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ORIGINAL ARTICLE

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Shear creep and mechanosorptive behavior of nail-plate-jointed laminated-veneer lumber

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Abstract The objective of this research was to evaluate the mechanosorptive deflection of shear creep of nail-plate-jointed laminated-veneer lumber. The joint was composed of steel gusset and nails, 40mm in length and 2.8mm in diameter (Zn40). The specimens were loaded parallel (PA) and perpendicular (PE) to the grain. Shearing loads applied were 50 and 100kgf, and the load levels were 11% and 22% (PA) and 7% and 14% (PE) of the maximum strength obtained from static testing. The creep test specimens were loaded for 1500h. A few general conclusions could be drawn from this study: The mechanosorptive deflection (δ_{ms}) is defined as $\delta_{ms} = \delta_t - (\delta_c + \delta_{sh}) - \delta_o$, where δ_t is total deflection, δ_c is pure creep, δ_{sh} is shrinkage-swelling behavior, and δ_o is the initial deflection. Changes in relative humidity may cause more severe creep deflection than constant humidity, especially during the drying process. The mechanosorptive deflection is greater at the lower load level than that at the higher load level. The mechanosorptive effects seem to be somewhat more resistant in the parallel direction than in the perpendicular direction.

Key words Creep · Mechanosorptive behavior · Three-parameter model

Introduction

Nailed joints, bolted joints, and those made with split ring connectors are commonly used in timber engineering designs. There are few studies on the mechanosorptive effects of nailed joints of laminated veneer lumber (LVL) with changing relative humidity (RH). Most studies of creep have been limited to a controlled environment because of the difficulty applying long-term variable environment to test specimens. Feldborg and Johansen[1] studied the creep of nailed and nail-plate joints under constant and cyclic conditions. They found that for nailed joints with long-term loading under constant conditions at 65% RH the creep coefficient was roughly 1.7, whereas the average after nine cycles at 50%–80% RH was 7.3. The effect of the humidity cycles was significant. Several investigators have been concerned with the development of models to simulate creep under a controlled environment and under changing environment behavior in nailed joint.[2–4] Feldborg and Johansen[5] studied the creep of nailed and nail-plate joints under constant and cyclic conditions. Most nailed joint creep models are based on phenomenological studies of lateral slip stiffness. The action of nailed joint creep testing is observed to vary with the amount of loading and exposure conditions, such as changes in RH. The purpose of this study was to determine shear creep and mechanosorptive deflection of nail-plate-jointed LVL under changing RH when loaded parallel to the grain (PA) and perpendicular to the grain (PE).

Creep test procedures

The creep test specimens (40 × 90 × 90mm) were cut from LVL beams. The LVL beam was 4cm wide, 14cm thick, and 180cm long and was composed of approximately 3mm thick Douglas-fir veneer (13-ply). The specimens had had no surface coatings applied. The modulus of elasticity (MOE), measured by the edgewise static bending test, was 145.7 (10^3kg/cm^2). The moisture content (MC) was 11% and the specific gravity 0.57. Creep test specimens were made of three-member joints with steel side members as follows:

PA: steel gusset jointed parallel to the grain of LVL
PE: steel gusset jointed perpendicular to the grain of LVL

Figure 1 shows the dimensions of the test specimen and steel gussets. The gussets were made of steel plates with a

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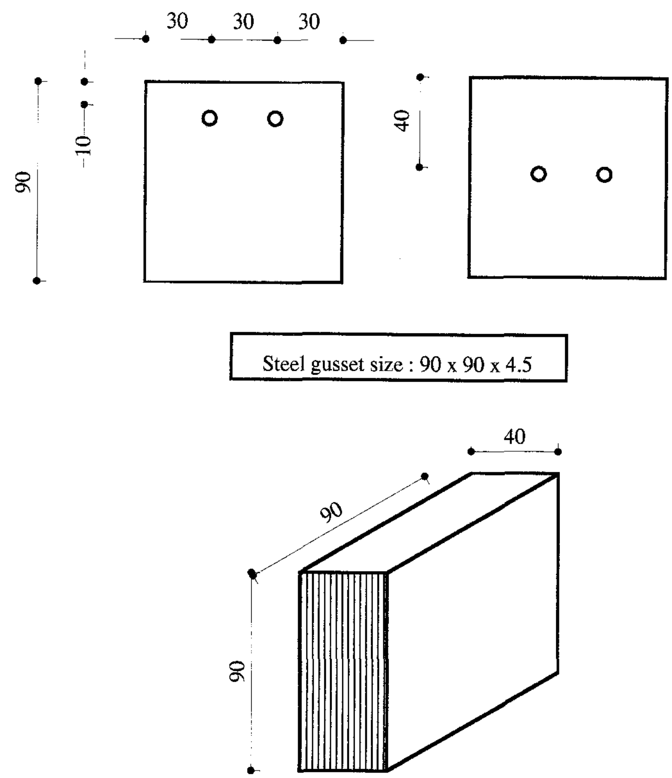

Fig. 1. Shape of steel gusset and main member of laminated-veneer lumber (LVL). Dimensions are in millimeters

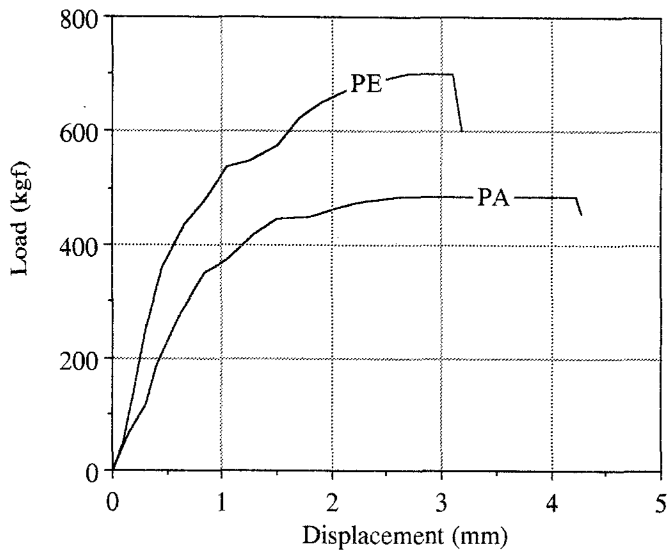

Fig. 2. Load-displacement curves of PA and PE. *PA*, steel side members jointed parallel to the grain of LVL; *PE*, steel side members jointed perpendicular to the grain of LVL

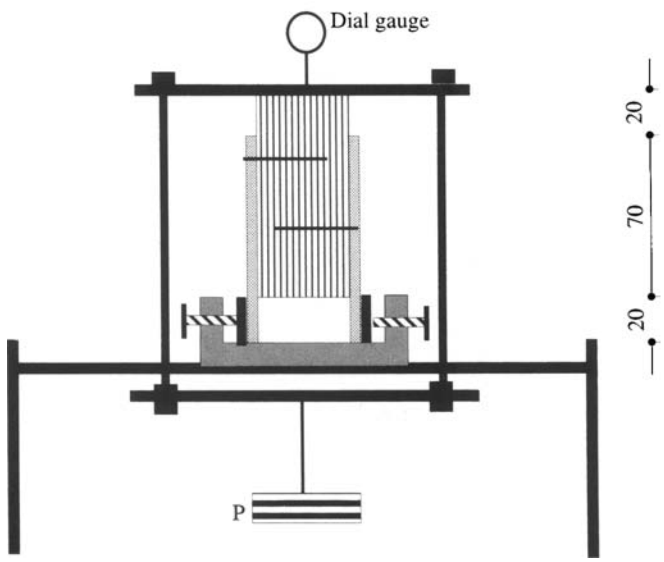

Fig. 3. Representation of the experiment. Dimensions are in millimeters. *P*, load

thickness of 4.5mm. The nails were driven by hand hammering without predrilling. The nails were Zn40, 40mm in length and nominally 2.8mm in diameter. The specimens were classified into two groups according to the directions (PA, PE), with 10 specimens in each group. Four specimens from each group were tested for ultimate strength. Figure 2 shows load-displacement curves from the static test. Each curve represents the average of four specimens. The creep test was conducted under two constant loading conditions with changing RH, at 50 and 100kgf. The loads were 11% and 22% (PA) and 7% and 14% (PE) of the average ultimate strength. Two specimens in each group were tested under each loading condition. Creep deflection represents the average of two specimens. The dead weights on a creep test apparatus were applied by a lever arm. The experimental Aitc was an open shed. The testing method for shear creep of nail-on-plate jointed LVL is shown in Fig. 3. The creep test specimens were loaded for 1500h.

One specimen in each group was used for determining MC, which was monitored by a load cell recording weight change at the same time as measuring deflection of the loaded specimens. The following discussions are based on the average MC of two specimens. The actual MC changed from 11% to 16%.

During the test period one specimen in each group was unloaded and the deflection due to pure swelling and shrinkage under changing RH was measured. The same measurement was done on the loaded specimen (Fig. 3).

The following abbreviations are used for the test variables in the presentation of results:

PA50(100): creep deflection when loaded parallel to the grain with a constant load of 50 or 100kgf
PE50(100): creep deflection when loaded perpendicular to the grain with a constant load of 50 or 100kgf
CPA[or CPE] 50(100): corrected creep obtained by subtracting the deflection of the unloaded specimens from the total creep deflection of the loaded specimens

The deflection was recorded at 1, 2.5, 5, 10, 20, and 30min; then at 5-h intervals until 200h; and afterward every 3 days at 1700h (5:00 p.m.) until the test was finished. Deflection

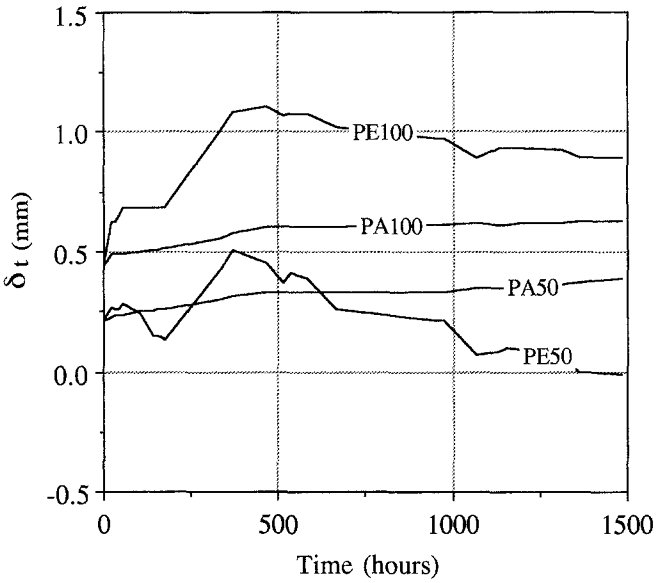

Fig. 4. Total creep deflection (δ_t) curves under varying relative humidity

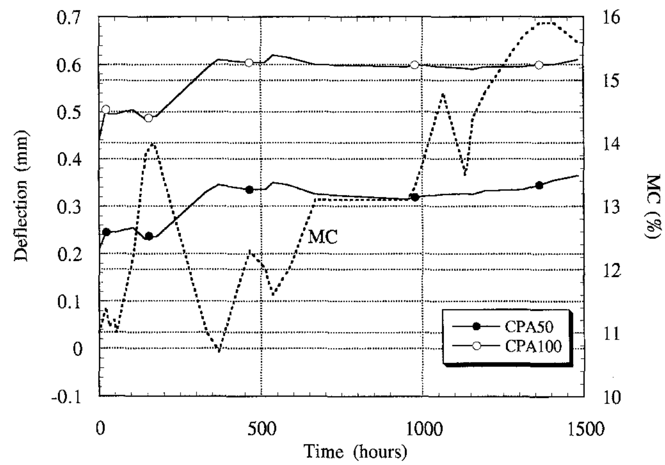

Fig. 5. Relation between corrected creep deflection and moisture content (*MC*). Correction was made from the total creep for the loaded specimen minus the deflection for the unloaded specimen ($\delta_t - \delta_{sh}$)

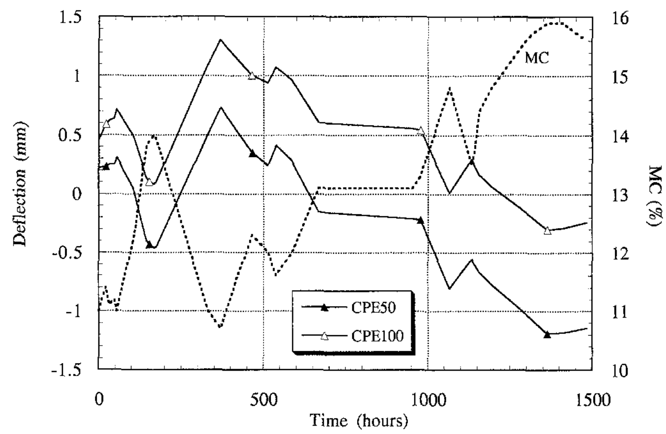

Fig. 6. Relation between corrected creep deflection and MC. Correction was made from the total creep for the loaded specimen minus the deflection for the unloaded specimen ($\delta_t - \delta_{sh}$)

was measured to an accuracy of 0.01 mm. The RH and temperature were measured simultaneously at 1-h intervals beginning from the measurement of instantaneous elastic deflection. Average values for RH and temperature were obtained from the value measured at 3-day intervals. The RH varied between 50% and 80% with occasional extreme values, reaching below 40% and almost as high as 90%. In general, the average humidity did not change more than 10% in 3 days, although occasionally there was a change of 15%–20%.

Results and discussion

Creep deflection under changing RH

The mechanical properties of wood joints or connections depend on the MC, and the dimensional changes induced by moisture variation often lead to deflections substantially greater than those caused by mechanical loading. Moreover, the interaction of moisture changes with mechanical loading may lead to excessive creep deflections in wooden structures.

The total creep under changing RH is assumed to consist of four main parts: one elastic part, one part describing pure creep under constant-humidity conditions, one part describing the shrinkage–swelling behavior, and finally one mechanosorptive part. The constitutive relation is then

$$\delta_t = \delta_o + \delta_c + \delta_{sh} + \delta_{ms}$$

where δ_t = total creep; δ_o = instantaneous deflection; δ_c = pure creep; δ_{sh} = deflection due to the shrinkage-swelling behavior; δ_{ms} = mechanosorptive deflection.

Figure 4 shows the results for total creep (δ_t) of specimens under changing RH. Figure 5 and 6 show the relation between the creep of subtracted deflection due to the shrinkage–swelling dimensional change under changing environment from the total creep (corrected creep = $\delta_t - \delta_{sh}$) and the MC. The discussion that follows is based on the corrected creep values. The deflections of CPA50 and CPA100 gradually increased with time. Within a short time the deflection change for CPA was less than that for CPE. Deflections for CPE gradually decreased from the instantaneous elastic deflection, a tendency that could be related to the change in MC. The tendency for the deflections for CPA were similar, and the mechanism of deflection is simple in an exposed environment. Deflections for CPE are more complex than those of CPA. Creep of CPA at 150 h, the effect of creep deflection under changing RH during the first desorption (MC was changed immediately to 3%), is significant; and then it stabilized. It has been well demonstrated that specimens loaded parallel to the grain are affected by the applied stress levels. The deflection for CPE50 is greater than that for CPE100 in a varying humidity environment. The irregular changes of the deflection were caused by the different MC of specimens due to changes in RH and temperature. The desorption process causes an increase in deflection, and the adsorption process acts in the opposite way (recovery). Until 50h of load the deformation is caused by mechanical forces; changes after that time are caused by sorption stress. From the above results, we assumed that the change is opposite, and a decrease in MC produces an increase in creep deflection at low load levels.

Mechanosorptive deflection

The curve of total creep is the sum of the creep of the affected load in a controlled environment and the quantity of deflection in a varying environment. Arima et al.[6] reported that creep deflection of a nailed joint was affected by the applied maximum load and time, and that it was stabilized by adding plastic strain to the nailed joint. Therefore we applied a three-parameter model to determine pure creep in a controlled environment of nail-on-plate jointed LVL. Assumption of a controlled environment was based on the experiment's initial conditions.

Prediction of corrected total deflection can be expressed as the sum of the creep in a controlled environment (three-parameter model) and the deflection resulting from varying environmental conditions. This equation (three-parameter model) can be expressed as follows:

$$\text{MPA(MPE)} = r_o + r_1[1 - \exp(-\beta t)] \quad (1)$$

$$\delta_{ms} = \text{CPA (CPE)} - \text{MPA (MPE)} \quad (2)$$

where r_o = instantaneous deflection; r_1, β = coefficients; CPA (CPE) = corrected creep deflection ($\delta_t - \delta_{sh}$); MPA (MPE) = three-parameter model ($\delta_c + \delta_o$); and δ_{ms} = difference of experimental data and three-parameter model (mechanosorptive deflection).

We applied a three-parameter model curve fitting up to 150h for the CPA series to 50h for CPE. The mechanosorptive deflection was estimated from Eqs. (1) and (2). Under the action of an applied load, load-displacement characteristics are entirely curvilinear. A common simplification when relating load and deformation in an axially loaded timber joint is to define an expression of the form $P = \kappa\delta$, from which is obtained $\kappa = P/\delta$, defining the slip modulus (κ) as load (P) per unit slip (δ). The joint elastic deflection (δ_o) is than given by $\delta_o = P_o/\kappa$. Mechanosorptive deflection relates rate to a stress-dependent function of the rate of moisture content change. To compare the mechanosorptive behavior between two directions with different load levels, the mechanosorptive deflection, (δ_{ms}) is defined as

$$\Delta\delta_{ms} = m\, P_o/\kappa\, \Delta\text{MC} \quad (3)$$

where, m is a material parameter for the interaction between stress and moisture change; $\Delta\delta_{ms}$ is the difference in mechanosorptive deflection between the actual point deflection and the previous point deflection after 150h. We derived a ΔMC value by the same method. The overdot, representing the time derivative in Eq. (3), assumes a linear dependence of the mechanosorptive deflection on load and MC change, although this assumption has been experimentally verified to only a limited extent. To obtain material parameter m for each test condition, a least-squares linear regression analysis was performed using the mechanosorptive deflection as the dependent variable and MC as the independent variable. It was used to fit Eq. (3) (Figs. 7, 8).

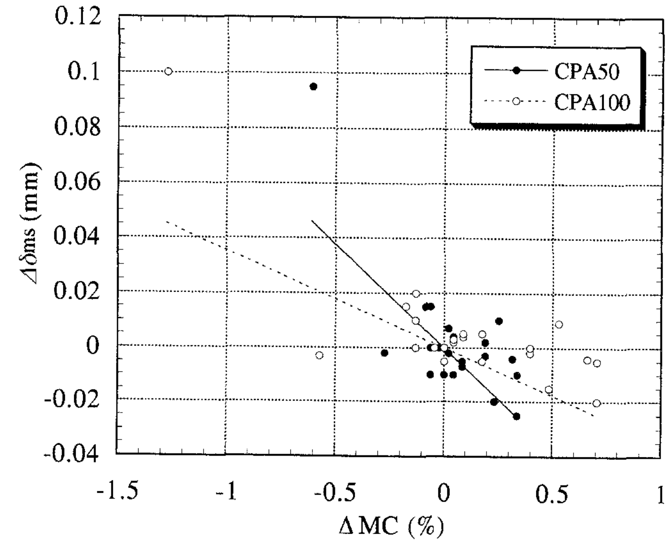

Fig. 7. Assumed mechanosorptive parameter ($\Delta\delta_{ms}$) according to Eq. (3) at different load levels

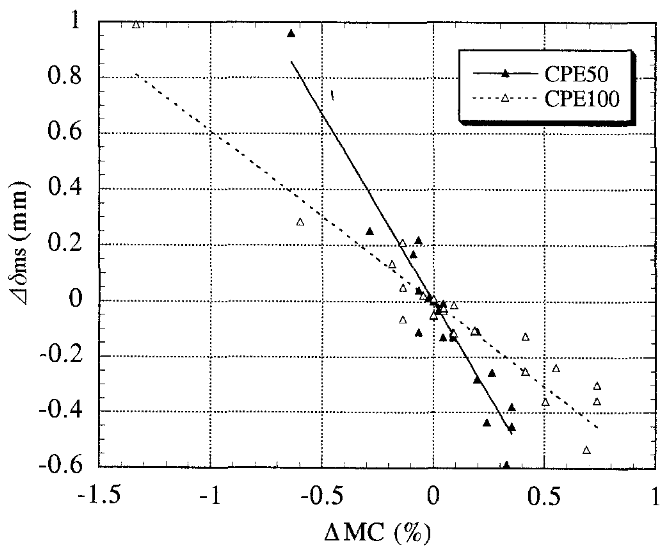

Fig. 8. Assumed mechanosorptive parameter according to Eq. (3) at different load levels

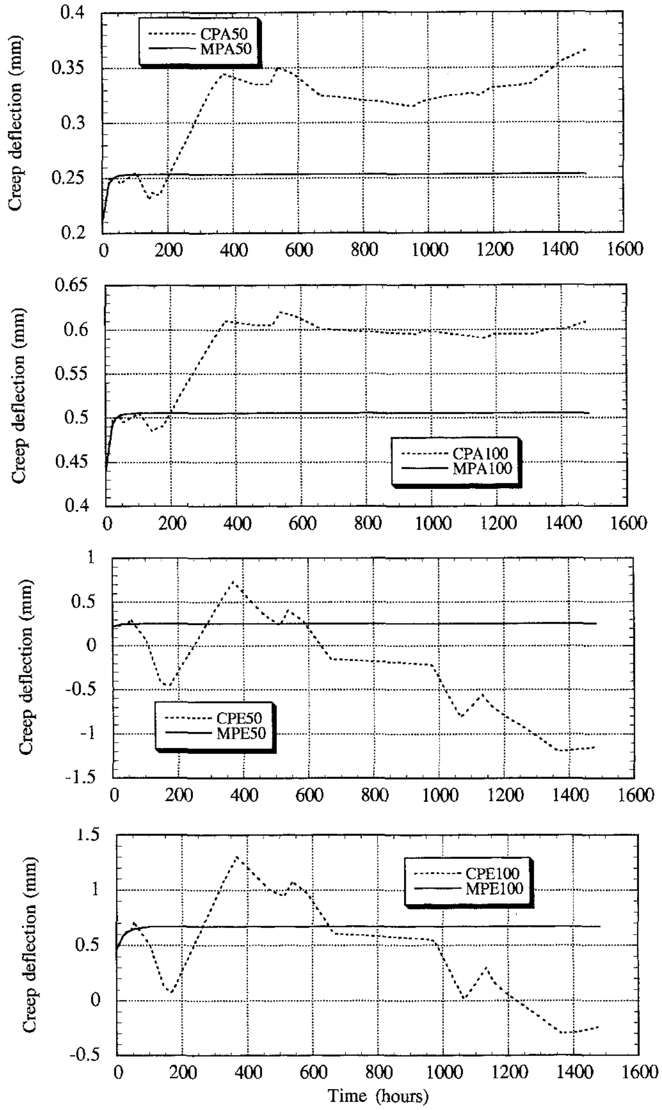

Fig. 9. Plots of the projected three-parameter model equation and experimental data (corrected creep deflection)

Estimation of mechanosorptive model parameters

Figure 9 shows the plot of the three-parameter curve during the creep test. The estimated parameters are as follows:

$$\mathrm{MPA50} = 0.21 + 0.0332\,[1 - \exp(-0.0595t)] \quad r = 0.97$$
$$\mathrm{MPA100} = 0.44 + 0.0505\,[1 - \exp(-0.1342t)] \quad r = 0.99$$
$$\mathrm{MPE50} = 0.22 + 0.03311\,[1 - \exp(-0.07196t)] \quad r = 0.93$$
$$\mathrm{MPE100} = 0.46 + 0.2126\,[1 - \exp(-0.0426t)] \quad r = 0.99$$

Table 1 gives the results of data fitting: The mechanosorptive parameter was obtained by dividing the slope of the curve for the mechano-sorptive deflection versus MC change by the corresponding joint elastic deflection.

Table 1. Estimated mechanosorptive parameter for different load levels when fitted to Eq. (3)

Load level	Mechanosorptive parameter	Correlation coefficient (r)
PA50	−0.075	0.71
PA100	−0.035	0.67
PE50	−1.348	0.96
PE100	−0.610	0.96

The slope of the mechanosorptive parameter is higher for specimens at a lower load level during the desorptions than the specimens at a higher load level. This mechanosorptive deflection increase can be seen at the lower load level than at the higher load level. Mechanosorptive effects in the PA direction seem to be somewhat more resistant than in the PE direction.

Conclusion

The results of our study indicate that the mechanosorptive deflection decreases with increasing load level and increasing MC changes. There was less mechanosorptive deflection increase in a highly stressed joint than in a low-stressed joint. The PA direction seems to be somewhat more resistant to mechanosorptive effects than the PE direction. The mechanosorptive behaviors are caused by the interaction of sorption and mechanical stress. The desorption process causes increases in displacement, and the adsorption process acts in the opposite way (recovery). Creep of PA at 150h, the effect of mechanosorptive behavior during the first desorption (MC was changed immediately to 3%), was significant, and then it stabilized. It has been well demonstrated that specimens loaded parallel to the grain were severely affected by the load levels. The deflections of PE50 are greater than that of PE100 with a change of humidity. It is known that changing the RH considerably accelerates the creep rate of a nailed joint.

References

1. Feldborg T, Johansen M (1987) Slip in joints under long-term loading. In: Structral Division CIB-W18. Dublin
2. Bazant ZP, Meiri S (1985) Measurement of compression creep of wood at humidity changes. Wood Sci Technol 19:172–182
3. Polensek A (1982) Creep prediction for nailed joints under constant and increasing loading. Wood Sci 15:183–192
4. Schaffer E (1972) Creep of wood in a changing moisture environment. Wood Fiber 3:232–235
5. Feldborg T, Johansen M (1988) Timber joints under long-term loading (splice joints under alternating relative humidity). SBI report 193
6. Arima T, Sato M, Mashita K (1981) Report of the building research institute. Building Research Institute, Ministry of Construction, pp 45–52