MICROSCOPICALLY VISIBLE INTERNAL SURFACE AREA OF EARLYWOOD AND LATEWOOD OF LOBLOLLY PINE

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ABSTRACT

Microscopically visible internal surface (MVIS) areas of earlywood and latewood of loblolly pine were estimated. Steps of calculation for MVIS area are described. For the study tree, there was no difference in MVIS area between earlywood and latewood for the same volume in spite of difference in specific gravity. However, on a unit-weight basis, MVIS area decreased with increasing specific gravity.

Keywords: *Pinus taeda*, earlywood, latewood, internal surface area, lumen surface areas, specific gravity.

INTRODUCTION

Physical properties of wood are generally dependent upon its microscopic or minute structures. For example, dimensional stability and strength properties of wood and the characteristics of paper are related to cell-wall thickness, fiber length and diameter, and fibril angles. In the case of softwood, wood properties and paper characteristics are greatly affected by tracheids because these long fibrous cells constitute 90 percent or more of the cells of softwoods (Kollman and Côté 1968; Panshin and DeZeeuw 1971).

Wood, a porous material, has rather extensive microscopically visible, permanent internal surface area. The permanent internal surface of softwoods consists chiefly of fiber cavity or lumen surfaces of the tracheids, together with that of ray cells and resin canal cavities. Rough estimation of the microscopically visible surface of softwoods has been made by Stamm (1964) from the average number of tracheids per centimeter in the tangential and radial directions and the dry volume specific gravity of the wood. On the basis of measurements made on 27 different softwoods including loblolly pine, Stamm (1946) used an average value of 300 (ranging from 200 to 400) for the number of tracheids per centimeter in both tangential and radial directions. The average tracheid diameter, D, was therefore $^1/_{300}$ or 0.00333 cm. The average lumen diameter, d, was calculated according to the equation $d = D(1 - g/1.46)^{1/2}$ where g is the specific gravity of wood, and 1.46 is the specific gravity of wood substance (Stamm 1964). Assuming the lumen to be circular, the surface area of lumen per centimeter length was obtained by multiplying the lumen circumference, C, by unity. Multiplication of this value by the number of tracheids in a square centimeter of cross section of wood (300 × 300 = 90,000) gave the lumen surface area per cubic centimeter of wood, which was then converted to area per gram of wood. According to the above calculation, Stamm obtained a lumen surface of 0.08 m^2/cm^3 or 0.2 m^2/g on the basis of the surface of ray cell and resin canal cavities being negligible in comparison.

For a rough estimation, the above calculation assuming 300 tracheids per cen-

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timeter as an average in both tangential and radial directions is justified. However, theoretically, a more realistic estimation can be obtained by using average numbers determined for tangential and radial directions of the species in question. Radial diameter of a tracheid is known to vary according to its position in the growth increment. Sharp contrast generally exists between radial diameters of earlywood and latewood tracheids (Koch 1972; Panshin and DeZeeuw 1971). Radial diameter of earlywood tracheids is on the whole much greater than tangential diameter. It is also greater than the radial diameter of latewood tracheids. Tangential diameter of latewood tracheids is practically the same though sometimes appears slightly smaller than that of earlywood tracheids. However, there is also an indication that tangential walls are sometimes thinner than radial walls of latewood tracheids (Koch 1972). Furthermore, configuration of the cross section of lumens of earlywood and latewood tracheids often differs significantly. Thus, it is believed that better estimation of lumen surface area can be achieved if exact numbers of tracheids per unit length in tangential and radial directions are known and used in calculations and if factors such as cross-sectional lumen configuration and possible difference in thickness between tangential and radial walls are taken into consideration.

This paper reports values of microscopically visible internal surface (MVIS) areas of earlywood and latewood of loblolly pine (*Pinus taeda* L.). Measurement techniques and calculation steps are described in detail. Possible implications of the findings are discussed.

SPECIMEN PREPARATION AND MEASUREMENT

A one-inch disc was removed from 20 feet above ground level of a mature log of loblolly pine (*Pinus taeda* L.). Eight sample blocks were removed from rings 25–29 (from the pith) at points equally spaced around the circumference of the stem. Sample blocks were one inch in both longitudinal and tangential dimension; the radial dimension of these 5-ring blocks (average 0.8 inch) varied according to growth ring width.

Each block was subdivided into two equal halves by splitting along the radial direction. One of the halves was separated into earlywood and latewood bands which were used in the determination of earlywood and latewood specific gravities on an oven-dry volume basis according to the method described in earlier papers (Yao 1968, 1970). The other half was surfaced with a microtome prior to oven-drying and was used for microscopic measurements. Tracheid counts were made for earlywood and latewood bands of ring 26 and ring 28 while kept in an oven-dry condition using a method described in an earlier paper (Yao 1974). In each of the tangential and radial directions, three counts were made, two along lines near the edges and one along the center line. A Leitz Ortholux microscope with an incident light ultra-pak objective was used.

CALCULATION OF INTERNAL SURFACE

Microscopically visible internal surface (MVIS) area was estimated from the number of tracheids per centimeter in the tangential and radial directions and dry-volume specific gravity (g). Fractional void or lumen volume V_f was calculated according to the equation (Stamm 1964):

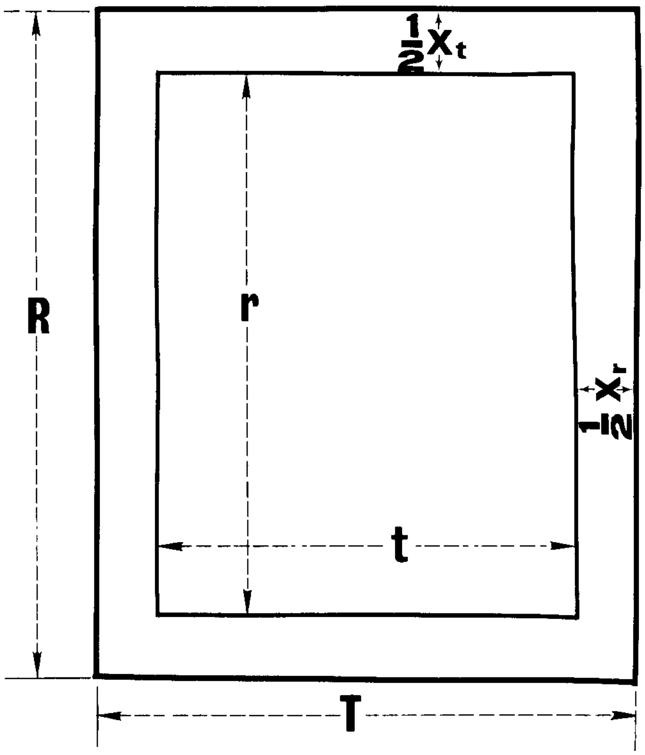

FIG. 1. Diagram of an earlywood tracheid showing cross-sectional wall and a rectangular lumen. R = radial tracheid diameter, T = tangential tracheid diameter, r = radial lumen diameter, t = tangential lumen diameter, X_r = double radial wall thickness, and X_t = double tangential wall thickness.

$$V_f = 1 - g/1.46 \tag{1}$$

Tangential diameter, T, and radial diameter, R, of earlywood and latewood tracheids (Figs. 1 and 2) were obtained by dividing one centimeter by the number of tracheids per centimeter in these two directions. Because of obvious differences in the configuration of cross sections of earlywood and latewood tracheids, separate calculation procedures were used for earlywood and latewood.

Steps of calculation for earlywood MVIS area

On the basis of microscopic examinations and literature (Panshin and DeZeeuw 1971), earlywood MVIS area was calculated according to the assumption that tracheid and lumen cross sections are rectangular, and tangential and radial walls of earlywood tracheids are the same thickness. According to the assumption (Fig. 1), the following relations are found:

$$A_t = T \cdot R \tag{2}$$

and

$$A_m = V_f \cdot A_t = (1 - g/1.46) \cdot TR \tag{3}$$

Also

$$A_m = t \cdot r = (T - X_t)(R - X_r) \text{ or}$$

$$A_m = (T - X)(R - X) \tag{4}$$

where: $X = X_t = X_r$.

In these equations, A_t represents the cross-sectional area of a tracheid; A_m the cross-sectional area of lumen; V_f the fractional void or lumen volume; g the specific gravity; T the tangential tracheid diameter; R the radial tracheid diameter; t the tangential lumen diameter; r the radial lumen diameter; and X the double wall thickness of tracheid. By combining Eqs. (3) and (4),

$$(1 - g/1.46)T \cdot R = (T - X)(R - X), \tag{5}$$

a polynominal equation is derived as

$$AX^2 - BX + C = 0 \tag{6}$$

where: $A = 1$, $B = T + R$, $C = 0.685T \cdot R \cdot g$.
Since T, R, and g are known values obtained from measurements, double wall thickness, X, can be obtained by solving Eq. (6). Then, the perimeter of the rectangular lumen, P; the MVIS area per tracheid per unit (cm) length, S_t; the MVIS area per cubic centimeter of wood, S_c; and finally the MVIS area per gram of wood, S_g, are calculated using the following equations:

$$P = 2(t + r) = 2(T + R - 2X) \tag{7}$$

$$S_t = P \cdot \text{unity} \tag{8}$$

$$S_c = S_t \cdot N \tag{9}$$

where N = number of tracheids per square centimeter of cross section and

$$S_g = S_c/g. \tag{10}$$

Steps of calculation for latewood MVIS area

The cross-sectional lumen configuration of latewood tracheids varies much more than earlywood tracheids. It varies from rectangular to circular but is most frequently elliptical. Also, sometimes the radial walls of a latewood tracheid are about 23% thicker than the tangential walls for loblolly pine (Koch 1972). Because of the greater variability of lumen configuration of latewood tracheids, calculations were based on four different assumptions.

Assumption 1.—Both tracheids and lumens are rectangular in cross section, and radial and tangential walls are the same in thickness. Since this assumption is exactly the same as the assumption made about earlywood, the steps of calculation for latewood MVIS area are the same as those for earlywood.

Assumption 2.—Both tracheids and lumens are rectangular in cross section, but radial cell walls are 23% thicker than tangential walls. This assumption causes calculation modifications relating to wall thickness. For this assumption, Eq. (4) becomes

$$A_m = (T - 1.23X_t)(R - X_t) \tag{11}$$

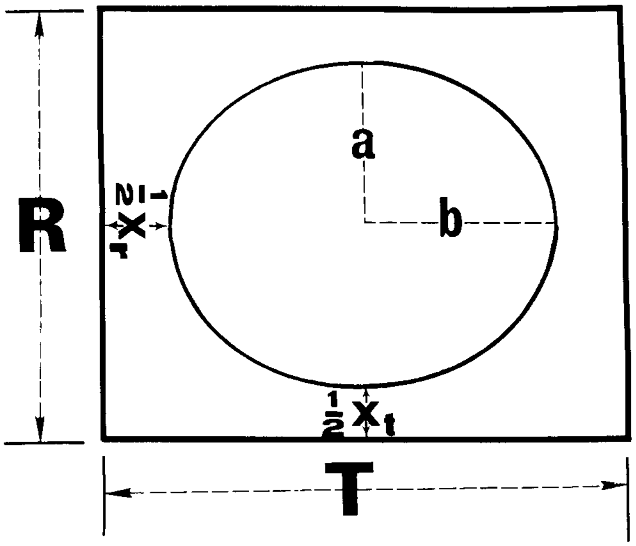

FIG. 2. Diagram of a latewood tracheid showing cross-sectional wall and an elliptical lumen. R = radial tracheid diameter, T = tangential tracheid diameter, a = ½ radial lumen diameter, b = ½ tangential lumen diameter, X_r = double radial wall thickness, and X_t = double tangential wall thickness.

because the double radial wall thickness, X_r, equals 1.23 times the double tangential wall thickness, X_t. All the other steps of calculation are the same as Assumption 1 or as those for earlywood. The equation developed to obtain double wall thickness is

$$AX_t^2 - BX_t + C = 0 \tag{12}$$

where: A = 1, B = 0.813T + R, C = 0.566T·R·g.

Assumption 3.—Tracheids are rectangular but lumens are elliptical in cross section. The radial cell walls are 23% thicker than tangential walls. This assumption (Fig. 2) uses relations from Eq. (2) ($A_t = T \cdot R$) and Eq. (3) ($A_m = V_f \cdot A_t = (1 - g/1.46)T \cdot R$). Figure 2 also shows that

$$A_m = \text{area of ellipse} = \pi ab \tag{13}$$

where: a = ½ radial lumen diameter
b = ½ tangential lumen diameter.

Combining Eqs. (3) and (13) yields

$$1 - g/1.46TR = \pi ab$$

or

$$a = (1 - g/1.46)TR/\pi b. \tag{14}$$

According to the assumption that $X_r$equals $1.23X_t$, the following expression is found:

$$(T - 2b)/(R - 2a) = 1.23. \tag{15}$$

Substituting Eq. (14) in Eq. (15) yields

$$(T - 2b)/[R - 2(1 - g/1.46)TR/\pi b] = 1.23. \qquad (16)$$

Equation (16) is then reduced to

$$Ab^2 - Bb + C = 0. \qquad (17)$$

Since T, R, and g are known values obtained from measurements, b can therefore be solved. Then, the value of a can be obtained using either Eq. (14) or (15). Finally,

$$X_t = R - 2a \qquad (18)$$

and

$$X_r = T - 2b. \qquad (19)$$

Then, the circumference of an elliptical lumen, C; MVIS area per tracheid per unit length, S_t; MVIS area per cubic centimeter of wood, S_c; and finally MVIS area per gram of wood, S_g, are calculated using the following equations.

$$C = \pi[2(a^2 + b^2)]^{1/2} \qquad (20)$$

$$S_t = C \cdot \text{unity} \qquad (21)$$

$$S_c = S_t \cdot N \qquad (9)$$

and

$$S_g = S_c/g. \qquad (10)$$

Assumption 4.—Tracheids are rectangular, but the lumens are between rectangular and elliptical in cross section. Radial cell walls are 23% thicker than tangential walls. For this assumption, values of MVIS area of latewood are essentially averages of those obtained using Assumptions 2 and 3.

RESULTS AND DISCUSSION

Average dry-volume specific gravities of earlywood and latewood of the study species were determined to be 0.319 and 0.771, respectively. The fractional lumen volumes were 0.782 for earlywood and 0.472 for latewood. Microscopic measurements revealed that there were, on the average, 257 tracheids per cm in the tangential direction with a standard deviation of 16 and 207 tracheids per cm in the radial direction with a standard deviation of 13 for earlywood. For latewood, there were on the average 275 tracheids per cm in the tangential direction with a standard deviation of 15 and 341 tracheids per cm in the radial direction with a standard deviation of 14. In the tangential direction the number of latewood tracheids per cm was only slightly greater than that of earlywood. The author has no definite explanation for the small yet significant difference in number of tracheids per cm tangential width between earlywood and latewood. It was perhaps due to inclusion of small diametered fusiform initials (prior to reaching their maximum tangential diameter) in the latewood of the study samples.

From the number of tracheids per cm in both cross-sectional directions, the number of tracheids per square centimeter was calculated to be 53,199 for earlywood and 93,775 for latewood. Also, according to the number of tracheids per unit tangential and radial lengths, the average tangential and radial diameters of

TABLE 1. *Estimated transverse tracheid dimensions and MVIS areas of loblolly pine earlywood and latewood.*

	Transverse Tracheid Dimensions				Microscopically Visible Internal Surface (MVIS) Area		
	Lumen Diameters		Double Wall Thicknesses		per tracheid per cm	per cm^3	per gram
	Tangential μm	Radial μm	Tangential μm	Radial μm	m^2	m^2	m^2
				Earlywood			
	33.9	43.3	5.0	5.0	1.544×10^{-6}	0.082	0.257
				Latewood			
Assumption							
1	26.3	19.2	10.3	10.1	0.909×10^{-6}	0.085	0.111
2	25.2	20.2	9.2	11.3	0.906×10^{-6}	0.085	0.110
3	28.1	22.8	6.5	8.1	0.805×10^{-6}	0.076	0.098
4	26.7	21.4	7.9	9.7	0.855×10^{-6}	0.080	0.104

earlywood tracheids were 38.9 μm and 48.3 μm, respectively, while those of latewood tracheids were 36.4 μm and 29.3 μm respectively.

Using described methods, lumen diameter, double-wall thickness, MVIS area per tracheid, and MVIS area per cm^3 and per gram of wood were estimated. These values are listed in Table 1. Cell walls of latewood were about twice as thick as that of earlywood. There was practically no difference in MVIS area per cm^3 or per gram of latewood between calculations made according to Assumptions 1 and 2. However, a distinct difference was found between values of MVIS area of latewood calculated according to Assumptions 2 and 3. As shown in Table 1, MVIS area per gram of latewood decreased from 0.110 to 0.098 as the cross-sectional lumen configuration was changed from rectangular (Assumption 2) to elliptical (Assumption 3).

Observation of the study specimen showed that cross-sectional lumen configuration of latewood tracheids varied from rectangular to elliptical but, on the whole, was more or less between rectangular and elliptical. Hence, values obtained from calculations made according to Assumptions 2 and 3 were averaged. These averages are listed in the last row of Table 1 as values for the category Assumption 4.

Results of the study clearly demonstrated that the MVIS area per unit volume of earlywood (0.082 m^2) and that of latewood (0.080 m^2) were practically the same in spite of the impression that the MVIS area of earlywood should be larger due to its more porous nature (larger lumen volume). These calculated values agree with those calculated by Stamm (1964), 0.08 m^2/cm^3. Average MVIS area per earlywood tracheid per unit tracheid length (1.544×10^{-6} m^2) was indeed larger as compared with latewood tracheids (0.855×10^{-6} m^2), but there were more latewood tracheids for the same volume. Therefore, it should always be possible, as in the case of this study, that the MVIS areas for the same volume of earlywood and latewood would be similar. The results suggest that on a unit-volume basis MVIS area of a softwood may not be affected by its specific gravity.

On a unit-weight basis, MVIS area of earlywood was about 2.5 times larger

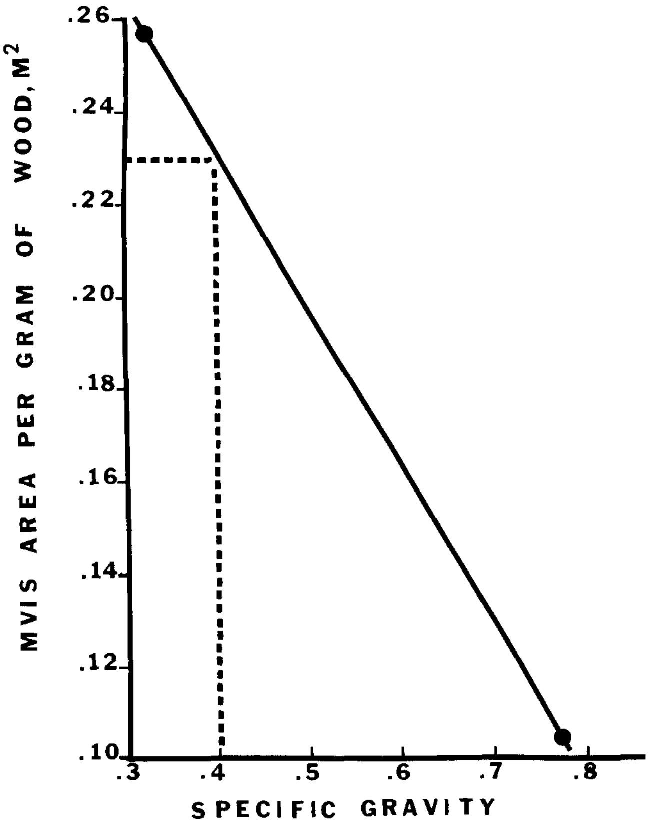

FIG. 3. Area of microscopically visible internal surface per gram of wood versus specific gravity.

than that of latewood. The results suggest that for the study species, the MVIS area does tend to decrease with increasing specific gravity when it is expressed on a unit-weight basis. This phenomenon can be explained by the fact that for the same weight, wood with lower specific gravity will inevitably have greater void volume which, in turn, means larger MVIS area. Assuming a straightline relationship between MVIS area per gram and specific gravity within a range from 0.319 (earlywood) to 0.771 (latewood), an MVIS area of 0.23 m^2/g was obtained by extrapolation for a specific gravity of 0.4 (Fig. 3). This value is of the same magnitude as the one obtained by Stamm (1964), namely 0.2 m^2/g.

CONCLUSIONS

For the study tree MVIS area per cm^3 for earlywood (0.082 m^2) and that for latewood (0.080 m^2) were practically the same. However, great difference in MVIS area per gram existed between earlywood (0.257 m^2) and latewood (0.104 m^2). The ratio was about 2.5 to 1.

MVIS areas per single earlywood and latewood tracheid per cm of length were 1.544×10^{-6} m^2 and 0.855×10^{-6} m^2, respectively, a difference of 80 percent. However, for one cubic centimeter of wood there were only 53,199 earlywood tracheids as compared with 93,775 latewood tracheids, or there were about 1.8

times as many latewood tracheids, a difference of 77 percent. Hence, for the same volume of wood, the greater number of latewood tracheids compensates for the smaller MVIS area per latewood tracheid.

To sum up, results of this study indicate that there was no difference in MVIS area between earlywood and latewood for the same volume. In other words, on a unit-volume basis, MVIS area was not affected by specific gravity. However, on a unit-weight basis, MVIS area decreased with increasing specific gravity.

This study shows that for the same volume, earlywood and latewood of softwood of any specific gravity expose an approximately equal amount of lumen surface. This finding may have value in the study of the effects of wood structure on decay and treating. It suggests that, theoretically, equal effectiveness could be achieved with the same amount of creosote or other oil-borne preservatives per unit wood volume (pound per cubic foot, for example) in spite of a difference in specific gravity (fast or slow grown) if the empty-cell process is employed. The statement is made, of course, on the assumption that only coating of the lumen surface is necessary and is obtained by the empty-cell process.

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