Bending properties of Yellow-poplar laminated veneer lumber subjected to 1-year open-shed exposure
Tang, R. C., Lee, Jong N., and Kaiserlik, Joe

ABSTRACT
The effect of long-term open-shed environmental exposure on the mechanical properties of laminated veneer lumber (LVL) was investigated. LVL billets were fabricated with rotary-peeled yellow-poplar veneers and liquid phenol formaldehyde resin using commercial continuous hot-pressing process and conditions. Two groups of 2.44m long specimens, 25 in each group, randomly selected from a large sample size of over 250 members cut from the LVL billets were prepared for this study. Group I specimens had crushed-lap veneer-joints and group II had scarf veneer-joints. All specimens in both groups were exposed to an open-shed environment for one year and then edgewise bending tested. The relative humidity and the temperature under the open-shed, as well as the temperature on the inner surface of the roof, and the surface temperature of members on the top and bottom of LVL racks were continuously monitored during the 1-year open-shed environmental exposure period. The highest temperature recorded on the inner surface of the open-shed roof was 52.2°C (126°F) while the air temperature, as hot as 37.8°C (100°F) and as cold as -9.4°C (15°F), was recorded. Average temperatures of 43.9°C (111°F) and 37.2°C (99°F) were recorded respectively on the top 10 specimens and bottom 10 specimens in the LVL rack when the air temperature inside the open-shed was 37.8°C (100°F). During the 1-year open-shed exposure, many high RH (90-98%) days were observed while low RH recorded was 23%. Statistical analysis of the testing results indicated that the edgewise bending stiffness and the strength probability of the tested yellow-poplar LVLs can be adequately described by a lognormal distribution and linear regression model for their distributions were developed. Furthermore, comparison between open-shed exposed groups and the groups conditioned under 65% RH and 95% RH at 23.9°C (75°F), as reported in a previous study was made. At the constant 65% RH conditions, strength and stiffness of crushed-lap veneer-joint group was higher than those with scarf veneer-joints but significant hygrothermal effect on the strength distribution, due to the 1-year open-shed environmental exposure, was not observed in both groups. However, significant hygrothermal degradation on the stiffness of yellow-poplar LVL with crushed-lap veneer-joints, after being subjected to 1-year open-shed exposure, was observed but such an effect was not found in the group with scarf veneer-joints.

INTRODUCTION
A number of engineered wood composite products have been designed, developed and used in the light- and medium-frame building constructions in recent years (Vining 1991). Laminated veneer lumber (LVL) is one of these well-developed engineered wood composite products. The primary structural applications and uses of LVL are in the timber structural systems in which high strength supporting members are needed for sustaining heavier loads on long open-spans and as flanges for I-joists/I-beams fabrication. It was reported that the LVL production in North America (US and Canada) was 448 x 10^3 m^3 (16 x 10^6 ft^3) in 1991 and increased 137.5% in 1997 to 1,064 x 10^3 m^3 (38 x 10^6 ft^3) and continued growth is highly expected in the 21st century (Lyddan et al. 1998). LVLs are currently used as flanges in 70% to 75% of the structural wood composite I-joists produced in North America, and about 50% of the current LVL production is used for I- joist fabrication and the other half is used as beams and headers for residential and non-residential construction. Furthermore, they reported the production of wood composite I-joists was 191 million linear m (627 million linear ft) in 1997 and a continuous increase in the 21st century was predicted. This high potential marketing opportunity

1 Professor, School of Forestry and Wildlife Sciences, Auburn University, AL 36849-5418, USA
2 Postdoctor Fellow, School of Forestry, Wildlife and Fisheries, Louisiana State University, Baton Rouge, LA 70803-6202, USA. Formerly Graduate Research Assistant at Auburn University
3 Product Development Manager, Engineered Lumber Products, Georgia-Pacific Corporation, Roxboro, NC 27573, USA
would be a challenge to the wood composite products industries to effectively and efficiently utilize forest resources for the development of high structural performance LVL products.

It is known that softwood LVLs are used extensively as flanges in the fabrication of commercial I-joist products and for long-span and heavy-loaded beams and headers (Dawick 1991, Koch 1973 and Kunesh 1978) because of their unique characteristics of high strength and uniform stiffness. However, most of these products were fabricated with high-quality veneers that were rotary-peeled from softwood logs such as Douglas-fir and southern pines, which are known as the major structurally used timber species in North America. Only limited commercially produced LVL, fabricated with soft hardwood veneers, are used in light- and medium-frame building constructions because of product quality and strength performance considerations. In general, hardwood LVL members are used as framing components for sofas, bookcases, shelving, bed rail, etc. (Hoover et al. 1984 and 1987).

In recent years, attempts have been made for the development of hardwood LVL products for structural uses (Blackman 1992, FPL 1972, Green and Evans 1994, Hsu 1988, Kimmel and Janowiak 1995 and Lee et al. 1999). It was reported by Kimmel and Janowiak (1995) that LVLs fabricated with yellow-poplar (YP) veneers had very good mechanical properties and were comparable to nominal 2 by 4 solid YP lumber in structural performance (Gerhards 1983). A study on the long-term thermal-exposure-effect on the LVL products was conducted recently at the USDA-Forest Products Laboratory in Madison, WI, and results indicated that YP LVLs performed structurally equivalent to Douglas-fir LVLs after 2 years of exposure under constant environment conditions of 65.6 C (150 F) and 75% relative humidity (Green and Evans 1994). More recently, Lee et al. (1999) reported that YP LVLs with crushed-lap veneer-joints are as stiff and strong as those without veneer-joints under the environmental conditions of 65% relative humidity (RH) and 23.9 C (75 F), but members with scarf veneer-joints had relatively lower mechanical properties. Furthermore, they indicated that the stiffness and strength properties of YP LVLs without veneer-joints are equivalent to those of southern pine LVLs fabricated with C grade veneers and faced with 2-layers of B grade veneer as reported in a previous study at Auburn University (Tang and Pu 1997). In the study of bending properties of LVLs, fabricated with softwood veneers or hardwood veneers, most tests were conducted under ambient indoor environmental conditions or controlled environmental conditions at constant medium-high RHs and temperature (e.g. Biblis 1996, Green and Evans 1994, Hesterman and Gorman 1992, Hsu 1988, Lee et al. 1999, Tang and Pu 1997, and Youngquist et al. 1984). However, the information concerning bending properties of LVLs exposed to long-term changing environments, under open-shed or attic conditions, is very limited, especially in the LVLs fabricated with different types of veneer-joints. Such information may be useful to Structural Engineers for the design of a safe and durable timber structural system in service and to wood composite lumber I-joist industries for improving their LVL structural performance. In this paper, YP LVLs fabricated with different types of veneer-joints were edgewise static bending tested after being subjected to 1-year open-shed exposure for the assessment of their structural performance, as affected by the long-term daily/hourly changes in environmental conditions.

**MATERIALS AND METHODS**

Rotary-peeled YP (Liriodendron Tulipifera L.) Veneers, 0.3175 cm (1/8 in.) and 0.4233 cm (1/6 in.) thick by 132 cm (52 in.) wide by 254 cm (1 in.) long, were used to fabricate the LVL specimens for this study. All veneers were dried to approximately 7% MC and grade D veneers were visually sorted out following the Voluntary Products Standard PS1-95 (NIST 1995). The remaining sheets of B and C grade veneers were randomly mixed and then used for the fabrication of LVL billets with commercial liquid phenol-formaldehyde resin. Press conditions were similar to those used in our previous studies on southern pine LVLs (Tang and Pu 1997). Details on the description of veneer-joint designs and distribution in the LVL billets and their dimensions can be found in our previous study on the bending properties of YP LVLs (Lee et al. 1999). Two groups of specimens, 25 in each group, randomly selected from a large sample size of over 250 members were prepared for this open-shed exposure study: Group I specimens, 8.89 cm (3.5 in.) wide by 4.45 cm (1.75 in.) thick by 243.8 cm (96 in.) long, contained 11 plies of 0.4233 cm (1/6 in.) thick veneer and each ply had 1:9 slope scarf-joints which were stepwisely distributed 15.24 cm (6 in.) apart in adjacent plies (i.e. scarf-joints in each ply were approximately 244 cm (8 ft) apart); and Group II specimens, 8.89 cm (3.5 in.) wide by 3.81 cm (1.5 in.) thick by 243.8 cm (96 in.) long, contained 13 plies of 0.3175 cm (1/8 in.) thick veneer and each ply had 3.81 cm (1.5 in.) long crushed-lap joints also stepwisely distributed with a cyclic sequence of 15.25 cm (6 in.) to 30.48 cm (12 in.) arrangement (i.e. crushed-lap joints in each ply were also approximately 244 cm (8 ft) apart).

Specimens in both veneer-joint groups were stacked with 1.27 cm (0.5 in.) thick wood sticks and placed under an open-shed environment for one year to simulate the attic conditions in a light- and/or medium-frame building. Thereafter, all
specimens were reconditioned under 65% RH at 23.9 C (75 F) and then edgewise static bending tested according to ASTM Standard D 198 (ASTM 1994) for the evaluation of 1-year open-shed-exposure effect on their bending properties. During the 1-year open-shed exposure, fluctuations of temperature and RH under the open-shed were recorded by a Honeywell Hygrometer. In addition, the temperatures on the inner surface of the roof and the surface of LVL members on the top and bottom racks were continuously monitored by using an IR Digital Thermometer.

RESULTS AND DISCUSSION

Temperature (T) and RH
The fluctuations of T and RH under the open-shed environment during the 1-year exposure period were recorded and plotted in Figure 1, whereas the daily readings of T at the inner surface of roof, T of top and bottom members in the LVL racks and the air T values recorded by the Honeywel Hygrothermal Chart-Recorder were illustrated in Figure 2. Highest T recorded on the inner surface of open-shed roof was 52.2 C (126 F) while air T, as hot as 37.8 C (100 F) and as cold as -9.4 C (15 F), under the roof was recorded. Average Ts of 43.9 C (111 F) and 37.2 C (99 F) were recorded, respectively on the top 11 LVL specimens and bottom 10 specimens in the rack when the air T was 37.8 C (100 F). During the 1-year open-shed exposure, many high RH (i.e. 90-98%) days were observed while lowest RH recorded was 23%.

Edgewise bending properties
The results of edgewise bending MOE and MOR of the LVL specimens subjected to 1-year open-shed exposure are tabulated in Table 1. For comparative purposes, the corresponding values for the groups tested under the controlled environmental condition of 65% RH at 23.9 C (75 F) as reported in previous studies (Lee et al. 1999 and Tang et al. 1999) were included in this Table 1.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Veneer-Joint Type</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-shed</td>
<td>Crushed-lap</td>
<td>12.51</td>
<td>80.60</td>
</tr>
<tr>
<td></td>
<td>Scarf</td>
<td>12.29</td>
<td>71.16</td>
</tr>
<tr>
<td>65% RH/23.9 C</td>
<td>Crushed-lap</td>
<td>14.80</td>
<td>80.94</td>
</tr>
<tr>
<td></td>
<td>Scarf</td>
<td>12.20</td>
<td>72.99</td>
</tr>
<tr>
<td></td>
<td>No joints</td>
<td>14.88</td>
<td>81.47</td>
</tr>
<tr>
<td>95% RH/23.9 C</td>
<td>Crushed-lap</td>
<td>12.07</td>
<td>52.99</td>
</tr>
<tr>
<td></td>
<td>Scarf</td>
<td>10.20</td>
<td>52.72</td>
</tr>
<tr>
<td></td>
<td>No joints</td>
<td>13.03</td>
<td>56.39</td>
</tr>
</tbody>
</table>

* 25 LVL specimens in each environment group and 1 Mpa = 145 psi.

It is evident from Table 1 that the edgewise bending MOR of YP LVLs was not influenced by the 1-year open-shed environment exposure as compared with those tested under controlled environmental conditions of constant 65% RH at 23.9 C (75 F). However, the groups tested under controlled environmental conditions of 95% RH at 23.9 C showed much lower edgewise bending MOR than those subjected to 1-year open-shed exposure. A significant effect of 1-year open-shed exposure on the edgewise bending MOE was observed in the LVLs with crushed-lap veneer-joints but such an effect was not found in the group with scarf veneer-joints. The attribution of 1-year open-shed-exposure effect on the reduction of edgewise bending stiffness of YP LVLs with crushed-lap veneer-joints but not on their strength is uncertain because such an effect was not observed in the specimens with scarfed veneer-joint and additional studies on longer open-shed exposure are needed.
Fig. 1. Fluctuations of Temperature and Relative Humidity under an open-shed during 1-year Exposure Test of YP LVLs.

Fig. 2. Temperature recorded from LVL's surface and under the roof of the open-shed.
Fig. 3. Edgewise bending stiffness distribution of YP LVLs after being subjected to 1-year open-shed exposure.

Fig. 4. Edgewise bending strength distribution of YP LVLs after being subjected to 1-year open-shed exposure.
The statistical distribution of edgewise bending MOE and MOR for the tested YP LVLs after 1-year exposure under the open-shed environment and then reconditioned under 65% RH at 23.9 C (75 F) are plotted, respectively, in a lognormal fashion in Figures 3 and 4. A mathematical model for each veneer-joint group was also developed on the basis of regression analysis of these lognormal plots of MOE and MOR and all these models are included in the figures. For comparative purposes, the data for the groups conditioned and tested under constant 65% RH at 23 C (75 F) were included in these two figures. It is evident from these figures that the lognormal plots describe well the statistical distributions of the stiffness and strength probabilities of YP LVL. The general form of mathematical models for YP LVLs, as given in Figures 3 and 4, is a natural log of MOE (or MOR) or Ln (MOE or MOR) = a + b x R; where R designates the standard statistical order, and a and b are constants related to material properties. When R is equal to zero, i.e. Ln(MOE or MOR) = a, then MOE or MOR = exp[a], which represents the mean MOE or MOR value of the LVL group tested. The b values in the mathematical models designate the slope of MOE or MOR distribution lines and they represent the coefficients of variation (COV). As shown in these figures, b values (COV) for the MOE and MOR distributions for the crushed-lap and scarf joint groups subjected to 1-year open-shed exposure are, respectively, 6.1, 5.7, and 5.8 and 6.9 percent. These results suggest that YP LVLs still had very uniform edgewise bending stiffness and strength properties even after being subjected to 1-year open-shed exposure.

CONCLUSIONS AND REMARKS

Based on the results of this study, the following conclusions may be drawn:

1. A significant hygrothermal effect on the strength properties of YP LVLs, with either crushed-lap or scarf veneer-joints and exposed to 1-year open-shed environment, was not observed. However, such an effect was shown on the stiffness properties of specimens with crushed-lap veneer-joints but not on the scarf veneer-joints.

2. The hygrothermal effect on the bending properties of YP LVLs subjected to 1-year open-shed exposure was insignificant as compared with those conditioned and tested under constant 95% RH at 23.9 C (75 F),

3. The edgewise bending stiffness and strength probability of the tested YP LVLs, after being subjected to 1-year open-shed exposure, can be adequately described by a lognormal distribution.

4. Additional researches are needed for testing LVLs fabricated with different wood species veneers and subjected to longer (i.e. 2 or more years) open-shed exposure for collecting information for predicting the long-term hygrothermal effect on the serviceability of LVL members in a structural system.

ACKNOWLEDGMENTS

The funds for this investigation were provided by the National Research Initiative Competitive Grants Program (NRCGP) and the Alabama Agricultural Experiment Station of Auburn University. The authors are indebted to these agencies for their support and to Georgia-Pacific Corporation for the contribution of all LVL testing materials for this study.

REFERENCES


