.48  | 2.15   | 8.19   | 0.32   | 19.89  | 0.67  |
| Saturated 160°C  | 52.72  | 2.20   | 9.81   | 0.82   | 19.73  | 1.28  |
Equilibrium moisture content and dimensional stability

EMC of untreated birch in RH 85% was 15.2%. The difference to birch treated in saturated steam was 5.0% and even bigger compared to birch treated in superheated steam 6.8%. Dimensional stability was determined by measuring dimensions of samples in three different relative humidity conditions. This test showed that birch treated in superheated and saturated steam performed similarly in all RH (Fig. 2).

Acidity

The pH of birch treated in saturated steam (pH 2.90) was lower than the pH of birch treated in superheated steam (pH 3.54). As presented in Table 3, acid content of birch treated in saturated steam was more than three times higher than in superheated steam treated birch.
**Table 3.** Measured pH, consumed alkali during titration and acid contents (mainly acetic acid) of thermally modified birch.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Consumed alkali, NaOH [ml]</th>
<th>(Acetic) acid content* [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated 160°C</td>
<td>2.9</td>
<td>43.2</td>
<td>2.90</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>15.7</td>
<td>0.97</td>
</tr>
<tr>
<td>Superheated 185°C</td>
<td>4</td>
<td>-</td>
<td>0.39</td>
</tr>
<tr>
<td>Reference</td>
<td>3</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*Acetic acid content was determined on the rough assumption that most of the titrated acid equivalents arise from acetic acid.

**DISCUSSION**

There is only small L*a*b* colour value difference between birch treated in saturated steam at 160°C and superheated steam at 185°C. The difference is less than three units in lightness (L*) and 1.5 units in redness (a*). EMC of thermally modified birch with both the treatment methods was significantly lower than EMC of untreated birch. The difference in EMC between untreated and thermally modified birch increases with higher relative humidity (RH). Birch modified in saturated steam at 160°C is clearly more acidic compared to birch modified in superheated steam at 185°C. Some preliminary bending strength and Brinell hardness tests were carried out as well. Reduction of bending strength is bigger than expected in saturated steam process. This might have the consequence that the heat treatment temperature should be decreased and the operating moisture content of wood optimized. Any significant difference in hardness was not detected.

**CONCLUSIONS**

Both the thermal treatments carried out in either superheated or saturated steam in this study result in several positive properties. First of all improved dimensional stability and weather resistance are the desired characteristics. But there are also properties which are requiring compromises and optimization regarding the process and parameters used during the process. Thermal modification in saturated steam produces more acidic birch compared to thermal modification in superheated steam. This might have consequences, requiring more research e.g. concerning surface treatment and fixation.
REFERENCES


