Influence Of Gelatinous Fibers On The Shrinkage Of Silver Maple

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ABSTRACT. The degree of lean was found to have a significant influence on the longitudinal and transverse shrinkage of three soft maple trees. This may be accounted for by differences in the cell wall layer thickness and fibril angle.

A MAJOR PROBLEM associated with leaning trees is the development of reaction wood, which in hardwoods is termed tension wood. Tension wood occurring on the upper side of the leaning stem often has a high proportion of gelatinous fibers in contrast to normal wood, which has few, if any. Problems encountered in the sawing, seasoning, machining, or pulping of tension wood have been described by many authors, for example, Wahlgren (1957), Barefoot (1963), Perem (1964), and Koch and Hamilton (1968).

The longitudinal shrinkage and cell wall structure of tension wood are well documented by Pillow (1953), Wardrop and Dadswell (1955), Perem (1964), Norberg (1966), Mia (1968), and others. Much less is known about the effect of tension wood on the transverse shrinkage of hardwoods. The purpose of this study was to determine how the presence of tension wood affects both longitudinal and transverse shrinkage in soft maple (*Acer saccharinum* L.) and how it influences specific gravity, lignin content, and the sorption of water vapor. A previous study had shown that this species, which is being increasingly utilized for furniture and pulp, contains large numbers of gelatinous fibers (Arganbright and Bensend, 1968).

Procedure

Three soft maple trees approximately 45 years old, located on a river bottom site in central Iowa, were used to provide the sample material. The three trees were chosen on the following basis: Tree 1 had no lean except for a slight amount in the upper crown and was used to provide control samples. Tree 2 had 10 degrees of lean and was chosen to provide samples with a medium number of gelatinous fibers. Tree 3 had a lean of 28 degrees and was chosen to provide samples with a large number of gelatinous fibers.

Six 12-inch-thick disks were removed from each tree: five disks, which divided the merchantable height into four equal segments, plus one at breast height. From each disk, a 3-inch-wide, pith-centered slab was sawn from bark to bark. The slabs were cut parallel to the grain in the plane of the lean; in Tree 1, this plane was determined by the slight lean in the upper crown. Each slab was then reduced to a series of tangentially paired 1-by-1-by-12-inch samples with planed surfaces. The three trees gave a total of 110 such samples.

The 12-inch-long samples were trimmed to a uniform length and then cut into microtome, sorption, and shrinkage specimens. Microtome blocks 0.75 inch long were cut from each end of the specimens. These blocks were used to obtain 1/2-inch-square microtome sections 20 microns thick. The percentage of gelatinous fibers was determined by the method of Arganbright and Bensend (1968). An image of a stained microtome section was projected onto a grid system, and a count made of the number of gelatinous fibers and the total number of

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fibers falling within the squares. The sampling grid system used was modified so that six grid squares were equidistantly spaced on a diagonal across the microtome section. The estimated percentage of gelatinous fibers in each 12-inch specimen was determined by comparing the total number of gelatinous fibers with the total number of fibers obtained from the two end specimens.

Specific gravity determinations, made on the shrinkage specimens, were based on green volume and ovendry weight. After the green volumes were determined, the shrinkage blocks were slowly air-dried before ovendrying, and the shrinkages from green to the ovendry condition were determined. All three dimensional measurements were made on each 1-by-1-by-4-inch shrinkage specimen.

Sorption measurements were made on a selected number of specimens (1-by-1-inch and 0.05 inches along the grain) by using a sorption chamber similar to that described by Kelsey (1957). All sorption measurements were made at 30°C.

Lignin determinations were made on the shrinkage specimens after shrinkage measurements had been completed. Tappi Standard T13 m-54 was used with the following modifications. The sample size was 0.5 rather than 1.0 gram, medium rather than fine porosity alundum crucibles were used, and lignin was reported as a percentage by weight of the ovendry extracted wood rather than on an unextracted basis.

Results

Means for the parameters measured from each of the three trees are given in Table 1. The data are divided into samples from the upper, lower, and combined upper and lower sides for each tree. A grand average for all samples combined is given in the last column. An upper si[illegible] f Tree 1 with zero° lea[illegible] assigned on [illegible] basis of the slight lean in th[illegible] upper portion [illegible] the crown.

Trees 2 and 3 had approximately the sam[illegible] percentages of gelatinous fibers in the uppe[illegible] side of their boles, although Tree 3 had roughly three times as much lean.

Longitudinal shrinkage, as expected, was quite large in the upper side of the two leaning trees, reaching a maximum value of 1.18 percent in one sample. The upper and lower combined average longitudinal shrinkage for each of the leaning trees was greater than that of the control tree, and the upper side shrinkages of the leaning trees greatly exceeded their respective lower side values (Tables 1, 2, and 3). Radia[illegible]

Table 2. — TEST FOR THE DIFFERENCE BETWEEN TREES (UPPER SIDE ONLY).

Variable	"t" value for difference between 0° lean and average of trees with 10° and 28° leans		"t" value for di[illegible]fference betw[illegible] tree with 10° lean and tree with 28° lean	
	"t" value	d.f.	"t" value	d.f.
Lignin (%)	5.278**	46	1.111	46
Sp. Gr.	2.639**	47	2.861*	47
Long. Shrinkage (%)	12.536**	47	2.377*	47
Rad. Shrinkage (%)	4.178**	46	1.722	46
Tang. Shrinkage (%)	0.622	46	—3.375**	46
Vol. Shrinkage (%)	1.046	46	—1.879	44

*Significant at the 5% probability level.

**Significant at the 1% probability level.

Table 1. — MEAN VALUES FOR THE UPPER, LOWER, AND COMBINED SIDES OF THREE SOFT MAPLE TREES.

Variable	Tree 1, 0° Lean			Tree 2, 10° Lean			Tree 3, 28° Lean			All Trees
	Upper	Lower	Combined	Upper	Lower	Combined	Upper	Lower	Combined	
Gelatinous Fibers (%)	7.0	0.5	3.8	50.2	1.9	26.0	51.3	0.0	18.9	16.3
Lignin Content (%)	23.10	23.61	23.31	21.08	22.57	21.87	20.49	24.59	22.85	22.69
Specific Gravity	0.44	0.45	0.45	0.45	0.44	0.44	0.46	0.49	0.48	0.46
Longitudinal Shrinkage (%)	.41	.35	.39	.88	.29	.58	1.00	.49	.71	.55
Radial Shrinkage (%)	4.12	4.25	4.17	3.26	3.93	3.60	3.60	3.80	3.71	3.85
Tangential Shrinkage (%)	9.60	9.67	9.63	10.01	11.37	10.69	8.81	10.10	9.55	9.93
Volumetric Shrinkage (%)	13.68	13.81	13.73	13.71	15.11	14.41	12.98	13.44	13.53	13.87

shrinkages for Trees 2 and 3 were less than those of the control tree regardless of bole position. In contrast to the longitudinal shrinkage, the mean value for radial shrinkage for the upper side in both leaning trees was smaller than the corresponding value for the lower side, the difference being highly significant in Tree 2 with 10° lean (Table 3). In Tree 2 with 10° lean, both upper and lower sides had a larger tangential shrinkage than Tree 1 with zero° lean. There was no difference in the specific gravity of Trees 1 (zero° lean) and 2 (10° lean), but Tree 3 (28° lean) had a higher specific gravity. Lignin contents from the leaning trees were lower than those of the control tree, with the exception of the lower side of Tree 3, which had the maximum lignin content for the three trees. The upper (tension wood) side of the leaning trees had a lower lignin content than did the lower side.

Simple and multiple regressions were used to compare the relationships observed in the means. Multiple-regression data are omitted since they only confirmed the conclusions drawn from the simple regressions. The significance levels and correlation coefficients for the significant simple regressions are presented in Table 4.

Longitudinal Shrinkage

In both Trees 2 (10° lean) and 3 (28° lean), the combined upper- and lower-side data showed a highly significant positive correlation between longitudinal shrinkage and percentage of gelatinous fibers. In Trees 1 and 2, the same result was found for the upper side treated separately. For Tree 3, however, there was no relationship between percentage of gelatinous fibers and longitudinal shrinkage on the upper side. There were very few gelatinous fibers observed on the lower side of Tree 2, and none observed on the lower side of Tree 3; consequently, no underside relationships were found. A correlation coefficient of 0.893 was obtained when samples from all trees were pooled.

For Tree 1, the lower side of Tree 2, and the upper and lower sides of Tree 3 treated separately, there was no correlation between lignin content and longitudinal shrinkage. The upper side of Tree 2 did show a significant negative correlation, and the combined data of the upper and lower sides of both leaning trees showed a highly significant negative correlation.

Table 3. — TEST FOR DIFFERENCE BETWEEN UPPER AND LOWER SIDES OF TREES.

Variable	Tree No.	Lean	"t"	d.f.
	1	0°	−1.017	29
Lignin (%)	2	10°	−2.712*	32
	3	28°	−6.750**	31
	1	0°	−1.212	35
Sp. Gr.	2	10°	−2.301*	32
	3	28°	−3.761**	36
	1	0°	2.292**	35
Long. Shrinkage (%)	2	10°	12.217**	32
	3	28°	11.087**	36
	1	0°	−0.760	29
Rad. Shrinkage (%)	2	10°	−3.743**	32
	3	28°	−1.581	31
	1	0°	− .275	29
Tang. Shrinkage (%)	2	10°	−4.243**	32
	3	28°	−3.213**	31
	1	0°	− .400	29
Vol. Shrinkage (%)	2	10°	−3.712**	32
	3	28°	−2.342*	31

*Significant at the 5% probability level.

**Significant at the 1% probability level.

The control tree and the upper sides of the two leaning trees showed no association between specific gravity and longitudinal shrinkage. The lower sides of both leaning trees showed a negative correlation between specific gravity and longitudinal shrinkage: For Tree 2 it was significant and for Tree 3, highly significant. The pooled data for Tree 2, however, showed a significant positive correlation.

Transverse Shrinkage

Transverse shrinkage in the leaning trees frequently decreased significantly with an increase in percentage of gelatinous fibers. For radial shrinkage, this was true for the upper side of Tree 2 (10° lean) but not for Tree 3 (28° lean). The upper side of both leaning trees showed a significant decrease in tangential shrinkage with increasing percentage of gelatinous fibers. Pooling all the data for radial and tangential shrinkage also gave highly significant negative relationships with percentage of gelatinous fibers. Neither radial nor tangential shrinkage was strongly correlated with lignin content.

Except for radial shrinkage in Tree 3, upper-side specific gravity in the leaning trees was not correlated with transverse shrinkage.

Table 4. — SIGNIFICANCE LEVELS AND SIMPLE CORRELATION COEFFICIENTS FOR THE UPPER,

Dependent Variable	Independent Variable	Tree 1 (0°)			Tree 2 (10°)	
		Upper	Lower	Combined	Upper	Lower
Longitudinal Shrinkage	Gel. fibers (%)	0.872**	N.S.	0.794**	0.842**	N.S.
	lignin (%)	N.S.	N.S.	N.S.	—.519*	N.S.
	Sp. Gr.	N.S.	N.S.	N.S.	N.S.	—.600*
Radial Shrinkage	Gel. fibers (%)	N.S.	N.S.	N.S.	—.585*	N.S.
	lignin (%)	N.S.	N.S.	N.S.	N.S.	—.518*
	Sp. Gr.	.480*	.698**	.701**	N.S.	.826**
Tangential Shrinkage	Gel. fibers (%)	N.S.	N.S.	N.S.	—.533*	N.S.
	lignin (%)	N.S.	N.S.	N.S.	N.S.	N.S.
	Sp. Gr.	N.S.	.568*	.555*	N.S.	.606**
Volumetric Shrinkage	Gel. fibers (%)	N.S.	N.S.	N.S.	—.604*	N.S.
	lignin (%)	N.S.	N.S.	N.S.	N.S.	N.S.
	Sp. Gr.	.591**	.684**	.704**	N.S.	—.716**
Specific Gravity	Gel. fibers (%)	N.S.	N.S.	N.S.	N.S.	N.S.
	lignin (%)	N.S.	N.S.	N.S.	N.S.	—.532*
Lignin	Gel. fibers (%)	N.S.	N.S.	N.S.	N.S.	N.S.

**Significant at the 1% probability level.

*Significant at the 5% probability level.

N.S. Non-significant

On the lower side, however, specific gravity had a highly significant positive correlation with both radial and tangential shrinkage for Tree 2 and a significant correlation with tangential shrinkage for Tree 3. Tree 1 (zero° lean) showed a significant or highly significant positive correlation between specific gravity and transverse shrinkage except for the upper-side tangential shrinkage. There was a very narrow range of specific gravities, and this probably had a bearing on all results. Volumetric shrinkage showed approximately the same relationships as the transverse shrinkage since it was calculated from the radial and tangential shrinkage data.

Specific Gravity

Specific gravity showed no definite correlation with percentage of gelatinous fibers.

Lignin Content

Lignin content was not related to percentage of gelatinous fibers in Tree 1 or in the two leaning trees when it was separated into the two bole positions. Highly significant relationships were found within the two leaning trees when the samples were pooled and when all data were pooled because of the lower lignin contents of the samples from the tension-wood tissue of the leaning trees.

Sorption

Sorption isotherms were determined for samples containing 20, 34, 59, 72, and 85 percent gelatinous fibers, in addition to control specimens with no gelatinous fibers. Comparison of the sorption isotherms showed that the samples with gelatinous fibers were no different from the control samples. A typical isotherm is shown in Figure 1.

Discussion

Our data indicate (Table 1), as is generally accepted, that tension-wood tissue from the upper side of the bole has greater longitudinal shrinkage than does normal wood from the lower side. This is further substantiated by the highly significant correlations between longitudinal shrinkage and percentage gelatinous fibers (*i.e.*, tension-wood tissue) for the com-

COMBINED SIDES OF THREE SOFT MAPLE TREES.

Tree 3 (28°)			
Upper	Lower	Combined	All Trees
N.S.	N.S.	0.829**	0.893**
N.S.	N.S.	—.682**	N.S.
N.S.	.646**	N.S.	.222**
N.S.	N.S.	N.S.	—.536**
N.S.	N.S.	N.S.	N.S.
.448*	N.S.	N.S.	N.S.
—.541*	N.S.	—.673**	—.344**
N.S.	N.S.	.351*	N.S.
N.S.	.563*	.601**	N.S.
N.S.	N.S.	—.621**	—.359**
N.S.	N.S.	N.S.	N.S.
N.S.	.555*	.573**	N.S.
N.S.	N.S.	—.512**	N.S.
N.S.	N.S.	.463**	N.S.
N.S.	N.S.	—.789**	—.658**

bined data of the three trees and for all data combined. The highly significant correlations for the upper sides of Trees 1 and 2 further indicate that increasing longitudinal shrinkage is associated with increasing concentrations of gelatinous fibers. A number of other workers have found the same relationship (Pillow, 1950; Wahlgren, 1957). For Tree 3, there was no relationship between longitudinal shrinkage and percentage of gelatinous fibers on the upper side. This is probably due to the narrow range of percentage of gelatinous fibers found. In Tree 3, the concentration of gelatinous fibers ranged from 20 to 81 percent, with 67 percent of the values between 46 and 58. In Tree 2, however, the concentration of gelatinous fibers on the upper side ranged from 6 to 87 percent, with a rather uniform distribution over the entire range.

Our data in general indicate a negative correlation between transverse shrinkage and increasing percentage of gelatinous fibers. No relationship was found for radial shrinkage in the upper side of Tree 3, but again, this may be because of the narrow range of gelatinous-fiber concentrations. Previous work on transverse shrinkage is somewhat contradictory. Some researchers have found a positive relationship between transverse shrinkage and number of gelatinous fibers (Clarke, 1937; Dadswell and Wardrop, 1949). The only work showing a negative relationship between these two variables was done by Barefoot (1963). He reported that transverse shrinkage decreases when either gelatinous fibers or the incipient form of tension wood is present. Since reduced lignification would not explain this result, Barefoot states that the decrease in tangential shrinkage is due to decreases in specific gravity, while radial shrinkage is controlled by fibril angle and specific gravity. Acceptance of Barefoot's explanation is made difficult by the lack of a consistent relationship between specific gravity and shrinkage in our data.

Although both leaning trees showed the same general properties of increased longitudinal shrinkage together with decreased transverse shrinkage, the two trees had many distinct differences. Some of those differences are:

1) The upper side of Tree 3 (28° lean) had the lowest lignin percentage and, the lower side, the highest of the two leaning trees.
2) The upper side of Tree 3 had a higher longitudinal shrinkage than the upper side of Tree 2 (10° lean).
3) Even though Tree 3 had a higher specific gravity on both upper and lower sides than did the control, Tree 3 had lower radial shrinkages. (Both leaning trees had lower radial shrinkages than the control, and in

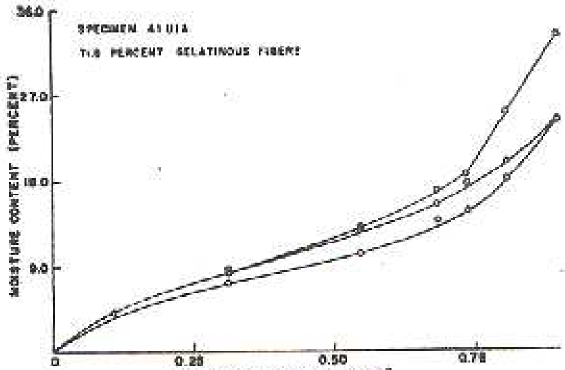

Figure 1. — An example of a sorption isotherm for tension wood in soft maple.

Table 5. — CELL WALL LAYER THICKNESS AND FIBRIL ANGLE AS RELATED TO LEAN IN SOFT MAPLE (MANWILLER (1967)).

	Lean	Lean 10°[1]		Lean 20°[2]	
	0°	G		G	
Primary + S_1	0.51μ	0.41μ		0.50μ	
Fibril Angle	44°	45°		49°	
S_2 Layer	1.40μ	1.74μ		1.01μ	
Fibril Angle	12°	12°		25°	
S_3 Layer	.48μ	......		.31μ	
Fibril Angle	20°			26°	
G Layer	......	.78μ[3]		1.40μ[4]	
Fibril Angle		8°		15°	
Total Wall Thickness	2.39μ	2.93μ	1.72μ	3.22μ	2.21μ

[1] 18 percent gelatinous fibers.

[2] 48.5 percent gelatinous fibers.

[3] Remained in place.

[4] Partly separated.

both instances, the upper side radial shrinkage was less than that on the lower side.)

4) The upper side of Tree 3 had the lowest tangential shrinkage of all three trees. This occurred even though the specific gravity was higher than that of either side of Tree 1 (zero° lean) or Tree 2 (10° lean).
5) The percentage of gelatinous fibers was highly correlated with longitudinal shrinkage on the upper side of Tree 2 but was not significantly correlated on the upper side of Tree 3.
6) The specific gravity was slightly higher on the upper side as compared with the lower side for Tree 2, but the opposite was true for Tree 3.

In a separate project conducted in the same laboratory but using different trees, Manwiller (1967) obtained the cell-wall-layer thickness and fibril angles presented in Table 5. There were distinct differences in the cell walls of a tree leaning 10° and one leaning 20°. In the tree with 10° lean, the S_2 layer was thicker and the *G* layer thinner than for the tree with 20° lean. Also, the *G* layer remained in place during microtome sectioning in the samples from the 10° tree but was detached in the samples from the 20° tree. The fibril angle for both the S_2 and *G* layers in the 20° tree was double that of the 10° tree. The S_3 layer was not observed in the 10° tree but was in the 20° tree.

The results reported by Manwiller (1967) appear to explain some of the differences we observed between Tree 2 (10° lean) and Tree 3 (28° lean). The greater longitudinal shrinkage of tension wood in the 28° tree would be expected, not only because of reduced lignification of the upper side, but also by the larger fibril angle in the S_2 and *G* layers as well as the presence of an S_3 layer in severely leaning trees. Norberg and Meier (1966) separated fragments of the *G* layer from microtome sections and found no appreciable longitudinal shrinkage upon drying. Using polarized light, they observed a strong birefringence in the S_2 as well as the S_1 layer. This indicated to them that increased longitudinal shrinkage of tension wood must be due to the large fibril angle of the S_2 layer. Our data appear to substantiate this

Our data show Tree 2 (10° lean) to higher specific gravity on the upper side Tree 3 (28° lean) to have higher specific ity on the lower side. Manwiller's data that the S_2 layer on the upper side of a 10° tree is much thicker than for the 20° tree and that the *G* layer makes up only 27 percent of the cell wall for the 10° tree as compared with 43 percent of the 20° tree. If the *G* layer has lower density, this would account in part for the differences in specific gravity.

The relationship of degree of lean to the properties of tension wood appears to explain some of the discrepancies found in the literature. Excessive lean seems to result in an extreme stimulus on the upper side of the tree. As compared with an intermediate lean, our data indicate a thinner S_2 and thicker *G* layer, the presence of an S_3 layer, greater fibril angles in the S_2 and *G* layers, lower lignin content, and a lower specific gravity on the upper side (compared with the lower side).

In the tension wood zones, it would appear that the variables of cell-wall organization, layer thickness, and fibril angle may partly explain the differences in density and both longitudinal and transverse shrinkage between trees of medium and high degrees of lean.

It is possible that discrepancies in the literature may be due to some researchers using trees with a high degree of lean and others using trees with an intermediate lean. As a result, tension wood has been reported to have higher specific gravity by some researchers and lower by others. There has been much disagreement on the relationship of tangential and radial shrinkage to the presence of tension wood, and this also may have resulted from difference in the degree of lean in the trees used.

The variables used in our study do not fully explain the fundamental difference between the shrinkage of nonleaning and the upper and lower sides of leaning trees. The properties of tension wood will not be fully explained until more information is known about the physical and chemical variations in the cell-wall structure of leaning trees.

Summary

Interrelationships in silver maple (*Acer saccharinum* L.) between number of gelatinous fibers and longitudinal and transverse shrinkage were studied. Data were obtained on the effect of lignin and specific gravity on these parameters. As expected, longitudinal shrinkage was greatest on the upper side of the leaning trees and increased with increase in lean. Radial shrinkage was less on both the upper and lower sides of the leaning trees than in the nonleaning control. The tension wood, however, shrank less radially than the corresponding underside wood. Tangential shrinkage was greater on both sides of the tree with a 10° lean than for the control but lower on the upper side and higher on the lower side of the 28° leaning tree than for the control. The two leaning trees displayed a number of other differences that may account for the discrepancies in the literature about the properties of tension wood.

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