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The Swelling Response of Loblolly Pine (*Pinus Taeda*) Juvenile Wood to Water Submersion[*1]

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ABSTRACT

Juvenile and transitional-juvenile wood samples from loblolly pine (*Pinus taeda*) were immersed in water to investigate longitudinal and tangential swelling properties. Increment cores from twenty-six loblolly pine trees were sampled at breast height (1.37 m). Earlywood rings 5 and 9 were separated from the core, extracted, oven-dried and immersed in water at room temperature. The variance in longitudinal swell was significant for ring 5 compared to ring 9 ($p = 0.001$). It was found that tangential swell might predict longitudinal swelling of juvenile wood at ring 9 but not at ring 5. Poor correlation in ring 5 suggests that swelling response in younger juvenile wood may differ. The swell response at ring 5 did not follow the shrinkage models discussed in the literature while ring 9 adhered to the expected curve.

Keywords : dimensional stability, juvenile wood, loblolly pine, longitudinal, microfibril angle, *Pinus taeda*, swell, shrinkage, tangential.

1. INTRODUCTION

An increase in the volume of managed plantation loblolly pine (*Pinus taeda*) sites in the southern United States has recently resulted in more juvenile southern yellow pine lumber being processed (Larson *et. al.*, 2001). As a result, genetic and silvicultural effects on period of juvenility are being investigated (Larson *et. al.*, 2001). Juvenile wood is detrimental in many physical and mechanical properties because of its decreased specific gravity, fiber length, cell wall thickness, latewood percent and cellulose content, as well as, increased extractive content, lignin and microfibril angle (MFA) (Zobel and Sprague, 1998). Therefore, knowledge of swell variation in the juvenile wood zone could be useful for tree breeding programs.

Longitudinal swelling of wood, when the moisture content is below the fiber saturation

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point (FSP), occurs either by increased relative humidity (RH) or by water exposures. Longitudinal swelling is also related to MFA, which is basically the mean angle of the aggregate cellulose chains with respect to the axis of the tracheid. As moisture enters the cell wall material, swelling occurs perpendicular to the microfibril axis. A theoretical study was conducted on the water absorption: the first water molecules attach to free hydroxyl groups and then as swelling occurs, hydroxyl sites are broken and new sites are available for further sorption (Morisato *et. al.*, 1999). The following equation by Harris and Meylan (1965) suggests that longitudinal strain will increase dramatically at microfibril angles greater than 35 to 40 degrees.

$$\varepsilon_x / \varepsilon_o = [1-(E/S)\sin^2\alpha \cos 2\alpha] / \Delta \qquad (1)$$

where $\Delta = 1 + E/3B + (2E/3S)(1-3\sin^2\alpha \cos^2\alpha)$, ε_x is the strain in longitudinal dimension, α is microfibril angle, E/S is the ratio of elastic modulus of microfibrils and shear modulus of remaining matrix, and B is the overall modulus of the matrix.

Longitudinal swell is a slightly different response than longitudinal shrinkage. By definition, longitudinal shrinkage is the percent change in dimension from FSP to a drier condition whereas longitudinal swell is the percent change in dimension from oven-dry to a more humid condition. Due to the hysteresis effect, one would not expect to see the same magnitude of response for adsorption and desorption experiments.

The effect of MFA on longitudinal dimensional stability has been successfully modeled (Barber 1968, Barber and Meylan 1964, Harris and Meylan 1965, Pang 2001, Meylan 1968, Yamamoto 1999, Yamamoto *et. al.*, 2001). The models implied a curvilinear trend between longitudinal and tangential shrinkage when MFA exceeded 30 degrees. It is assumed that swelling would follow a similar trend. Assuming that MFA above 30 are good indicators for juvenile wood, then the first ten years of growth of loblolly pine would be expected to show the curvilinear relationship for shrinkage and perhaps swelling (Ying *et al.*, 1994, Megraw *et al.*, 1998).

Longitudinal swell could vary in a predictable pattern from the first to the last tracheid in an earlywood or latewood ring. Bergander (2001) found that MFA decreases within a ring for spruce and loblolly pine (Pillow *et al.*, 1959). Such patterns of variation for longitudinal swell within a ring make sample preparation a critical task. Careful and consistent sampling within each ring would thus be needed especially since ring width can vary greatly between stands and trees. Sampling of the whole ring may be needed to yield an accurate swell estimate when high variations in ring width exist.

The variation in longitudinal shrinkage has been also shown to differ between juvenile and mature wood in the butt log region (Megraw *et al.*, 1998). In mature wood, the variation in shrinkage was negligible while variance was greater in juvenile wood (Harris and Meylan 1965, Megraw *et al.*, 1998). It is not known if swelling variation for specimens submerged in liquid water will follow the same response as shrinkage.

The objectives of this study were to: (a) determine the relationship between tangential and longitudinal swell for rings submerged in water; and, (b) evaluate the trend, mean and variation in longitudinal swell for ring 5 and 9 of loblolly pine wood.

2. METHODS and MATERIALS

Twenty-six loblolly pine (*Pinus taeda*) increment cores (12-mm diameter), obtained at breast height, were taken from three locations to assure a wide range of growth rates and seed source

Table 1. Summary statistics for site diameter at breast height (excluding bark; n=26)

Age	Mean diameter (mm)	Diameter range (mm)	Standard deviation
10	169	133～206	23.7
14	164	127～197	24.8
16	165	108～200	27.1

(Table 1). The sites were located in the coastal region of South Carolina (United States). A standard spacing of 2.44×2.44 m was present for all stands and never had been thinned before 10 years of age. Mortality rates were of negligible difference among annual rings (Megraw *et al.*, 1998). The stand ages at breast height were 10, 14, and 16 years in age collectively. Typical burn and under story control were performed for all stands. Each increment core was selected in a random direction. Collection in a north-south direction was not feasible for these studies since loblolly pine has many knots, gaul, or compression wood at breast height. Upon collection of the increment core, compression wood and knots were avoided. Samples were sealed into labeled bags 203 mm long by 38 mm wide. The bags were stored in ice coolers within two hours and then transported to a freezer.

The specimens were allowed to equilibrate to ambient room temperature and humidity. Rings 5 and 9 earlywood sections were cut with a razor blade to approximately 10-mm longitudinally by 5-mm tangentially with a variable radial thickness dependent on earlywood ring width. Latewood samples were not prepared since radial thickness, in many specimens, was not wide enough to isolate only the latewood. All variations were accounted for by measuring each dimension and weight with a digital caliper (accurate to 0.127-mm) and weight scale (accurate to 0.0001 g) respectively, at 22°C and 30% *RH*.

The specimens were extracted using a Soxhlet apparatus with toluene for a 24-h. period. The toluene mix was then removed and replaced with acetone for another 24-h. period. The specimens were then left in a chemical fume hood at ambient room temperature for an hour to remove residual fumes.

Following extraction and outgassing, the specimens were placed in a convection oven for 24 h at 105°±3°C and then transferred to an airtight plastic container containing Drierite.® Each specimen was placed inside a separate sealed plastic bag within the airtight container so that opening and closing the container would minimally influence unmeasured specimens. Oven-dry dimensions and weights were measured.

The oven-dry specimens were firmly positioned under a linear variable differential transducer (LVDT) and immediately submerged in water to minimize error attributed to swelling due to room environment. Swell rates were recorded with data acquisition software, to an accuracy of 0.00254 cm. The swelling of each specimen was measured until no more significant longitudinal swelling occurred. Total time lapsed was 20 min. Real-time data of longitudinal swell were recorded for each sample to ensure that no slippage or irregular trends occurred. Tangential and longitudinal dimensions were measured in the water-saturated condition.

After the swelling was complete, the specimens were placed in a container near 100% *RH.* Each specimen was placed inside a separate plastic bag within the container so that opening and closing of the container would minimally influence unmeasured specimens. Bags were constantly checked to ensure that no condensation occurred along the surface touching the specimens. Variation in RH throughout the container

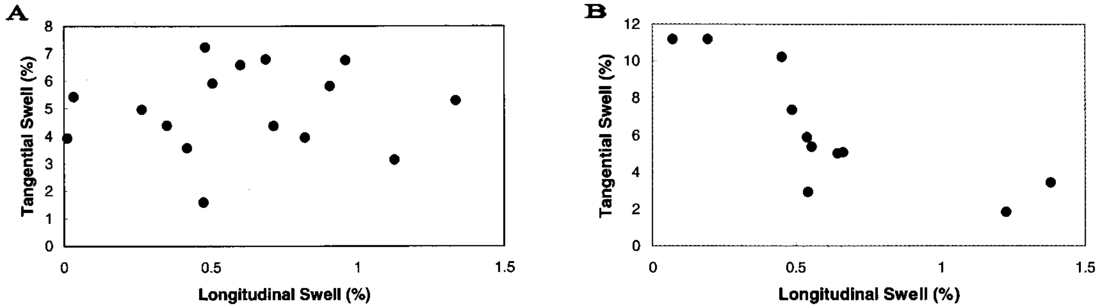

Fig. 1. A scatterplot of longitudinal versus tangential swell for (A) ring 5 and (B) ring 9.

was minimized by agitation of the water with a stir bar. The water was not in direct contact with the bags holding the specimens. The specimens were left in the humid environment until equilibrium was reached. Upon equilibrium, each bag was closed so that further opening of the container for measurements would not confound sample weight over time.

Weights and dimensions were remeasured at near 100% *RH*. The specimens were equilibrated at 22°C and 30% *RH*. Dimensions and weights were recorded.

3. RESULTS and DISCUSSION

Figs. 1(a) and 1(b) show the relationship between tangential and longitudinal swell for earlywood rings 5 and 9, respectively. For ring 5, a statistical trend between tangential and longitudinal swell was not present, and therefore, they were considered independent of one another. These results were not consistent with the shrinkage trends, in the juvenile zone, as inferred by models and empirical data (Barber 1968, Barber and Meylan 1964, Harris and Meylan 1965, Pang 2001, Meylan 1968, Yamamoto 1999, Yamamoto *et al.*, 2001). Specifically, the work of Meylan (1968), who measured tangential and longitudinal shrinkage trends for 7 year old *Pinus jeffreyi*, inferred a curvilinear relationship between tangential and longitudinal shrinkage. The difference in response may be attributed to the difference in species and/ or the magnitude and variation of the swelling response to water differs when compared to the shrinkage response in water vapor conditions.

For ring 9, a tangential versus longitudinal swell relationship existed (Fig. 1(b)). It is speculated the relationship at ring 9 might be an indication of transition wood. The relationship in Fig. 1(b) followed a similar trend as that described by shrinkage models and empirical data (Barber 1968, Barber and Meylan 1964, Harris and Meylan 1965, Pang 2001, Meylan 1968, Yamamoto 1999, Yamamoto *et al.*, 2001). A few specimens in Fig. 1(b) appeared to have a low swelling response which is characteristic of shrinkage values reported for mature wood while other samples had high swell response.

Some specimens had a negligible to very slightly negative longitudinal swelling response to water submersion. However, these specimens were not reported due to the inability of the equipment to provide accurate readings within this swelling range. Measurement in this range is inherently difficult, even with an LVDT, since the height of the specimens were only 10 mm, a height dictated by the 12 mm diameter increment core borer.

The longitudinal swell values were higher than shrinkage values reported in the literature for loblolly pine (Megraw *et al.*, 1998). This

Table 2. Directional swell summary statistics for longitudinal and tangential direction of loblolly pine

Age	Statistical parameter	Longitudinal Swell (%)	Tangential Swell (%)
Ring 5	Mean	0.715	5.27
	Standard deviation	0.576	1.49
	Coefficient of variation	80.5	28.3
	Confidence interval (95%)	[0.419, 1.011]	[4.67, 5.87]
	Sample size	17	26
Ring 9	Mean	0.587	6.07
	Standard deviation	0.372	2.87
	Coefficient of variation (%)	63.4	47
	Confidence interval (95%)	[0.377, 0.797]	[4.86, 7.28]
	Sample size	15	24

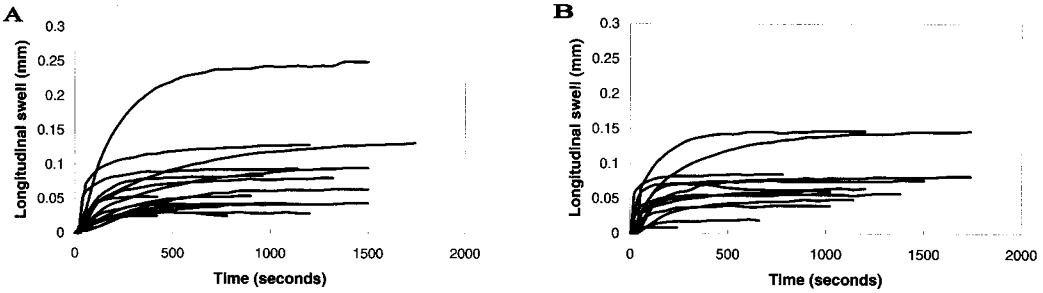

Fig. 2. Longitudinal swell versus time for (A) ring 5 and (B) ring 9.

was unexpected since swelling should be lower in dimensional change (%) compared to shrinkage due to the hysteresis effect. While conclusive remarks cannot be made, this behavior may be indicative that mean swelling response in water might differ from that obtained through vapor diffusion.

Comparing rings 5 and 9, there was no significant difference in either longitudinal or tangential swell (Table 2). This was attributed to large variation in swell at the same age between different trees. Longitudinal swell had an 80.5% coefficient of variation (CV) at ring 5 and a 63.4% CV at ring 9. The CV calculated in this study was across three sites. The variation in data did not appear to differ from the shrinkage data for year 7 for Megraw *et al.*, (1998) who saw an estimated 50% CV for two sites.

The decrease in longitudinal swell variation ($p = 0.001$) over time was expected. Megraw *et al.*, (1998) saw a negative slope in shrinkage variation from ring 3 to ring 10 for samples taken at breast height. He also observed a leveling off of the variation in shrinkage over time in the mature wood region.

The wide range in variation in longitudinal swell is presented in Figs. 2(a) and 2(b), for ring 5 and 9, respectively. The swelling curves were asymptotic to a final increased dimension with respect to time. It appeared as if a wide variation in time to stabilization was needed, however, this was partly attributed to the variation in radial thickness that had to be allowed to assure a representative mean longitudinal swell per ring. For specimens of near equal volume, ring 9 appeared to stabilize faster. This was perhaps due to a lower mean swell in ring 9 than ring 5 even though that was not determined to statistically differ.

It should be noted that preliminary testing showed the removal of extractives to yield slightly higher swelling values in the longitudinal direction. The literature supports this result and attributes the removal of extractives to increased moisture sorption capacity. Wangaard and Granados (1967) showed that both polymolecular and monomolecular sites are opened for sorption after removal of extractives. Choong (1969) theorized that extractives have a bulking effect in wood and take up sorption space normally available for water molecules. Likewise, Choong (1969) experimentally observed higher equilibrium moisture content for species lower in extractives. For this study, removal of extractives increased the mean and range of swell values in the longitudinal direction. Some individual samples experienced longitudinal swelling greater than 1.0%. The typical range of longitudinal swelling in nonextracted wood is 0 to 0.3% (Siau 1995). A larger range in swell values was useful because it increased the chance of seeing the trend observed in Fig. 1b in which the change in slopes agreed with theoretical projections (Harris and Meylan 1965).

4. CONCLUSIONS

This study was designed to evaluate the variation in swell response of juvenile wood submerged in water. The variation in mean swell response was determined for loblolly pine trees taken from three separate sites. The large phenotypic variation could perhaps be useful to a tree improvement program that needs significant variation of traits. However, one needs to keep in mind that the CV was measured each site and is probably an overrepresentation of the variance expected from one site. Moreover, it was unknown how the variation should be partitioned or if any would be attributable to genetic variation.

The swelling curve appeared to follow a similar trend to shrinkage models at ring 9. The lack of correlation at ring 5 did not agree with models in the literature. One important note is that the range of longitudinal swell at ring 5 was almost equivalent to that of ring 9 (Figs. 1a and 1b), which justifies comparison of the trends. More investigation of longitudinal swell in the innermost juvenile wood zone of loblolly pine would be useful.

No statistical relationship was found between longitudinal and tangential swell for pure juvenile earlywood (ring 5) based on water submersion experiments at ambient room temperature. The response at ring 9 was similar to curvilinear trend of published shrinkage models. Comparing the mean longitudinal swell of ring 5 to 9 showed to not statistically differ, however it was lower as expected in ring 9.

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