Design of form stable and visually crack free edge-glued oak panels

J. Johansson, D. Sandberg1

Abstract

Edge-glued panels are very popular in for example cabinet doors or work-tops in the kitchen. The surrounding climate for these products is often severe, due to large seasonal variations in the relative humidity in the indoor air, and problems due to distortion and crack development often arise. This paper describes a study of how the annual ring orientation and the lamella width affect the distortion and crack development in edge-glued oak panels (Quercus robur L.) exposed to moisture changes.

35 panels with different characteristics were tested in varying climates over a period of 175 days. The relative humidity was changed every 14 days in the interval from 20 to 88 % and temperature was kept at 20˚C. The panels were measured each 7 days in order to monitor any distortion. The crack development was measured at the beginning and at the end of the test.

The results show that the annual ring orientation of the lamellae is a significant factor affecting the cupping and crack development. The lamella width is a significant factor affecting the surface unevenness.

It is concluded that to minimise the risk of cracks in the panels and minimise cupping vertical annual rings are preferable. If surface evenness is important the lamellae of the panels should be decreased in width.

Introduction

Distortion (cupping and surface unevenness) and development of cracks in edge-glued panels as a result of changing moisture conditions often create problems in service. Nevertheless, wood is a popular material in applications where the environmental conditions for the material may be hard. Edge-glued panels used for cabinet doors or work-tops in the kitchen are examples of such products.

The way to manufacture a panel with optimal characteristics with regard to distortion is described by e.g. Mitchell (2005), Suchsland (2004), Sandberg et al. (1998), Grønvold (1957), Perry (1953), Lipka (1950), Miller (1950), Peck et al. (1950) and Wanggaard (1947). All studies recommend vertical annual rings (Figure 1) considering optimal resistance to distortion. Figure 2 describes some possible ways of arranging the material in the panels. Alternated vertical annual rings minimise distortion.

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Additional factors to consider regarding distortion are the lamella width. Narrow lamellae are considered to give smaller distortion and the lamellae should also have the same initial moisture content as in relation to the user environment, see e.g. Mitchell (2005), Suchsland (2004), Grønvold (1957), Perry (1953) and Miller (1950).

The intention of the present study was to investigate how distortion and development of cracks in edge-glued panels of oak (Quercus robur) exposed to varying humidity conditions were affected by the two factors annual ring orientation and lamella width. These two factors are important to consider when designing the edge-glued panels. The objective is to receive information of how to design edge-glued panels with minimum of distortion and visible cracks.

Materials and Methods
Experimental design and panel manufacturing
A total of 35 panels were manufactured with the dimensions 600x400x20 mm. During the test the panels were exposed to a climate according to Table 1. The climate corresponds to a possible indoor climate in Sweden, RH in the interval 25–85 % and a relatively constant temperature, 20°C (Nevander et al. 1994). The difference between the test climate and a normal indoor climate is that the changes in moisture condition appear directly from a dry to a moist climate. The condition for the material is therefore very rough.

The experiment was designed as a factorial experiment, were the annual ring orientation had two levels and the lamella width had three levels. The panels used in the test were designed according to Table 2. Panels with similar design were grouped together in six panel groups A–F. Before gluing, the lamellae were conditioned for 20 days at 20°C and 30 % RH, corresponding moisture content in the panel was measured to 6±1 %.

Table 1 – Climate cycle during the test.

<table>
<thead>
<tr>
<th>Time of exposure (Days)</th>
<th>0</th>
<th>1–9</th>
<th>10–30</th>
<th>31–50</th>
<th>51–63</th>
<th>64–76</th>
<th>77–175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity, RH (%)</td>
<td>30</td>
<td>49</td>
<td>88</td>
<td>30</td>
<td>88</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2 – Design of the panels used in the study.

<table>
<thead>
<tr>
<th>Panel group</th>
<th>No. of panels</th>
<th>Design</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>Longitudinal annual rings, lamella 23 mm</td>
<td><img src="image1" alt="Illustration" /></td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>Longitudinal annual rings, lamella 40 mm</td>
<td><img src="image2" alt="Illustration" /></td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>Longitudinal annual rings, lamella 60 mm</td>
<td><img src="image3" alt="Illustration" /></td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>Vertical annual rings, lamella 23 mm</td>
<td><img src="image4" alt="Illustration" /></td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>Vertical annual rings, lamella 40 mm</td>
<td><img src="image5" alt="Illustration" /></td>
</tr>
<tr>
<td>F</td>
<td>5</td>
<td>Vertical annual rings, lamella 60 mm</td>
<td><img src="image6" alt="Illustration" /></td>
</tr>
</tbody>
</table>
Measurements and statistical methods

The results were analysed by statistical software SPSS. Experimental data for wood are not normally distributed. In the analysis of the lengths and areas of cracks, the assumption of normality is not valid (Söderström 1990, Sandberg et al. 2005). This was also observed in this study and the crack development was therefore analysed with a non-parametric method (Wilcoxon/Kruskal-Wallis). The same phenomena is observed in the cupping of the panels. Karnis et al. (2002) say that cupping may be converted to curvature as indicated in eq. [1] The cupping and surface unevenness were studied with a multivariate analysis of variance, since the measurements were conducted over time. Each measurement was regarded as a dependent variable. In all the tests, a confidence interval of 95 % was used.

The cupping and surface unevenness were measured on panels placed on three points of support, resting on a plane table. A dial indicator was swept along a line over the surface with measurement points between (at the glue line) and in the middle of each lamella. The surface unevenness was determined as a Ra value according to eq. [2] from the deflection (h) of a measurement point from the line connecting the two adjacent measurement points. Crack development was measured visually. In each panel, the lengths of all cracks with a width greater than or equal to 0.1 mm (estimated as the smallest observable crack) were measured.

\[
\rho = \frac{8h}{4h^2 + D^2} \cdot 1000 \ [\text{m}^{-1}]
\]  

where: \( \rho \) = Curvature  
\( h \) = Deflection of the panel  
\( D \) = Panel width

\[
Ra = \frac{\sum |R - R_{\text{average}}|}{n}
\]

where: \( Ra \) = Surface unevenness (mm)  
\( R_{\text{average}} \) = Average centreline (mm)  
\( n \) = Number of panels

Results

Distortion

Evaluation of the cupping shows that the annual ring orientation had a significant effect on the cupping when the panels were exposed to a high humidity (88 %). Figure 3 illustrates the mean, absolute cupping of the panels as a function of time. Panels with vertical annual ring orientation will cup less than panels with longitudinal annual rings. The lamella width had a significant effect on the surface unevenness. In Figure 3 the mean surface unevenness of the panels is described. Wider lamellae give greater surface unevenness.

Development of visible cracks

There was a significant difference in crack development between the panels with longitudinal annual rings and the panels with vertical annual rings in the case of internal cracks and cracks related to the edges of the panels. The lamella width affected the crack development for cracks related to the glue line in the panels, although the frequency of the glue lines was affected by the width. Figure 4 shows the mean crack length in the different groups.
Discussion

In this study it appears that the effect of distortion in the end-products will be situational dependent, i.e. dependent on which resulting variable that is important in the specific use.

The cupping of the panels was affected by the annual ring orientation. Cupping of panels can probably be avoided by correct fastening devices, although this may increase the risk of crack development since the tensions in the panels will increase. Cupping occurs as a result of an anisotropic shrinkage and swelling in different directions in the wood. Cupping occurred even when the lamellae in the panels were alternated, and it may therefore be concluded that it is difficult to predict and avoid cupping.

Panels manufactured from lamellae with vertical annual rings resist cupping better than panels manufactured from lamellae with longitudinal annual rings.

The surface unevenness may be the most problematic factor to consider. The surface unevenness was here dependent on the lamella width. Narrower lamellae reduce the surface unevenness but, at the same time, the production may become more complicated.
The development of cracks in the panels is related to the annual ring orientation. Cracks should probably be avoided in all situations. The panels were tested unfinished in this test. Surface treatment may reduce or postpone the development of cracks, although the differences between the group with longitudinal annual rings and the group with vertical annual rings are considerable. If there is a probability of insufficient maintenance, vertical annual rings are preferable. The frequency of development of cracks related to the glue line depends on the lamella width, because of the greater frequency of glue lines. When the products are used under severe environmental conditions, the length of glue line should be minimised by using wider lamellae, although the risk of problems regarding surface unevenness will then increase. Cracks related to the glue line may also depend on the type of glue used.

Conclusions
The study shows that, to minimise the cupping and the risk of cracks development in the panels, vertical annual rings are preferable. If surface evenness is important, the lamellae of the panels should be reduced in width.

References