Environmental Friendly Wood Linings for Outdoor Exposure

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TT2-162

ABSTRACT

One of the most important parameters for the durability of wood linings for outdoor exposure is the amount of surface checks that are initiated already in the sawing procedure. The main object for this project is to test the durability under outdoor exposure for wood from two different sawing patterns. At conventional sawing pattern tangential surfaces are exposed, while the star-sawing method gives radial surfaces. The development of cracks and changes in appearance has been investigated on radial and tangential surfaces of pine (Pinus sylvestris L.) and spruce (Picea abies Karst.) which have been exposed for outdoor climates for 61 months. The annual ring orientation is the most important factor for crack development on weathering. The type of wood and impregnation treatment has only a marginal effect on the crack development. After 61 months of outdoor exposure, tangential surfaces of pine have 1.7 – 2.2 times more total crack length per unit area than the corresponding radial surfaces. In spruce, the total crack length on the tangential surfaces is 2.2 – 2.6 times greater than on the radial surfaces. Tangential surfaces of both pine and spruce have a greater number of cracks per unit area and wider cracks than the corresponding radial surfaces. Tangential and radial surfaces show the same colour change in the surface as a result of weathering.

KEYWORDS

Weathering
Pinus sylvestris L.
Picea abies Karst.
Cracks
Star sawing
1. INTRODUCTION

The sensitivity of the wood to degradation is one of its greatest weaknesses in outdoor usage. Like all biological materials, wood decomposes under the influence of the surrounding environment. When wood is exposed outdoors above ground, a complex decomposition process continues in the material as a consequence of chemical, biological, mechanical and light energy related factors. A common name for this process is "weathering" (Feist 1982).

The factors which are generally considered to cause changes in wood surfaces on weathering are sunlight (UV, visible and infrared radiation), moisture (dew, rain, and snow), temperature and oxygen (Hon 1983).

Because of the limited ability of light to penetrate into wood (Browne and Simonson 1957), the effect of the weathering is limited to a 2.5 mm thick surface layer and the erosion is slow, 5 – 12 mm per 100 years (Feist and Mraz 1978).

Investigations of the effect of weathering on wood, carried out by different researchers, have dealt with several aspects, e.g. colour change (Fengel and Wegener 1984, Sandermann and Schlumbom 1962, Sell and Leukens 1971), erosion (Arnold et al 1992, Feist and Mraz 1978, Feist and Hon 1984), free radicals (Hon et al 1980; Hon and Feist 1981; Hon and Shiraiishi 1991), surface wetting characteristics (Kalnins and Knaebe 1992; Kalnins and Feist 1993), anatomical changes (Miniutti 1967, Borgin 1970, 1971, Borgen et al 1975, Derbyshire and Miller 1981, Sandberg 1999), and strength (Derbyshire et al 1995, Raczkowski 1980). Of the whole electromagnetic spectrum, it is only the short wave length i.e. energy-rich region, which has a measurable influence on wood and which, is thus of technical interest. As a consequence, a large number of studies have been carried out within this field and summaries of earlier result have been published by e.g. Kenaga and Cowling (1959), Desai (1968), Kringstad (1969), Hon and Glasser (1979) and Hon and Shiraiishi (1991).

On a macroscopic level, the colour change of an untreated wood surface is one of the firsts and perhaps the clearest sign of the degradation of the wood during outdoor exposure. Visible light and UV-radiation alter the colour of the wood to a darker or lighter shade, depending on the type of wood (Sandermann and Schlumbom 1962; Fengel and Wegener 1984). After a long period of outdoor use, all types of wood develop a greyish appearance (FRN 1966; Sell and Leukens 1971) due to the fact that water -soluble decomposition products are removed and the more or less delignified fibres are exposed. If, on the other hand, the wood surface is protected against rain, it develops a dark red-brown surface (Browne 1959).

The photochemical degradation is a very slow process, which during a decade degrades only a few millimetres of the wood surface and leaves the underlying wood practically unaffected (Hon and Ifju 1978). The combined effect of water and sunlight degrades the main components of the wood and transforms the wood surface into a network of weakly connected cellulose fibrils which are strongly contaminated by spores from micro-organisms (Sell and Wälchli 1969). 

Visible cracks arise in the wood surface during outdoor exposure because of the growth of micro-cracks formed during the drying of the wood, photochemical reactions or moisture-induced stress fields (Coupe and Watson 1967). Stamm (1965a) considers that wood for outdoor use should have vertical annual rings giving radial surfaces. This minimizes the risk of cracks as a consequence of anisotropy in moisture movements. Cracks in the radial surface are also smaller than in the corresponding tangential surfaces (Browne 1960; Stamm 1965a, 1965b).

The aim of the present investigation has been to characterize differences in the degradation process on macro-level between radial and tangential wood surfaces of Scots pine and Norway spruce exposed outdoors above ground.
2. MATERIAL AND METHOD

In this test fully quarter-sawn and plain-sawn wood of Scots pine (*Pinus sylvestris* L.) (denoted for short pine) and Norway spruce (*Picea abies* Karst.) (denoted for short spruce) have been used. The timber for the investigation was of forest-scale quality and was taken from Sweden.

The sawing was carried out according to a sawing pattern, which was a combination of star sawing and through-and-through, as shown in figure 1. For the test only boards with a rectangular cross section was used. All the pieces were edged immediately after the sawing. The edging was carried out as parallel as possible to the pith direction of the wood, i.e. no so-called taper edging was carried out. All the test material was then dried simultaneously in a drying chamber with the same drying schedule.

The samples were planed on all surfaces to facilitate the determination of crack length and the planning was made with the top end in the planing direction to a depth of 2.5 mm. The final cross section dimension was 95 x 22 mm. After planning, the wood has been pressure impregnated with a CCA-agent.

From each board 4 knot-free and defect-free test pieces with a length of 484 mm have been prepared. The end-wood surfaces were sealed with an oil alkyd primer and a silicone-based sealing compound.

The dry density was determined for all samples: pine 565±44 kg/m$^3$ and spruce 475±42 kg/m$^3$.

The samples were exposed in Stockholm for 61 months (July 1997 – July 2002) at an inclination of 45 degrees towards the south. Three different surfaces were exposed; radial, tangential surface inside face exposed and tangential surface outside face exposed, figure 1. Table 1 presents a summary of the test material.

After outdoor exposure, all the samples were conditioned for two months at a temperature of 20°C and a relative humidity of 65%. Thereafter, the lengths of all cracks, i.e. both on the exposed flat side and on the back side, were determined with crack widths greater than 0.25 mm, which was the smallest crack width that could be measured in practice. The method for crack measurement is described in Malmquist (1984) and Sandberg (1999). For the analysis below the portion of specimens with observable cracks in each group was also determined.

![Figure 1. Sawing pattern used for preparation of the specimens.](image-url)
### Table 1. Densities of the 158 specimens of spruce and pine.

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Surface exposed to the south</th>
<th>Number of samples</th>
<th>Mean density, (kg/m$^3$)</th>
<th>Standard deviation, (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spruce</td>
<td>Tangential surface inside face exposed</td>
<td>30</td>
<td>484</td>
<td>43</td>
</tr>
<tr>
<td>2</td>
<td>Spruce</td>
<td>Tangential surface outside face exposed</td>
<td>31</td>
<td>483</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>Spruce</td>
<td>Radial surface</td>
<td>24</td>
<td>455</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Total spruce:</td>
<td></td>
<td>85</td>
<td>475</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>Pine</td>
<td>Tangential surface inside face exposed</td>
<td>17</td>
<td>559</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>Pine</td>
<td>Tangential surface outside face exposed</td>
<td>18</td>
<td>558</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>Pine</td>
<td>Radial surface</td>
<td>38</td>
<td>571</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Total pine:</td>
<td></td>
<td>73</td>
<td>565</td>
<td>44</td>
</tr>
</tbody>
</table>

3. ANALYSIS

The following analysis of cracks follows an earlier published paper (Söderström 1990). In a given group there are $n$ specimens and $k$ of them have observable cracks lengths $x_i$, where $i$ is in the interval from 1 to $k$. The number $k$ is assumed to be binomial distributed with

$$P(x > 0) = p$$  \hspace{1cm} (1)

and of course then

$$P(x = 0) = 1 - p$$  \hspace{1cm} (2)

The expectation value (mean value) of $x$ is then

$$E(x) = 0 \cdot (1 - p) + p \cdot E(x|x > 0) = p \cdot E(x|x > 0)$$  \hspace{1cm} (3)

The formation of cracks is a relaxation of energy according to the mechanisms of fracture mechanics. The probability find a crack in the crack length interval $\Delta x$ is proportional to the interval length $\lambda \Delta x$, where $\lambda$ denotes the intensity. The probability of finding no cracks in this interval is then of course $1 - \lambda \Delta x$. The probability of finding no cracks with lengths in the interval from 0 to $x$ is denoted $P(x)$. The probability of finding no cracks in the interval $x + \Delta x$ is assumed to be independent on $P(x)$ and $1 - \lambda \Delta x$ i.e.

$$P(x + \Delta x) = P(x) \cdot (1 - \lambda \Delta x)$$  \hspace{1cm} (4)

or in differential form

$$\frac{dP}{dx} = -\lambda x$$  \hspace{1cm} (5)

which integrated becomes

$$P(x) = e^{-\lambda x}$$  \hspace{1cm} (6)
Therefore, the probability to find a crack length \( x \) but less than \( x \) is \( 1-e^{-\lambda x} \). The frequency function is consequently \( \lambda e^{-\lambda x} \) i.e. the cracks length is distributed according to an exponential distribution. The mean value \( E(x|x > 0) \) is then

\[
E(x|x > 0) = \int_0^x \cdot e^{-\lambda x} \, dx = \frac{1}{\lambda}
\]  

which together with equation (3) gives

\[
E(x) = \frac{p}{\lambda}
\]  

The total crack length \( X \) is then

\[
X = \sum_{i} x_i
\]  

which is a gamma-distribution with the mean value \( E(X) \) and variance \( V(X) \) according to

\[
E(X) = \frac{np}{\lambda}
\]  

\[
V(X) = \frac{np \cdot (2-p)}{\lambda^2}
\]

According to the central limit theorem the mean crack length for a group is approximately a normal distribution as

\[
N\left(\frac{p}{\lambda}, \frac{2-p}{p \cdot n}\right)
\]

By using equation (12) for the various groups above and a normal distribution it is possible to assess the significance of the difference between the mean values of the crack length from the observations of the different groups.
4. RESULTS AND CONCLUSIONS

Table 2 presents the result from measurements of the crack lengths and analyzed with the method above, which gives a better estimation of the standard deviation than the ordinary method by assuming a normal distribution of the crack lengths.

<table>
<thead>
<tr>
<th>No. According to table 1</th>
<th>Mean crack length on exposed side, (mm)</th>
<th>Standard deviation, (mm)</th>
<th>Mean crack length on rear side, (mm)</th>
<th>Standard deviation, (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2769</td>
<td>505</td>
<td>602</td>
<td>135</td>
</tr>
<tr>
<td>2</td>
<td>3530</td>
<td>634</td>
<td>296</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>1586</td>
<td>352</td>
<td>50</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>5149</td>
<td>1248</td>
<td>445</td>
<td>108</td>
</tr>
<tr>
<td>5</td>
<td>6114</td>
<td>1441</td>
<td>338</td>
<td>79</td>
</tr>
<tr>
<td>6</td>
<td>2332</td>
<td>378</td>
<td>55</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2. Mean value of the crack length and the standard deviation on the exposed side and backside after five years of outdoor exposure.

From table 2 it is clear that there is a strong significant lower crack length at the surface of specimens with radial surfaces exposed to the outdoor climate. The same conclusion is valid for corresponding backsides. The explanation may be that the radial surfaces have varied densities over the surface depending on the early wood, with a low density, and the late wood, with a high density. The propagation of cracks is the result of relaxation of stored elastic energy and it is hindered by the local density gradients. The effect is at least clearly demonstrated in this paper for impregnated wood outdoor exposed without contact with soil. The amount of cracks is supposed to be the main factor for the estimation of service life as the crack promotes capillary suction of water that gives the condition for growing of mould and rot. Therefore, the estimated service life for e.g. wooden panels is higher for radial surfaces and this fact may be taken into account by a proper choice of the design factor B in the factor method according to ISO 15686-1.
5. REFERENCES


