Moisture Sorption and Hygroexpansion of Paraffin Wax Emulsion–Treated Southern Pine (*Pinus* spp.) under Dynamic Conditions

ThiThanh Chau
Erni Ma
Tiantian Yang
Jinzhen Cao

Abstract

Moisture sorption and hygroexpansion of southern pine (*Pinus* spp.) treated with 0.5, 1, and 2 percent concentrations of paraffin wax emulsion (PWE) under dynamic conditions were investigated. The specimens, 4 and 10 mm along the grain and 20 mm in radial and tangential directions, were exposed to sinusoidal relative humidity (RH) between 45 and 75 percent at 30°C for cyclic periods of 1, 6, and 24 hours, respectively. Moisture changes and lateral dimensional changes were measured during the cycling. The moisture and dimensional responses of the specimens varied sinusoidally as well. The amplitude of moisture and the moisture sorption coefficient decreased with increasing PWE concentration treatment, leading to moisture-repellent effectiveness (MRE) values ranging from 10 to 66 percent. The list of amplitudes of dimensional change and the humidity expansion coefficient were lower in the PWE-treated wood, reflecting the antideformation effectiveness (ADE) of PWE treatment. Moisture and lateral dimension changes lagged behind RH, and the phase lag increased with an increase in PWE concentration, indicating that PWE treatment had efficient effects not only on reducing the amount but also on slowing the rate of the sorptive and hygroexpansive behavior of wood. Notably, values of MRE and ADE herein were greater than those obtained under static conditions by a previous study, i.e., PWE presented better moisture repellency and dimensional stabilizing performance of wood in dynamic environments for more practical applications.

Hygroscopic properties of wood refer to the adsorption and desorption of moisture from the air. The moisture content (MC) of wood is closely related to temperature and the relative humidity (RH) of the environment. Wood moisture changes can cause dimensional changes, namely, the amount of wood swell or shrink, when adsorbing or releasing moisture. Therefore, wood hygroexpansion means that MC changes within the range between the ovendry state and the fiber saturation point; as a consequence of moisture getting into and out of nonamorphous areas in the wood cell wall, the aqueous layers of microfibrils become thicker or thinner (i.e., they swell and shrink, respectively) (Ma and Zhao 2012).

Dimensional changes restrict the utilization of wood; hence, researchers have attempted to investigate the various methods and distinct agents to obtain moisture repellence and dimensional stability (Stamm 1964, Feist and Peterson 1987, Bernard et al. 1994, Kumar 1994, Papadopoulos 2005, Hill et al. 2012). PWE, with its more favorable characteristics, has gradually become recognized in solid wood and wooden material treatment (Amthor 1972, Rowell and Banks 1985, Berninghausen et al. 2006, Leonovich and Butuzov 2007, Zhang et al. 2007, Scholz et al. 2009, Wang et al. 2014, Chau et al. 2015). Experimental results showed that PWE treatments were widely used in artificial board and initially used in solid wood (OuYang 1990, Liu et al. 2006).

Additionally, studies on moisture sorption and hygroexpansion of wood are conducted primarily in a static state, i.e., constant temperature and RH (Turc and Cutter 1984,

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The authors are, respectively, Master Degree Student, Associate Professor, PhD Student, and Professor, Beijing Forestry Univ., Beijing City, China (chauthithanh@huaf.edu.vn [corresponding author], maerni@bjfu.edu.cn; bjfu100514327@163.com, caoj@bjfu.edu.cn). This paper was received for publication in November 2016. Article no. 16-00061.

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Hernández 1993, Peralta 1995, Almeida and Hernández 2006, Ma et al. 2009, Zhou et al. 2014, Chau et al. 2015). Regarding this aspect, research on moisture sorption in the available literature has put much effort into two main areas: hygroscopic capability and sorption rate (Ma et al. 2009). Concurrently, hygroexpansion in a given study condition is influenced by many factors, such as MC, temperature, RH, and anisotropy (Droin-Josserand et al. 1988, Ma et al. 2005). The representative study of Noack et al. (1973) proposed the relation curves between MC and RH, swelling ratio and RH, and swelling ratio and MC, where their slopes were known as X (moisture expansion coefficient), Y (humidity expansion coefficient), and Z (moisture sorption coefficient), respectively. After that, some researchers applied these coefficients to their studies (Chomcharn and Skaar 1983a, Ma et al. 2010, Yang and Ma 2013, Zhou et al. 2014, Chau et al. 2015). However, their test conditions were too idealistic to offer an index to the use of wood products in service (Ma 2013). Therefore, the appropriate research was undertaken, i.e., research that was most similar to actual use conditions. The subsequent experimental environments were constant temperature and sinusoidal RH with various cyclic numbers and distinct cyclic periods, and mass and dimensions were periodically determined (Chomcharn and Skaar 1983b, Droin-Josserand et al. 1988, Ma et al. 2010). In the earliest study, Chomcharn and Skaar (1983b) subjected roundwood wafers of green basswood, yellow birch, and black cherry to sinusoidal varying RH between 77 and 47 percent at 25°C for many cycles at each of four different cyclic periods. The study also calculated dynamic X, Y, and Z and compared them with the results of a static condition study. Afterward, the studies series of Ma et al. had already shown some consequences and significance. Ma et al. (2010) studied similar behavior of Sitka spruce, and the Fourier approach was used for quantitative analyzing. Ma et al. (2010) further utilized the Fourier method to investigate the amplitude and phase lag along the thickness direction (surface, middle, and core layer). After that, Yang and Ma (2013) also studied the behavior of 4- and 10-mm-thick poplar. The study found that Z and Y values were in direct proportion to cyclic period but inversely related to specimen thickness. Yang and Ma (2015) further compared results obtained at 25°C and 40°C. Notable results showed that temperature increases resulted in decreased moisture and dimensional changes; there were positive correlations between temperature and amplitude of MC and dimensional changes and negative correlations between temperature and phase lag. Furthermore, sorption hysteresis and swelling hysteresis decreased due to an increase of temperature.

Therefore, in this study, by inheriting some of the work from the study of Chau et al. (2015), moisture sorption and hygroexpansion of PWE-treated wood in sinusoidal changes in RH were evaluated using an analysis electronic balance and four laser displacement sensors. The effect of PWE treatment on moisture sorption behavior was also examined using three concentrations of a waterproof agent, and some results were compared with outcomes of the static study by Chau et al. (2015).

Experimental

Materials

The test material was southern pine (*Pinus* spp.), free of visual defects, with dimensions of 4 and 10 mm along the grain and 20 mm in both tangential and radial directions. The specimens were divided into four similar groups according to weight; these included a control and treatments with 0.5, 1, and 2 percent PWE.

PWE was prepared in the laboratory, and the solid content was about 40 percent (Wang et al. 2014). The emulsion was diluted to concentrations of 0.5, 1, and 2 percent, recorded as 0.5, 1, and 2 percent PWE, respectively.

Methods

Wood treatments.—Wood samples were treated via a full-cell process. Specifically, test samples were submerged with treatment liquids and placed in a vacuum at –0.1 MPa for 30 minutes. Subsequently, the pressure was increased to 0.5 MPa and maintained for 1 hour. Finally, the pressure was relieved, and the samples were taken out.

The weight percent gains (WPG_s) were 0.7, 1.5, and 2.5 percent for 0.5, 1, and 2 percent PWE-treated wood, respectively, based on the calculation from Equation 1:

$$\mathrm{WPG}_s = \frac{m_t - m_u}{m_u} \times 100(\%) \tag{1}$$

where m is the average ovendry mass of the specimen before (u) and after (t) the treatment.

Moisture-repellent effectiveness and antideformation effectiveness.—An evaluation method was applied from a previous study (Rowell et al. 1985) in which the comparison of treated with untreated material was based on the change (in dimension or moisture absorbed) on exposure to moisture for a defined time. Hygroscopic improvement is expressed as moisture-repellent effectiveness (MRE) or antideformation effectiveness (ADE):

$$\mathrm{MRE(ADE)} = \frac{D_c - D_t}{D_c} \times 100(\%) \tag{2}$$

where D_c is the swelling (or moisture adsorption) of the control during exposure in moisture for t minutes and D_t is the swelling (or moisture adsorption) of the treated specimen, also for t minutes.

Dynamic moisture sorption.—The specimens were ovendried at 103°C ± 2°C, after which their ovendry weights and tangential and radial dimensions were simultaneously measured. They were then exposed to a 45 percent RH condition controlled by a saturated salt solution of potassium carbonate at 30°C ± 1°C and maintained inside the self-designed temperature conditioning chambers to achieve equilibrium state. They were then moved into a conditioning chamber where the temperature was kept at 30°C throughout the experiment.

Before the cyclic test, the specimens were initially reexposed to 45 ± 1.0 percent RH for 2 hours to further equilibrate at this condition; they were then subjected to a sinusoidal varying condition of (45 to 75) ± 1.0 percent RH for periods of 1, 6, and 24 hours, respectively. The RH in the chamber was programmed to vary in discrete steps according to a predetermined schedule, and a thermorecorder was placed around the test specimens to ensure the desired conditions. Weight changes as well as radial and tangential dimensional changes in response to the imposed RH were recorded by an electronic balance and four charge coupled device laser displacement sensors (Fig. 1). The precision of measurement was 0.1 mg and 1 μm for weight and dimension, respectively.

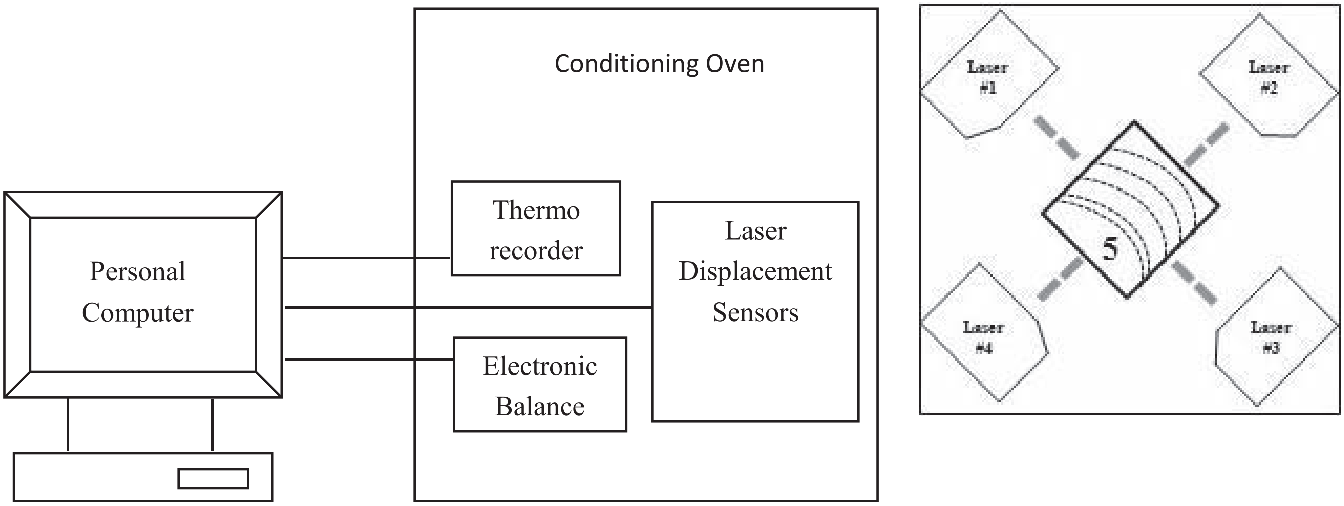

Figure 1.—Diagram showing the instrumentation detection of dimensional changes in Sample 5, in which laser heads 1 and 3 are for tangential measurement and laser heads 2 and 4 are for radial measurement.

In addition, every group had three end-matched samples for each cycle: one for dimension measurement and the other two for weight measurement. The dimensional and weight measurements were repeated three times. The dimensional measurement samples were rotated so that each of the three samples was measured for dimension once and weight twice. In this way, the effect of variability among specimens was reduced considerably. The average values of the three tests for weights and dimensions of the specimens were taken as the final result.

Results and Discussion

General moisture and dimensional responses

Moisture and dimensional responses of the 10-mm-thick untreated samples to sinusoidal varying RH cycled at 24 hours; an example is shown in Figure 2, in which moisture and dimensional changes are given in terms of values based on ovendry state. It is apparent that the moisture and dimensional changes are generally sinusoidal. However, it is found that the RH reaches its maximum values earlier than those in moisture and lateral dimensional changes, meaning that wood responses lagged behind the imposed RH. The result is consistent with previous studies (Ma et al. 2010; Yang and Ma 2013, 2015). Other specimens also exhibited the above tendency.

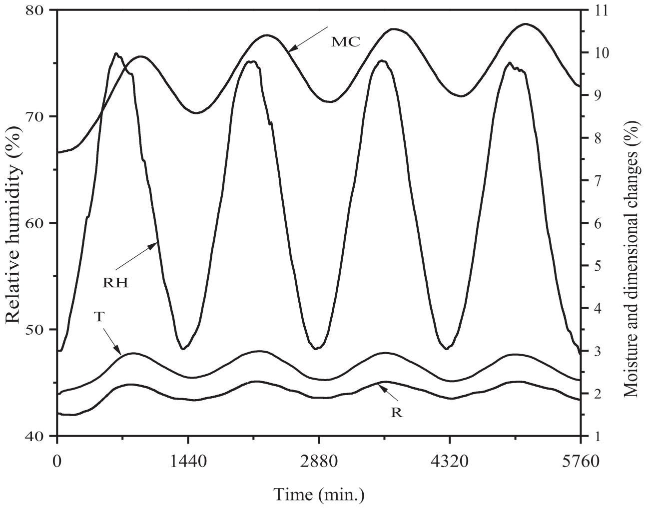

Figure 2.—Moisture content (MC), tangential (T), and radial (R) dimensional changes for 10-mm-thick untreated southern pine specimens with the change of relative humidity (RH) cycled at 24 hours.

Effect of PWE treatment on amplitude through moisture sorption processes

In this study, with a sine wave of RH, the absolute maximum displacement of MC and tangential (T) and radial (R) dimensions from the initial values were defined as amplitude values (A), which were expressed as a percentage.

Effect of PWE treatment on moisture amplitude.—Amplitude refers to the maximum amount of vibration that the physical quantity may reach, usually denoted by A, which is the physical quantity of the range and intensity of the vibration. In this study, when the sample is placed in the RH sinusoidal change, the amplitude is the absolute value of the maximum displacement of the initial value when the MC is proportional to the chord and the radial dimension; that is, the magnitude is equal to the maximum displacement. RH, MC, and tangential and radial amplitude are also a scalar, the unit being expressed as a percentage.

Table 1 presents the amplitude of MC for two thicknesses of both control and PWE-treated wood. It is evident that the amplitude of the control subjected to the longer cycle is larger than that in the shorter cycle. This was anticipated because there was sufficient time for the specimen, especially the interior, to respond to the RH changes at long cyclic periods.

However, the values for 10-mm-thick samples are lower than those for 4-mm-thick samples, i.e., there was a negative correlation between wood response amplitude and thickness where 10-mm-thick control values are 60 percent of 4-mm-thick values at the 1-hour cyclic period. This is because of insufficient time for thicker samples, especially their inner part, to respond to RH change.

Table 1.—Amplitude of moisture (A_m) and tangential (A_t) and radial (A_r) dimensional changes and ratio of tangential to radial (T/R) change amplitude (A_t/A_r) of southern pine.[a]

	Wood group							
	4-mm thickness				10-mm thickness			
Cylic period	Control	0.5% PWE	1% PWE	2% PWE	Control	0.5% PWE	1% PWE	2% PWE
1 h								
A_m	1.37	1.10	0.76	0.52	0.82	0.54	0.48	0.28
A_t	0.52	0.47	0.44	0.31	0.44	0.40	0.34	0.17
A_r	0.33	0.30	0.30	0.26	0.28	0.23	0.23	0.16
T/R	1.68	1.47	1.46	1.34	1.52	1.37	1.27	1.23
6 h								
A_m	2.82	2.5	2.33	1.66	2.01	1.74	1.11	0.95
A_t	0.95	0.85	0.74	0.60	0.79	0.62	0.52	0.37
A_r	0.60	0.58	0.53	0.43	0.55	0.45	0.40	0.29
T/R	1.69	1.45	1.44	1.38	1.49	1.32	1.25	1.25
24 h								
A_m	3.29	2.90	2.15	2.04	2.41	2.11	1.59	1.53
A_t	1.18	0.93	0.60	0.42	0.93	0.78	0.71	0.65
A_r	0.70	0.58	0.40	0.39	0.68	0.57	0.56	0.54
T/R	1.70	1.50	1.47	1.28	1.46	1.32	1.24	1.23

[a] PWE = paraffin wax emulsion.

Table 1 also expresses the PWE treatment influence on moisture amplitudes. It can be found that PWE treatment could reduce the A_m values in both thicknesses and three cyclic periods. Additionally, by applying Equation 2 for PWE-treated wood, the MRE is shown in Figure 3.

Combining the data in Table 1 and Figure 3, it can be seen that MRE values increase with an increase in PWE concentration but decrease in the cyclic period, varying in the range of 10 to 66 percent. The data at 1 hour show that PWE treatment dramatically affects moisture amplitude under dynamic conditions, while the thickness inconspicuously influences MRE values, which increase with an increase of PWE concentration. Therefore, the optimal MRE belongs to 2 percent PWE-treated wood and the 1-hour cyclic period, i.e., maximum values are 62 and 66 percent for 4-mm and 10-mm thickness, respectively.

PWE treatment effect on amplitude of lateral dimensional change.—Table 1 lists the lateral dimensional change amplitude of control samples and PWE-treated samples. For the control, the amplitude tendency of lateral changes is similar to that of moisture. The results also suggest that PWE treatment could reduce the amplitude of dimensional changes. It can be found that, for both 4-mm and 10-mm samples, the amplitude of lateral changes of PWE-treated samples is smaller than that of the control. Therefore, the ADE values were calculated according to Equation 2 and the study of Chau et al. (2015) and are shown in Figure 4. Under the same cyclic period, the ADE values are enhanced with the increase of PWE concentration treatment, while the values for the same thickness generally decrease with an increase of cyclic period, i.e., the 1-hour cyclic period exhibited the maximum values.

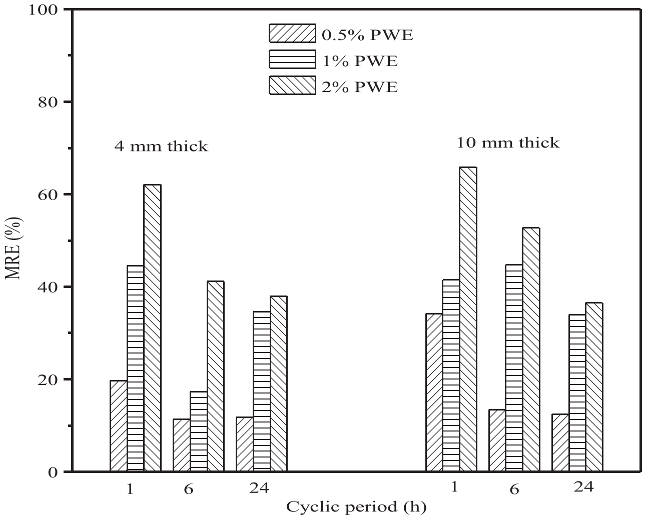

Figure 3.—Moisture-repellent effectiveness (MRE) of paraffin wax emulsion (PWE) treatments in the dynamic condition.

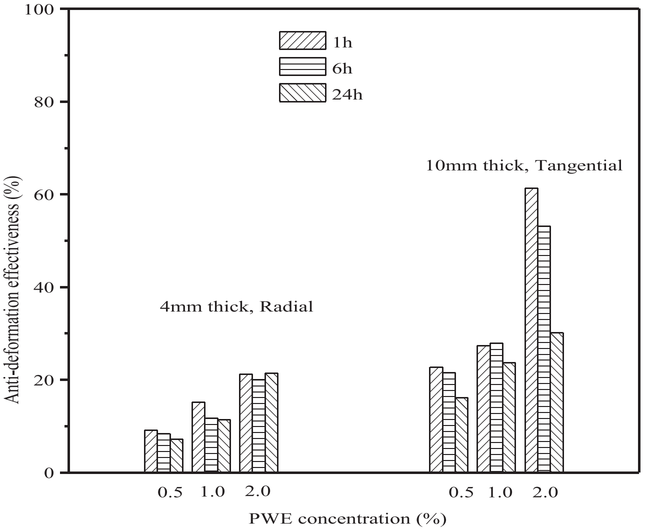

Figure 4.—Antideformation repellent effectiveness of paraffin wax emulsion (PWE) treatments in the dynamic condition.

Table 1 further suggests that wood is anisotropic with respect to its transverse dimensional changes at various cyclic periods. There is evidence that the T/R ratio of the 4-mm-thick control is close to 1.75, while T/R values of the 10-mm-thick samples are somewhat lower; these values are less than previous data (1.75 is the average value of T/R in the static adsorption condition between 45% and 75% RH) (Chau et al. 2015). Table 1 also shows the T/R ratio of PWE-treated wood compared with the control. The results suggest a series of values in different cyclic periods, and this ratio is reduced with a rising PWE concentration treatment.

Relationship between moisture and lateral dimensional changes.—Figure 5 further reveals the moisture and lateral dimensional changes in the 4-mm-thick control group. In the present study, MC increases from 7.65 to 10.94 percent with various cycles, and lateral dimensional changes also rise progressively. It can be found that the R^2 values are greater than 0.99, indicating a good relationship between radial as well as tangential dimensional changes and moisture and a good linear relationship between them. Other specimens also satisfy the above-mentioned relation.

The slope of the curve in Figure 5 indicates a unit of dimensional change per unit change of moisture, i.e., an index that compares the dimensional stability of wood, namely, the moisture expansion coefficient X. Hence, the X values were determined for four wood groups in 45 to 75 percent sinusoidal RH and are shown in Table 2. The table suggests that the X of the tangential direction is greater than that of the radial direction, confirming that the tangential dimension is more sensitive to moisture change. The X values of PWE-treated wood were not obviously stable; thus, this appraisal could not affirm the effectiveness of PWE treatment because of the absence of a chemical combining PWE and wood (Chau et al. 2015).

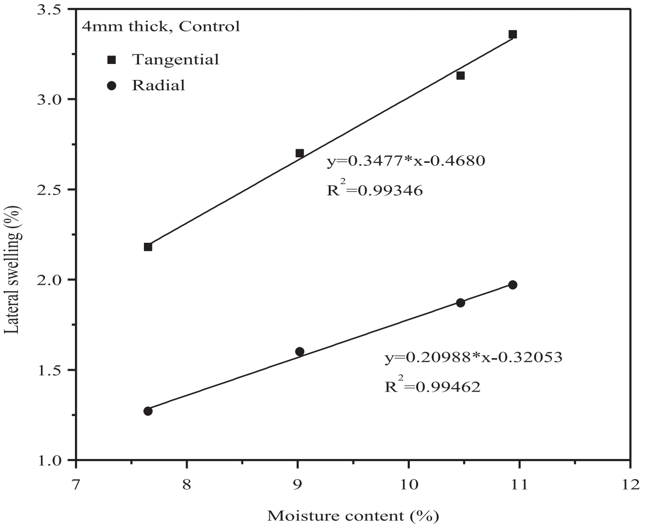

Figure 5.—Linear relationship between moisture content and lateral dimensional changes.

Effect of PWE treatment on phase lag during moisture sorption processes

Table 3 further summarizes the phase lag values of the control and PWE-treated wood. First, under the same cyclic period condition for samples of either untreated or PWE-treated wood, the phase lags of moisture and tangential and radial changes at 10-mm thickness are greater than those at 4-mm thickness, i.e., the phase lag was stronger in thicker samples and the response against RH was slower. Taking the 4-mm-thick control as an example, the obtained phase lags are similar to those of preliminary studies (Ma et al. 2010, Yang and Ma 2013), whereas the phase lags of 10-mm-thick samples were twice as much as in 4-mm-thick samples. Additionally, in both untreated and treated wood, the phase lags of MC are greatest, followed by those of radial and tangential dimensional changes, i.e., the response of tangential dimensional changes against RH was the quickest.

Furthermore, for PWE treatment, it is clear that the phase lags increase when PWE treatment concentration becomes higher, implying that PWE treatment has a suppression effect on moisture and lateral dimensional changes against

Table 2.—Moisture expansion coefficient (X), humidity expansion coefficient (Y), and moisture sorption coefficient (Z) under dynamic conditions.[a]

		Wood group							
	Cyclic period (h)	4-mm thickness				10-mm thickness			
		Control	0.5% PWE	1% PWE	2% PWE	Control	0.5% PWE	1% PWE	2% PWE
X_t	1	0.3796	0.3909	0.5789	0.5962	0.3566	0.6296	0.6667	0.6071
	6	0.3369	0.3360	0.3176	0.3614	0.3930	0.3563	0.5135	0.3895
	24	0.3587	0.3448	0.4186	0.3529	0.3859	0.3697	0.4465	0.4248
X_r	1	0.2409	0.2727	0.3684	0.5000	0.3293	0.4047	0.3598	0.5714
	6	0.2128	0.2200	0.2275	0.2892	0.2736	0.2586	0.3604	0.3474
	24	0.2218	0.2241	0.2884	0.2696	0.2822	0.2701	0.3522	0.3529
Y_t	1	0.0173	0.0157	0.0147	0.0103	0.0147	0.0133	0.0113	0.0057
	6	0.0317	0.0283	0.0247	0.0200	0.0263	0.0207	0.0173	0.0123
	24	0.0393	0.0310	0.0200	0.0140	0.0310	0.0260	0.0237	0.0217
Y_r	1	0.0110	0.0100	0.0100	0.0087	0.0090	0.0077	0.0077	0.0053
	6	0.0300	0.0290	0.0265	0.0215	0.0275	0.0225	0.0200	0.0145
	24	0.0233	0.0193	0.0133	0.0130	0.0227	0.0190	0.0187	0.0180
Z	1	0.046	0.037	0.025	0.017	0.027	0.018	0.016	0.009
	6	0.094	0.083	0.078	0.055	0.067	0.058	0.037	0.032
	24	0.110	0.097	0.072	0.068	0.080	0.070	0.053	0.051

[a] PWE = paraffin wax emulsion.

Table 3.—Phase lag of moisture and tangential and radial responses for southern pine specimens.[a]

	Phase lag (rad)								
	4-mm thickness					10-mm thickness			
Cyclic period	Control	0.5% PWE	1% PWE	2% PWE	Sitka spruce[b]	Control	0.5% PWE	1% PWE	2% PWE
1 h									
MC	0.62	0.83	0.94	1.05	0.6	1.25	1.31	1.53	1.59
T	0.44	0.73	0.77	0.79	0.46	0.84	0.86	0.90	0.94
R	0.47	0.79	0.84	0.86	0.53	0.95	1.05	1.15	1.15
6 h									
MC	0.56	0.78	0.90	0.94	0.44	1.16	1.21	1.23	1.28
T	0.42	0.43	0.47	0.55	0.36	0.68	0.72	0.75	0.87
R	0.46	0.48	0.52	0.55	0.41	0.73	0.76	0.78	0.96
24 h									
MC	0.52	0.72	0.77	0.79	0.31	0.79	0.79	0.85	0.97
T	0.37	0.44	0.47	0.59	0.27	0.47	0.54	0.57	0.78
R	0.43	0.48	0.52	0.65	0.30	0.61	0.67	0.67	0.78

[a] PWE = paraffin wax emulsion; MC = moisture content; T = tangential; R = radial.

[b] Excerpted from preliminary research data (Ma et al. 2010).

dynamic RH conditions, in which the effectiveness of 2 percent PWE treatment is the most notable.

Effect of PWE treatment on sorption hysteresis and swelling hysteresis

Effect of PWE treatment on sorption hysteresis.—Figure 6 demonstrates the relationship between moisture and sinusoidal RH, called the dynamic sorption isotherm curve. It is evident that moisture in the desorption process is greater than that in adsorption, indicating the existence of moisture sorption hysteresis under dynamic conditions. Other studies have also observed this hysteresis phenomenon (Ma et al. 2010, Yang and Ma 2013).

In order to quantify the proportion of hysteresis, the A/D ratio at the maximum value of adsorption moisture (A) to desorption moisture (D) was calculated for each cyclic period (Yang and Ma 2013), and the results are shown in Table 4. It is shown that, for the control, the 10-mm-thick A/D value is greater than that at 4-mm thickness. For PWE treatment at various concentrations, for all the cyclic periods, the A/D values of 2 percent PWE-treated wood are larger than those of the control, meaning that PWE treatment has a depressive effect on the moisture sorption hysteresis phenomenon. This is due to the fact that the cellulosic constituents exhibit moisture sorption, which further depends on the amorphous region size and quantities of free hydroxyl groups. However, after impregnating treatment, PWE existed in cell lumen and adhered to cell walls, hindering the moisture sorption ability of free hydroxyl groups; therefore, the hysteresis was weakened (Chau et al. 2015).

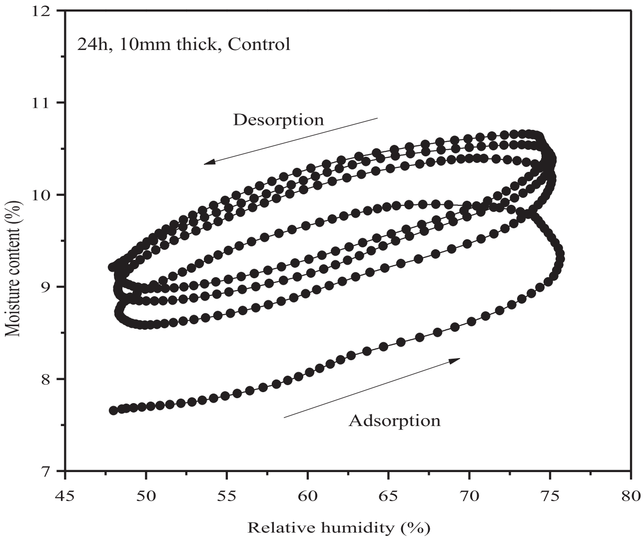

Figure 6.—Dynamic sorption isotherm of 10-mm-thick control southern pine wood.

Moreover, Figure 6 displays the mutual superimposed ovals on which the slopes of the long axis express the moisture change per unit change of RH, called the *Z* coefficient, as an evaluation index of hygroscopic characteristics of wood; *Z* values are also summarized in Table 2. It can be found that the controls of both thicknesses of samples reflect the same tendency, i.e., *Z* values decrease with a contraction in the cyclic period. Moreover, the *Z* values of the 4-mm-thick and 10-mm-thick controls were 0.110 and 0.068, respectively, indicating that thicker specimens have a weaker response ability to change RH. Furthermore, the *Z* value of 4-mm thickness in the dynamic condition is smaller than in the static condition (i.e., 0.1698), suggesting that the dynamic condition could drop the magnitude of wood hygroscopicity. In addition, the *Z* values of treated wood are less than those

Table 4.—Adsorption moisture to desorption moisture (A/D) values for southern pine wood under dynamic conditions.[a]

Thickness (mm)	Cyclic period (h)	A/D value			
		Control	0.5% PWE	1% PWE	2% PWE
4	1	0.894	0.900	0.929	0.928
	6	0.834	0.805	0.829	0.828
	24	0.780	0.770	0.740	0.900
10	1	0.945	0.960	0.963	0.964
	6	0.909	0.926	0.928	0.923
	24	0.909	0.912	0.926	0.928

[a] PWE = paraffin wax emulsion.

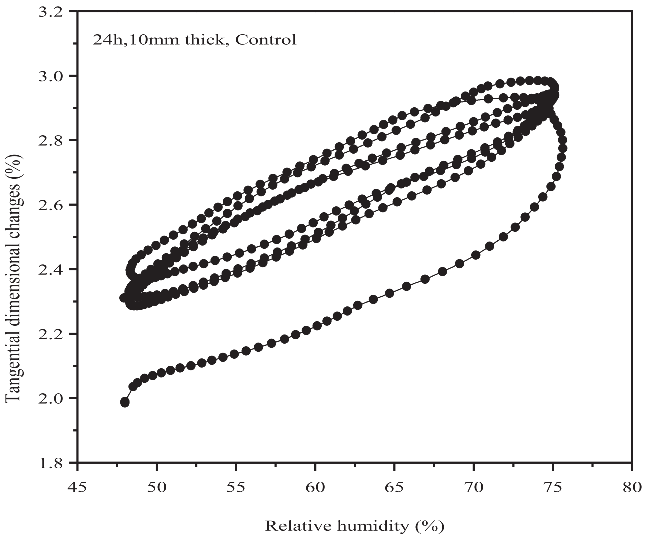

Figure 7.—Relationship between tangential dimensional change and relative humidity of wood sample.

from the control, and the most obvious results were found in 2 percent PWE-treated wood.

Effect of PWE treatment on swelling hysteresis.—Figure 7 represents the relationship between tangential dimensional changes and RH. Dimensional changes also exist similarly to the hysteresis phenomenon, i.e., the dimensional change ratios of the desorption process are greater than those of the adsorption process. Other groups also arise out of this swelling hysteresis.

Therefore, the humidity swelling coefficient (Y) in the dynamic condition, being the slope of long axis on the overlapped ovals in Figure 7, was calculated, and the values are shown in Table 2. For the control, Y values increase with an increase in the cyclic period and a decrease in specimen thickness, and tangential Y (Y_t) values are larger than those of the radial direction (Y_r). Moreover, for the 4-mm-thick control, the Y values of the dynamic condition are much lower than those of the static condition (0.0689 of Y_t and 0.0365 of Y_r, where the Y value of 24 hours was half that of the static condition) (Chau et al. 2015).

Again, the Y values of PWE-treated samples are lower than those of the control, indicating that PWE treatment could improve the dimensional stability of wood specimens. Furthermore, Y values of treated wood in dynamic condition were considerably less than those in the static condition. These results indicate that PWE treatment expresses favorable results in actual environments (Chau et al. 2015), further affirming that PWE is suitable for solid wood and practical use.

Conclusions

By comparing the moisture sorption and hygroexpansion between the control and PWE-treated southern pine, the following results are shown:

1. With PWE treatment, the amplitudes of moisture and lateral dimensional change of treated wood were lower than those of the control samples; X_t was greater than X_r, suggesting that tangential dimensional change was more prone to moisture in both the control and the treated samples.
2. The phase lag of treated samples was greater than that of the control; PWE-treated wood samples slowly responded to changes in RH, indicating that PWE treatment had an inhibiting effect on moisture and lateral dimensional changes under sinusoidal RH conditions.
3. All the wood groups exhibited the phenomenon of sorption hysteresis and swelling hysteresis. For sorption hysteresis, the A/D values of PWE-treated wood were less than those of the control at the same cyclic period. The Z value of 2 percent PWE-treated samples was the smallest. PWE treatments simultaneously decreased Y values, indicating further restrained dimensional changes.

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