ANATOMICAL AND PHYSICAL PROPERTIES OF BALSAM POPLAR (*POPULUS BALSAMIFERA* L.) IN MINNESOTA[1]

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ABSTRACT

Balsam poplar (*Populus balsamifera* L.), a north temperate boreal hardwood, is spread across the continent at the United States and Canadian border and elsewhere in the interior of Western Canada. For commercial purposes, it is categorized with the cottonwoods rather than the aspens. In this study of ten straight and sound balsam poplars from Minnesota, it was determined that they had some properties permitting them to be placed in both categories. Vessel number and size were more similar to the aspens as was specific gravity at 0.36 (oven-dry weight/green volume). Characteristics similar to the cottonwoods were an average moisture content of 140% and heartwood with a much higher moisture content than sapwood.

The general patterns for angiosperms were seen in these balsam poplars. Vessel numbers increased with height in the bole, and vessel diameter decreased with height. Vessel numbers decreased from pith to bark, while vessel diameter increased. A noteworthy exception to this pattern was that the southside of the trees had significantly more vessels, higher specific gravity, higher percentage of gelatinous fiber area, and significantly higher pH. All trees had an abundance of fibers laden with gelatinous layers ranging from 22 to 63% among the ten trees.

Keywords: Balsam poplar, *Populus balsamifera* L., anatomy, gelatinous fibers.

INTRODUCTION

Balsam poplar (*Populus balsamifera* L.) also is known as balm-of-Gilead, balm, bam, tacamahac, and black poplar, the latter chiefly in Canada. Balsam poplar is a north temperate tree species found in North America across much of Canada, Alaska, the northern tier of the Lake States, the northern New England States, and some western States (Roe 1958).

In Minnesota the commercial range is the north central and north eastern portions of the state, where it is found on moist rich soils in mixture with quaking aspen (*Populus tremu-*

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loides Michx.), paper birch (*Betula papyrifera* Marsh.), black and white spruce [*Picea mariana* (Mill.) B.S.P. and *Picea glauca* (Moench.) Voss.], and balsam fir [*Abies balsamea* (L.) Mill.]. The balsam poplar growing stock in Minnesota's northern forests is approximately 18% that of aspen (Jakes 1980). While generally scattered in a typical aspen stand, the trees usually are found in small discrete clumps that may or may not be the result of regrowth from earlier cuttings, some of which would be clones.

Balsam poplar is a potential source of raw material for the manufacture of oriented strandboard (OSB), but often it does not machine well (Shen 1980; Panning and Gertjejansen 1985; Gertjejansen and Panning 1985) and therefore is not desirable for OSB as is aspen, the preferred raw material. The poor machining qualities of balsam poplar have been attributed to its high gelatinous fiber content, but this relationship has never been established (Shen 1980).

This study was undertaken to better define the anatomical and physical properties of balsam poplar, and then in future studies determine if any of the properties were related to the machining difficulties peculiar to balsam poplar.

METHODS

Raw material collection

Ten balsam poplar trees were harvested for this study from five locations or sites in northern Minnesota. The outward appearance of all trees was that they were straight, sound, and round. The areas in which the trees were harvested have prevailing winds from the north-northwest during the winter months and from the south-southeast during the summer months (Baker 1983). The trees were harvested after leaf drop, which occurs in late September to early October (Ahlgren 1957). At this time, the stems are high in moisture, and the moisture content is stable until bud-break (Sauter 1966). Site characteristics, such as location, topography, stand type and density, plant associations, and soil characteristics were observed and the same understory and surrounding flora were present at all five sites.

After individual trees were selected and felled, the height, crown width, and diameter at breast height were determined. A 183-cm (6-ft) bolt was removed from the butt portion of the tree (lower bolt) and another 183-cm bolt (upper bolt) was removed from the top portion of the tree. A 15-cm (6-in.) small end diameter (inside the bark) was chosen to be the limiting diameter for the upper bolt. After cutting, the ends of the bolts were covered immediately with polyethylene to minimize moisture loss. The bolts were stored at 1 C in a cold room until additional processing required their removal.

Raw material processing

After removal from the cold room, a 5-cm (2-in.) disk was sawn from both ends of each 183-cm bolt and discarded. The fresh-cut ends were photographed to record the color and shape of the heartwood and sapwood, and any peculiar cutting characteristics such as extensive fuzziness or roughness were noted. A 5-cm (2-in.)-thick flitch (board) with a north-south orientation was cut from the center of each bolt. The width of the flitch was the diameter of the bolt. Each center flitch was sawn into five 30-cm (12-in.) segments, and the remaining piece (approximately 20 cm) from the end of the bolt was discarded. Each segment was numbered 1 through 5, with 1 being the lowest point on the flitch with respect to the original standing position of the tree. Each 30-cm segment then was cut into four 7.6-cm (3-in.) blocks. Eight anatomical, physical, and chemical properties were determined from the four blocks. Block 1 from each segment, and therefore the lowest with respect to its original position in the tree, was used for moisture content (MC) and specific gravity (SG) determinations. The remaining three blocks were utilized for determining hydrogen ion concentration and five anatomical characteristics.

Specific gravity and moisture content determinations

Prior to SG (oven-dry weight/green volume) and MC (oven-dry weight basis) determinations, the bark was removed from each of the blocks, and the blocks were separated into one heartwood and two sapwood portions (north sapwood and south sapwood) based on color difference between heartwood and sapwood.

Hydrogen ion determination

The hydrogen ion concentration (pH) was determined for two blocks coming from the fifth segment of the lower bolt of all trees. Each debarked block was divided into five sections: two sapwood, two heartwood, and one from the pith. The individual sections were placed in polyethylene bags, and while still in the polyethylene bag, were individually compressed in a hand-operated hydraulic press causing sap to be expressed. Two ml of sap was collected in a Pasteur pipette and transferred into a 4-ml culture tube. The clarity and color of the expressed sap were described subjectively from "clear to milky brown." The pH of the sap was measured directly by inserting the sensing probe into the culture tube. During the measurement, the sap was agitated with a magnetic stirring bar until the digital reading of the pH meter had stablized. Stablization usually occurred within 5 to 8 min.

Sectioning and staining (xylotomy)

To compile anatomical information accurately, portions of each tree were cut into 20-μm-thick transverse-sections, stained, and then photographed utilizing light microscopy.

Eight 7-mm × 7-mm × 15-mm pieces were cut from each of the 5 segments of each bolt; two each from the north sapwood, north heartwood, south heartwood, and south sapwood. A total of 800 pieces were cut and used (10 trees × 2 bolts × 5 segments per bolt × 4 sapwood-heartwood positions per segment × 2 replications).

The sections were stained according to Robards and Purvis (1964). This staining technique provided good differentiation between the lignified cell walls and the less-lignified gelatinous layers in the fibers.

Anatomical measurement

Four 50× color photographic slides were taken of random locations from the 3 transverse sections mounted on each slide to provide a reasonable measure of the within-block variance. A total of 1,600 photographs (10 trees × 2 bolts per tree × 5 segments per bolt × 4 sapwood-heartwood positions per segment × 4 photographs per position) were taken.

Images were projected onto a screen at 500×, from which the number of vessels, rays, the diameter of the vessels and the width of the rays, and the percentage area of vessels, fibers, and rays were determined. The diameters of all vessels were measured both in the radial and tangential direction, and the tangential direction was used for diameter expression. The area was computed as an ellipse since most vessels fit that configuration.

Fibers containing gelatinous layers were identified with the unaided eye and expressed as a percentage of total fiber area. The thickness of the gelatinous layer in individual fibers was not measured. If a fiber contained a thin gelatinous layer, it was given equal weight with one that was thicker or one that occluded the fiber lumen.

The rays were counted and their width was measured for area determination. The area occupied by the fibers was derived by deducting the area sum of both vessels and rays from the total area.

Statistical analysis

The experimental design utilized a nested and split-plot analysis with tree and bolt as main plots with segments nested within bolt. Aspect (north and south) and position (sapwood-heartwood) were treated as split-plots. The data analysis was performed using the Statistical Analysis System (SAS 1985).

RESULTS

The eight anatomical, physical, and chemical properties that were analyzed statistically are in Table 1. Properties statistically analyzed by location in the tree are in Table 2. Four characteristics and properties in Table 3 were not analyzed statistically but are included as useful information.

TABLE 1. *Anatomical physical and chemical properties of 10 Minnesota balsam poplar.*[1]

Number of vessels[2] (Area = 1 mm^2)			Vessel diameter[2] (μm)			Vessel percentage[2] (% of total area)			Fiber percentage[2,3] (% of total area)[1]		
	Mean	Tree		Mean	Tree		Mean	Tree		Mean	Tree
A	79.2	2	A	76.7	1	A	36.5	2	A	74.1	8
BA	75.9	4	BA	72.3	6	BA	34.6	3	B	70.2	4
BA	74.6	3	BC	70.5	2	BA	33.1	6	CB	69.0	10
BA	73.1	9	BC	69.5	5	BA	33.0	1	CB	67.8	9
B	71.2	5	BC	69.0	10	BC	32.8	7	CB	67.6	5
B	69.8	7	DC	67.0	7	BC	32.8	5	CB	67.6	7
B	68.8	6	DC	67.0	3	BC	32.4	9	CB	67.3	6
C	58.9	8	DE	63.4	8	BC	31.3	10	CBD	67.0	1
C	56.3	10	DE	62.1	4	DC	29.4	4	CD	65.5	3
C	54.2	1	E	60.0	9	D	26.2	8	D	63.5	2
	68.2			67.8			32.2			68.0	

[1] Means with the same letter are not significantly different, Tukey's Studentized Range (Alpha = 0.05). Trees were sampled from five geographic sites: *1,2; 3,4; 5,6; 7,8,9; 10.*
[2] Each value represents an average of 40 specimens.
[3] Also includes ray area which averaged only 3.0% of the fiber area and ranged from 2.3 to 4.3%.
[4] Each value represents the average for the sapwood and heartwood; 20 north-south sapwood and 10 heartwood specimens.
[5] Oven-dry weight, green volume basis.
[6] Each value represents an average of 10 specimens.

Number of vessels

The vessel pattern in hardwoods has been elucidated by Aloni (1988). Generally there is a continuous increase in the size of individual vascular elements from leaves to roots, an increase in vessel diameter is associated with a decrease in vessel density, and the increase in diameter proceeds outward from the inner growth ring. The results of the present study showed that the ten balsam poplar trees fit this hardwood vessel pattern very well. The number of vessels per mm^2 increased with height in the tree. Specifically, the upper bolt had 76.8 vessels per mm^2 and the lower bolt only 59.2. In addition, the number of vessels decreased from the inner wood to the outer wood; that is, the sapwood had significantly fewer vessels than the heartwood, 61.6 per mm^2 versus 74.7 (Table 2).

There was one significant exception to the established patterns for angiosperms: the south side of the trees en masse had a statistically

TABLE 2. *Average value of properties and characters by position in the tree for 10 Minnesota balsam poplar.*[1]

	Bolt		Lateral position		Aspect[2]	
	Upper	Lower	Heartwood	Sapwood	South half	North half
Number of vessels per mm^2	76.8	59.2	74.7	61.6	69.9	66.4
Vessel diameter (μm)	65.3	70.2	65.9	69.6	67.3 ns	68.2 ns
Vessel area (% of total area)	33.1	31.3	31.9 ns	32.6 ns	32.5 ns	32.0 ns
Fiber area (% of total area)[3]	67.0	68.9	68.3 ns	67.6 ns	67.7 ns	68.2 ns
Gelatinous fiber area (% of total fiber area)	50.2	34.4	39.7	44.9	46.4	38.1
Moisture content (% on oven-dry basis)	132	148	166	127	126 ns	128 ns
Specific gravity (oven-dry wt. green vol. basis)	0.38	0.35	0.35	0.37	0.38	0.37

[1] All categories except moisture content and specific gravity are averages of 200 specimens. Moisture content and specific gravity values are an average of 100 specimens except the upper and lower bolt values where the sample size is 150.
[2] Each half includes both heartwood and sapwood except moisture content and specific gravity where only the sapwood was measured.
[3] Includes ray area of 3.0%
ns = not significant. All other values are significant at alpha = 0.05 according to Tukey's Studentized Range Test.

TABLE 1. *Extended.*

Gelatinous fiber area[2] (% of total fiber area)			Moisture content[4] (% ovendry basis)			Specific gravity[4,5]			pH[6]		
	Mean	Tree		Mean	Tree		Mean	Tree		Mean	Tree
A	63.6	9	A	152	8	A	0.39	9	A	8.2	2
BA	53.6	2	A	151	2	BA	0.38	10	BA	7.9	10
BA	51.8	3	BA	146	1	BAC	0.38	3	B	7.7	7
BA	50.3	4	BA	144	7	BDC	0.37	4	B	7.7	3
BC	45.5	10	BA	144	4	DC	0.36	7	B	7.7	4
BCD	40.5	8	BC	139	5	DC	0.36	6	B	7.6	1
BECD	38.0	6	BC	139	3	D	0.36	1	B	7.6	8
ECD	30.2	5	BC	137	6	D	0.36	5	BC	7.5	9
ED	26.7	1	DC	131	9	E	0.34	8	DC	7.0	6
E	22.6	7	D	121	10	E	0.34	2	D	6.8	5
	42.3			140			0.36			7.6	

larger number of vessels than did the north side. The south side had 69.9 vessels per mm^2 in the combined sapwood and heartwood, whereas the north side had slightly but significantly fewer at 66.4 vessels per mm^2 (Table 2).

Vessel diameter

Vessel diameter followed a straightforward pattern as in other hardwoods. It decreased with increasing height and increased from inner wood to outer wood. The upper bolt vessels averaged 65.3 μm, whereas the lower bolt vessels had a larger average diameter of 70.2 μm. Similarly the heartwood had smaller vessels (65.9 μm) than the sapwood at 69.6 μm (Table 2). The mean vessel diameter among trees ranged from 60.0 μm in tree 9 to 76.7 in tree 1 (Table 1). A wide range of vessel diameters for balsam poplar has been reported in the literature. Brown et al. (1949) reported a range of 75 to 150 μm for balsam poplar and cottonwood, and Micko (1987) found balsam poplar vessel diameters to range from 0.060 mm to 0.167 mm. Thus, the ten balsam poplar trees in this study fell into the lower end of the vessel diameter ranges reported above.

Vessel area and fiber area

Only the vessel and ray areas were measured and the fiber area deduced from the sum of those two characters. For all ten trees, the vessel area averaged 32.2% and the fiber and ray area 68.0% from measurements of 1,600 specimens (Table 1). Ray area was small, comprising only 3.0% of the 68.0% fiber and ray total.

If the vessel area of all upper bolts is compared to that of all lower bolts, the upper bolts had a slightly larger area; i.e., 33.1% versus 31.3% (Table 2). This can be explained by the inordinately large number of vessels in the uppermost segment of the upper bolt of all trees. According to Aloni (1988), the rate of vessel differentiation is determined by the amount of auxin the differentiating cell receives from the

TABLE 3. *Properties and characters of 10 Minnesota balsam poplars at breast height.*

Tree no.	Age (years)	Diameter (inch)	Rate of growth (inch/yr)[1]	Eccentricity of stem (%)[2] North	South
1	28	7.5	0.28	3.3	—
2	28	8.0	0.29	0.0	0.0
3	56	6.9	0.13	1.8	—
4	47	6.5	0.14	—	1.9
5	65	9.9	0.15	8.8	—
6	53	6.6	0.12	5.6	—
7	48	8.2	0.17	9.2	—
8	33	5.8	0.17	—	1.0
9	41	7.0	0.16	—	3.5
10	56	10.1	0.19	4.9	—

[1] Diameter of oven-dried wood excluding bark.
[2] Eccentricity is a measure of the deviation of the pith from the center of the north-south diameter. For example, the pith of tree 5 lies 0.87 inches south of the center of the N-S diameter (0.088 × 9.9 inches = 0.87 inches).

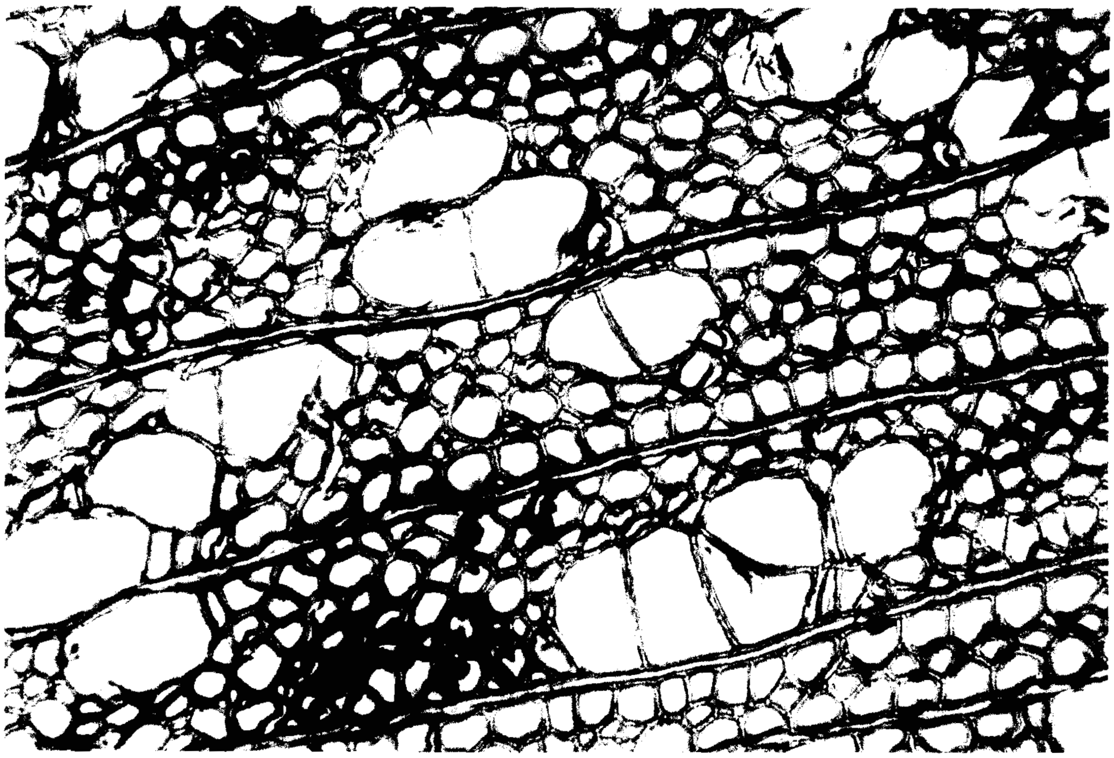

FIG. 1a. Micrograph is from the heartwood in bolt B or upper bolt of tree 1. Here the heartwood is nearly free of any gelatinous layers. (×50).

leaves. The uppermost segment was closest to the leaves and therefore would have had the highest auxin concentration during growth.

The vessel area and consequently the fiber area were not related to site. For example, trees 1, 5, 6, and 7 were from three different sites yet they all had approximately 33% vessel area.

Gelatinous fibers

Gelatinous fibers are fibers that have gelatinous layers (G layers) within the cell wall (Dadswell and Wardrop 1955). Gelatinous fibers are found as scattered cells or in groups in what is considered to be normal wood in many species of hardwoods (Côté and Day 1962). In studying gelatinous fibers in cottonwood, Isebrands and Bensend (1972) reported finding vessels surrounded by gelatinous fibers and relatively few gelatinous fibers in the last five to six tangential rows of the latewood. In tension wood, both vessels and rays remain structurally unaffected, and fibers in the latewood region are usually of the normal type, but the earlywood fibers contain gelatinous layers (Timell 1969). In quaking aspen, tension wood fibers have a primary wall, an S_1 and S_2 layer of a secondary wall, and an additional gelatinous layer inside the S_2 layer (Mia 1968). There is also a gelatinous fiber type that does not have an S_2 layer (Araki et al. 1983).

In this study, gelatinous fiber area ranged from 22.6% (tree 7) to 63.6% (tree 9) and averaged 42.3% of the total fiber area (Table 1). Gelatinous layers commonly were found in discrete cells (Fig. 1a) or in contiguous fibers intimately surrounding the vessel elements (Fig. 1b). It also was common to find gelatinous fibers in the latewood, but they were less prevalent than in the earlywood. Figure 2a shows portions of two annual rings, where only the last 1 to 2 rows of latewood fibers are devoid of gelatinous layers. Another variation of

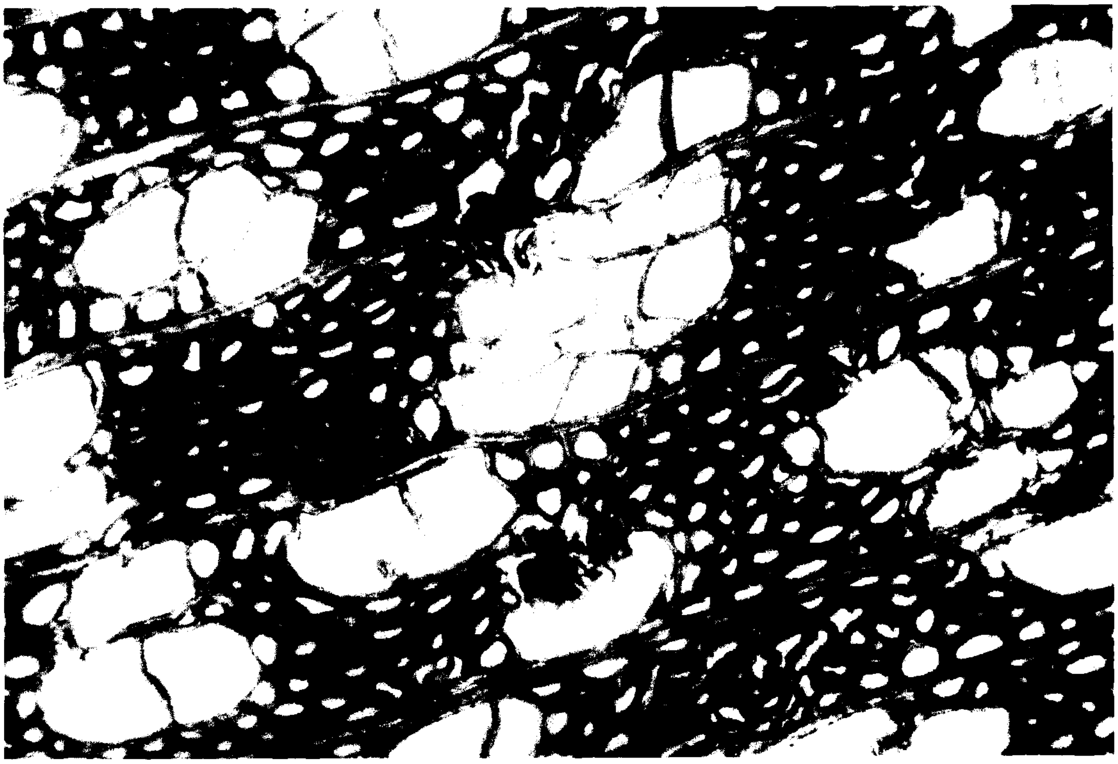

FIG. 1b. Micrograph of heartwood on northside of tree 1. This section is 30.5 cm (1 ft) above the section shown in Fig. 1a. Note that the gelatinous fibers completely surround the vessels. (×50).

gelatinous fiber patterns is in Fig. 2b where the earlywood on the left is nearly filled with gelatinous fibers while the last portion of the latewood fibers is devoid of gelatinous layers as was the subsequent earlywood. A small number of specimens had gelatinous fibers only in the last rows of the latewood.

The results of this study show that the gelatinous fiber content varied widely among the ten trees and there also was wide variation between trees from the same sites. For example, trees 1 and 2, both from the same site, had gelatinous fiber areas of 26.7 and 53.6%, respectively (Table 1). In addition, trees 7, 8, and 9, all from the same site, had average gelatinous fiber areas of 22.6, 40.5, and 63.6%, respectively. Also, the values of 22.6 and 63.6% represent the lowest and highest percentage of gelatinous fiber areas of all ten trees in this study.

Gelatinous fiber content also was not related to rate of growth. For example, in Table 3, tree 9 with the highest percentage of gelatinous fibers (63.6) had a growth rate similar to tree 7, yet the latter had the lowest percentage of gelatinous fibers (22.6). Another example is the almost identical growth rates of trees 1 and 2, yet tree 2 had twice the gelatinous fiber content of tree 1.

The upper bolts and the sapwood contained significantly larger amounts of gelatinous fibers than did the lower bolts and the heartwood. Also there were significantly more gelatinous fibers on the south side of the trees than on the north (Table 2). Only tree 2 had more gelatinous fibers on the north side than the south. Prevailing southerly winds during the growing season may be related to this phenomenon, but the literature is inconclusive on this subject (Von Müller-Stoll and Zenker 1967). Also, the eccentricity data of this study (Table 3) show that the north side radius av-

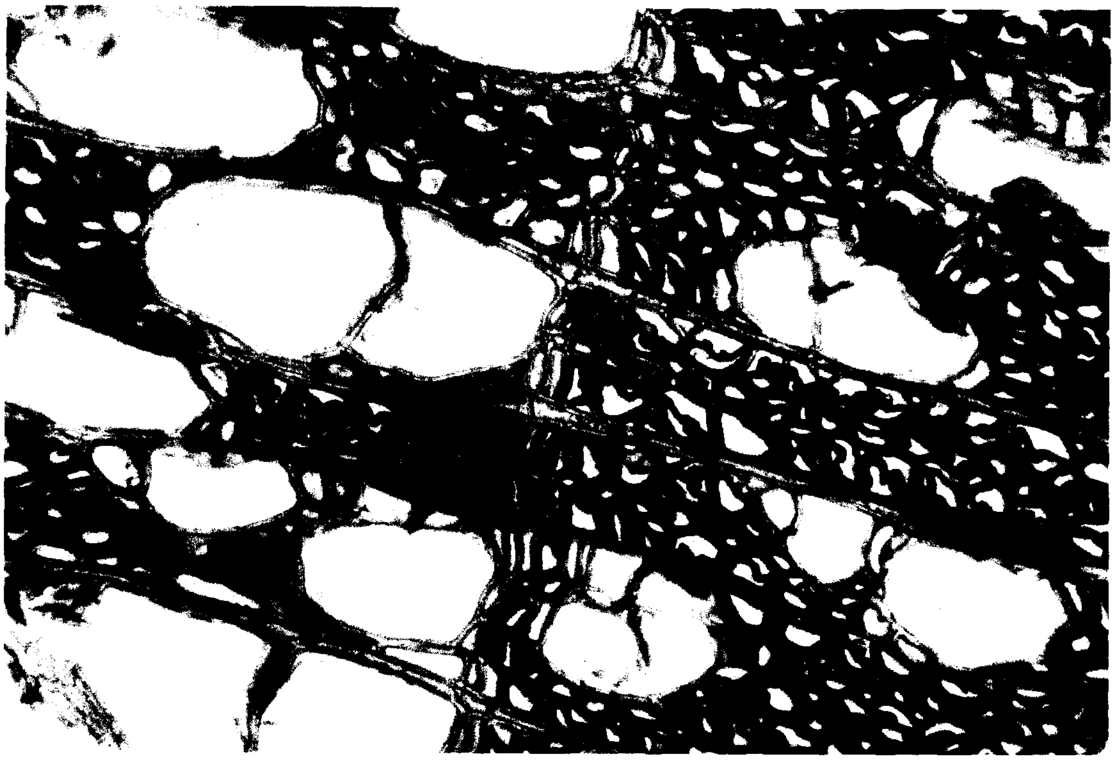

FIG. 2a. Cross section of tree 1 just above the stump showing gelatinous layers in the northside sapwood. Note that both latewood fibers on the left and earlywood fibers on the right of the annular ring contain gelatinous layers in nearly all fiber cells. Only 1 to 2 rows of latewood fiber-cells do not contain gelatinous layers. (×50).

erage was greater than that of the south side (pith was located nearer the south side), which is opposite of what would be expected if southerly winds were bending the trees toward the north during the growing season.

Another type of gelatinous fiber condition found in two trees and confirmed by light and scanning electron microscopy was that of a large band of light-colored fibers across several years' growth and extending vertically within the stem for up to 122 cm (4 feet). So prominent was this figuration in cross-section, that it could be seen with the unaided eye. The butt log of tree 6 had such a band that can be seen midway in the dark heartwood and prominent in the 10 o'clock position (Fig. 3). Light colored bands of fibers also have been reported by Perem (1964), who stated that they are comprised primarily of gelatinous fibers.

Moisture content

The average moisture content (MC) among all trees in this study ranged from 121 to 152% and averaged 140% (Table 1). This MC range fell between those reported by others (Panning and Gertjejansen 1985; Kellogg and Swan 1986). Moisture content was not significantly different for six of the ten trees.

Balsam poplar also has "wet pockets"; i.e., small volumes of exceedingly high MC. For example, tree 2, which had averaged 151% MC, had a wet pocket at 211% MC, and 30 cm lower, the MC was only 121%. In studying wetwood of balsam poplar in Minnesota, Wallin (1954) partioned MC into three categories: sapwood, heartwood, and wetwood. He found the MC range to be even larger than in this study; i.e., from 77% in sapwood to 216% in heartwood to 250% in the wetwood.

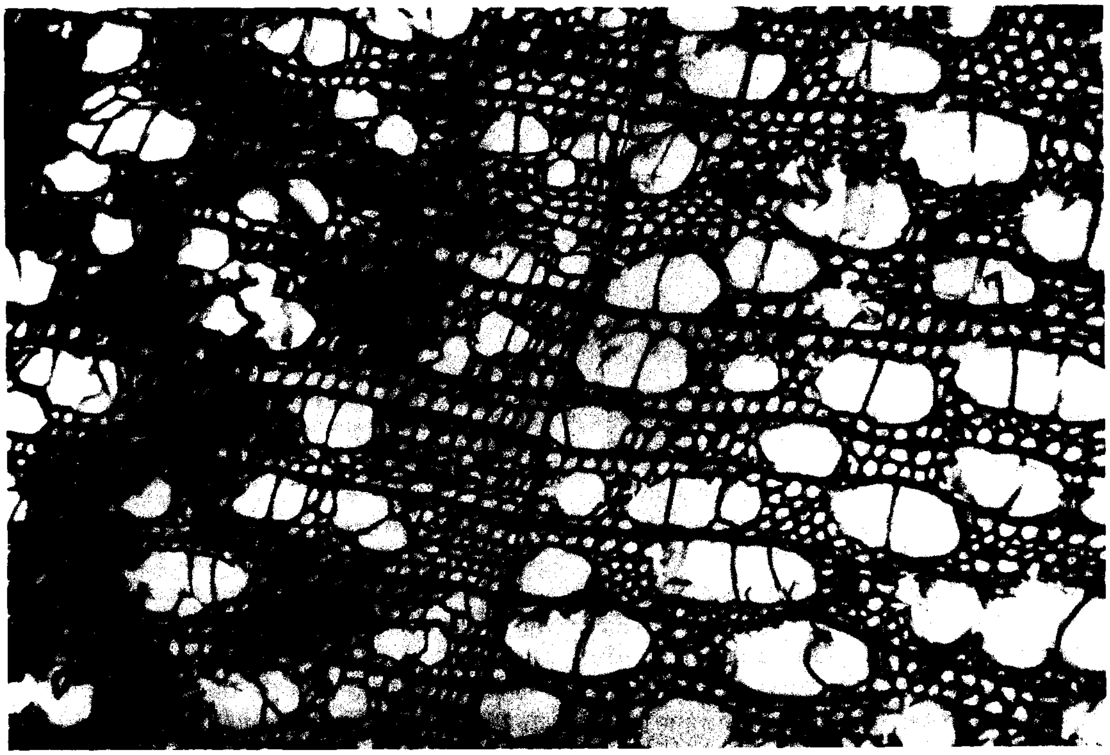

FIG. 2b. This micrograph is from a section of 152.4 cm (5 ft) above the section shown in Fig. 2a. Note the abundance of gelatinous material in the earlywood on the left side of the annular ring, and the absence of gelatinous material in the last rows of latewood. The earlywood on the right side of the growth ring is nearly devoid of gelatinous material. A typical section. (×20).

Specific gravity

The specific gravities (SG)[3] of the ten trees in this study averaged 0.36 and ranged from 0.34 to 0.39 (Table 1). The heartwood SG average was lower than the sapwood, 0.35 and 0.37, respectively; and the upper bolt average was higher than the lower bolt, 0.38 and 0.35, respectively (Table 2). Also, the southside sapwood SG was significantly larger than that of the northside, which is expected since the gelatinous fiber area also was larger on the southside.

A wide range of balsam poplar SGs have been reported in the literature. In studying heartwood in *Populus* sp., Clausen (1949) found the SG of the butt logs of balsam poplar near Aitkin, MN, to average 0.319. Wallin (1954), in studying wetwood of balsam poplar, found that trees from Cloquet, MN, had an average SG of 0.335. The range, however, was 0.28 to 0.36 for butt logs and 0.30 to 0.41 for top logs. Kennedy (1968) cites two studies that reported balsam poplar SGs of 0.30 and 0.372. Paul (1956) reported balsam poplar SGs of 0.301, 0.296, and 0.355 for Vermont, coastal Alaska, and inland Alaska, respectively. Kellogg and Swan (1986) found no significant difference in the SGs of balsam poplar from British Columbia (0.338) and Alberta (0.337). Singh (1986), in studying six major tree species from the Northwest Territories, found the SG mean value of trembling aspen and balsam poplar to be quite similar at 0.388 and 0.387, respectively.

[3] All SG values in the text are oven-dry weight green volume basis.

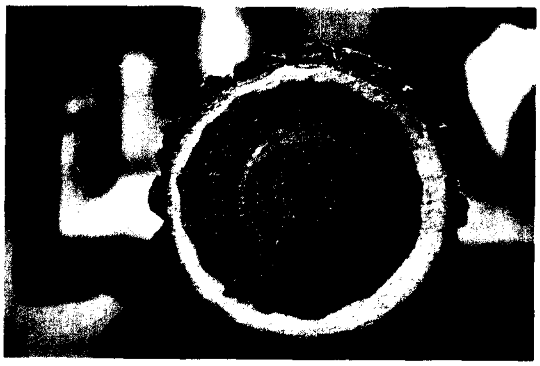

FIG. 3. Butt log of tree 6. Note the white ring-segment, comprising gelatinous fibers in the heartwood from a 9 o'clock to 12 o'clock position.

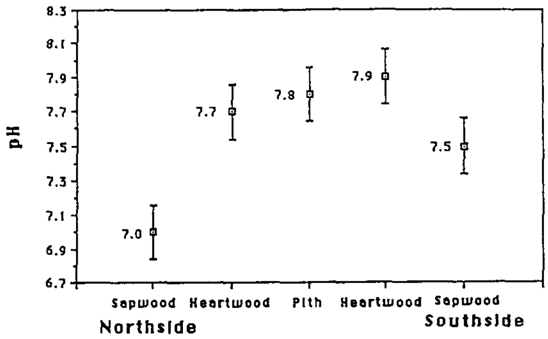

FIG. 4. The pH partitioned according to sapwood, heartwood, pith area, and north-south direction. The pH on the northside sapwood is lower and different from its southside counterpart.

The Wood Handbook SG value for balsam poplar is 0.31 (USDA 1987).

Age showed no relationship with SG in this study, which is in agreement with others (Kennedy 1968; Balatinecz and Peng 1987). Also, there was no correlation between growth rate and SG in this study, but growth rate-SG relationships are controversial. Paul (1956) reported a negative correlation between growth rate and SG in poplar, while Farmer and Wilcox (1966) found no correlation. Some workers reported both positive and negative correlations (Brown and Valentine 1963).

Hydrogen ion concentration

Hydrogen ion concentration (pH) measurements of the freshly expressed sap showed that the north sapwood pH 7.0 was statistically different from the south sapwood, north and south heartwood and pith, pH 7.5, 7.7, 7.9, and 7.8, respectively. The south sapwood, however, was not different from the north side heartwood. The two heartwood sections and the pith were not different from each other (Fig. 4).

In a study of chemical properties of black cottonwood and balsam poplar from British Columbia and Alberta, Swan and Kellogg (1986) found that the sapwood pH differed significantly from the heartwood pH. They reported an average heartwood pH of 8.12 for balsam poplar, which is slightly higher than the 7.8 found in this study. However, their average sapwood pH of 5.40 was much lower than the 7.3 found in this study (Fig. 4). In a study comparing balsam and aspen poplar trees in Alberta, Cyr and Laidler (1987) found the average pH of aspen to be 4.6 and that of balsam poplar to be 5.0. In this study of balsam poplar, the combined sapwood-heartwood 10 tree mean was 7.6 (Table 1).

The individual tree average pH in this study was relatively high, ranging from a low of 6.8 for tree 5 to a high of 8.2 for tree 2 (Table 2). Higher than usual pH sometimes can be associated with wetwood, especially bacterial wetwood (Wallin 1954). The presence of wetwood within the hardwood genus *Populus* appears to be the rule, but there can of course be exceptions (Ward and Pong 1980). In the poplars, the pH of the outer wetwood zone has usually been 7 to 8, while the inner and therefore older wetwood is ordinarily somewhat lower in pH but still above sapwood (Hartley et al. 1961). In studying balsam poplar in Minnesota, Wallin (1954) stated that wetwood was slightly basic, sapwood slightly acidic, and heartwood essentially neutral.

From the relatively high pH values of this study, one could infer that all of the trees sampled were afflicted with wetwood, especially bacterial wetwood. However, only five trees (1, 2, 5, 6, and 10) had the characteristic fetid odor of bacterial wetwood; five trees (3, 4, 7, 8, and 9) had no signs of bacterial wetwood.

Trees 2 and 6 had exorbitant quantities of sap, and the sap was brown and foamy, whereas the sap of tree 9 was clear as water. Tree 5, in addition to the fetid odor, had ring-shake and areas of discolored wood, especially in an area that would otherwise be considered sapwood. One novel observation was made from sections of the heartwood of tree 5 at 91 cm (3 ft) above the stump. Those sections smelled of anise. That odor is associated with a definite white-rot fungus. A microscopic examination, however, did not show any evidence of mycelium or even a single hypha in any of the 1,600 sections photographed. Aerobic bacteria were found with petri plate culturing in some sections, but isolation and identification were not done. No anaerobic isolations for bacteria or fungi were attempted.

SUMMARY

The results of this study showed that the ten balsam poplar trees fit the accepted hardwood vessel pattern very well. The vessel numbers were inversely related to vessel diameter. The upper bolt had more vessels than the lower bolt and the heartwood more vessels than the sapwood. The converse was true for vessel diameter i.e., the upper bolt had smaller diameter vessels. Not related, but found to be true nonetheless, was the observation that the number of vessels was greater on the southside than on the northside.

The relationship of vessels and fibers was complementary, 32.2% vessels and nearly 64.9% fiber. The area covered by the uniserate ray parenchyma was only 3.0%. The upper bolt had a slightly higher vessel area than the bottom bolt, and the inverse was true for the fiber area.

Gelatinous fiber area ranged from 22.6 to 63.6% among the ten trees. The preponderance of gelatinous fiber was found in the earlywood, but it also was common in the latewood. A small number of specimens had gelatinous fibers only in the last rows of the latewood. Gelatinous fiber content also was not related to rate of growth.

A statistically significant finding of gelatinous fiber occurrence in this study was that there were more gelatinous fibers on the south side of the trees than on the north, 46.4 versus 38.1%.

The average MC among all trees ranged from 121 to 152% and averaged 140% and was not significantly different for 6 of the 10 trees sampled. The MC of balsam poplars of this study had a relationship with cottonwood in that they had high overall MCs (140% average), and the heartwood MC (166% average) was higher than the sapwood (122% average).

The SGs of the ten trees averaged 0.36 and ranged from 0.34 to 0.39. The heartwood SG average was lower than the sapwood, and the upper bolt average was higher than the lower bolt. Also, the southside sapwood SG was significantly larger than that of the northside, which is expected since the gelatinous fiber area also was larger on the southside.

The north side sapwood pH was statistically different from the pHs of the south side sapwood, the heartwood, and the pith.

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