PROPERTIES OF NORTHERN ASPEN DISCOLORED WOOD RELATED TO DRYING PROBLEMS

J. F. G. Mackay

Research Scientist, Department of the Environment, Canadian Forestry Service, Western Forest Products Laboratory, Vancouver, British Columbia V6T 1X2

(Received 10 February 1975)

ABSTRACT

Discolored wood isolated from the inner sapwood area of trembling aspen and balsam poplar shrinks more and is weaker in compression perpendicular-to-the-grain, than adjacent normal sapwood. When the green moisture content is higher than that of adjacent normal wood, then the drying rate (E-value) is slower. Excessive shrinkage and wet pockets may be anticipated during kiln-drying; therefore drying practices must be adapted to allow for these difficulties.

Additional keywords: *Populus tremuloides*, *Populus balsamifera*, kiln-drying, shrinkage, collapse, compression strength, drying rate.

INTRODUCTION

To encourage wider utilization of the much-neglected resource of poplar timber in Canada, considerable attention must be given to increasing the production of dimension lumber. The predominant western Canadian species are trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*P. balsamifera* L.), and these have been grouped as northern aspen for grading under the National Lumber Authority softwood grading rules.

Lumber from these species must be kiln-dried and studies are therefore in progress to develop commercially acceptable kiln schedules. Existing schedules for 2-inch northern-aspen lumber can be classed as low-temperature schedules, when compared with those presently in use for many softwoods. Clearly, northern aspen dried under current schedules is at a disadvantage economically compared with softwood lumber dried in one-quarter to one-sixth of the time. However, existing guides to aspen kiln-drying, for example Irwin and Doyle (1961), warn against rapid drying because of collapse propensity in areas of excessively high moisture content (MC), usually termed wetwood, commonly found in the zone of sapwood-heartwood transition. Wetwood has been associated with bacteria by a number of workers. Knutson (1968) concluded that bacteria were not necessarily the causal agents of wetwood, but more recently Sachs et al. (1974) claimed that wetwood begins with an invasion of sapwood vessels by bacteria, probably from root infections.

A number of other studies have described some aspects of collapse and other undesirable properties of aspen wetwood. Clausen et al. (1949) found most collapse to be associated with wetwood, which they claimed was recognizable at the ends of sawn logs. Separation of boards containing wetwood and air-drying prior to kiln-drying almost eliminated severe collapse. Kemp (1959) demonstrated that when dry-bulb temperature was increased and the relative humidity was kept constant, the onset of collapse was advanced and it was invariably found to develop first in the wetwood zone. Haygreen and Wang (1966) compared some mechanical properties of aspen wetwood with adjacent normal sapwood and found that in all tests the wetwood was significantly weaker.

The most thorough investigation of aspen wetwood has been done by Knutson (1968). He attempted to quantify many of the measurable physical and chemical characteristics of green wetwood. A number of these are relevant to drying, including MC, permeability, and specific gravity. Wet-

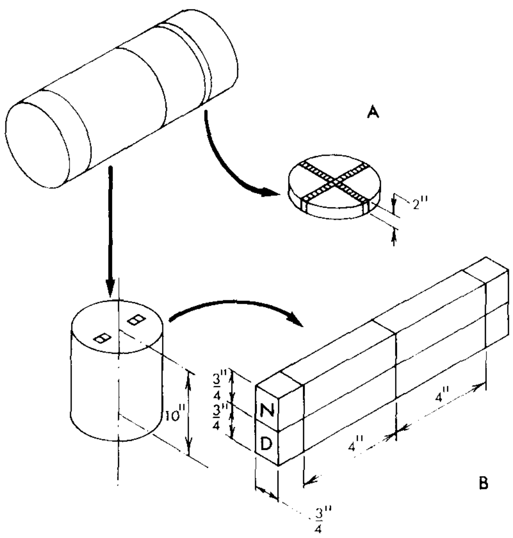

FIG. 1. Sawing patterns of A—MC blocks across two diameters of 2-inch-thick discs; B—shrinkage blocks from normal (N) and discolored (D) wood.

TABLE 1. *Moisture contents of apparent "wetwood" and of adjacent normal sapwood in eight trembling aspen and eight balsam poplar logs*

Tree		Moisture content (%)	
		Sapwood	"Wetwood"
Trembling aspen	1	76	135
	2	69	100
	3	73	68
	4	85	72
	5	79	111
	6	65	58
	7	59	88
	8	77	75
Balsam poplar	1	118	144
	2	83	120
	3	171	215
	4	97	135
	5	148	139
	6	118	165
	7	155	184
	8	126	112

wood was identified on the basis of wet appearance in 18 trees. In seven of these it was located in sapwood, in eight in transition zone, and in three in heartwood. In general, it was in the inner portions of sapwood and outer portions of heartwood. It is of interest to note, however, that while MCs were reported for normal sapwood, heartwood, and wetwood in 13 of these trees, in only 10 did the wetwood indeed have the highest MC. The specific gravity of wetwood occurring in the sapwood and transition zone was no lower than that of adjacent normal sapwood. Permeability to water flow parallel-to-the-grain was very much higher in normal sapwood than in wetwood.

Wallin (1954) found that in balsam poplar the specific gravities of wetwood, which was located in the transition zone, and of normal sapwood and heartwood were not significantly different.

Thompson (1969) described drying tests of aspen studs sawn so that no pith and little heartwood were included. The heart centers of aspen were considered to be of questionable use because of decay and grain direction. Fortunately, sapwood makes up the greater portion of most aspen logs, and drying defects are minimal when such a sawing pattern is used.

To divide the stem cross section accurately into sapwood, transition zone, and heartwood is highly subjective with these two species. In aspen, the sapwood is nearly white, while the heartwood varies from off-white to light brown. A distinct color boundary distinguishing the two is lacking, and the variable-width sapwood generally blends gradually into the heartwood.

No less difficulty exists with balsam poplar, but all areas have a distinctly darker grey coloration. Superimposed on this general pattern is the presence of darker-colored wood, often with a wet appearance, which has generally been referred to as "wetwood." Wetwood in both species occurs as isolated pockets, with its most common location the area bounded by inner sapwood and outer heartwood. In this study, this wood is referred to as discolored wood.

The aim of the study was to compare

TABLE 2. *Moisture content means of discolored wood and normal wood samples of trembling aspen and balsam poplar used in the principal tests*

Test	Mean Moisture Content (%)			
	Trembling aspen		Balsam poplar	
	Discolored	Normal	Discolored	Normal
Shrinkage	73.1 (30)[1]	82.1 (30)	134.8 (32)	119.0 (32)
Compression stress	78.7 (140)	73.2 (150)	121.3 (153)	93.5 (151)
Drying rate	68.4 (16)	62.4 (16)	100.9 (16)	100.6 (16)

[1]Number of samples in parentheses

some properties pertinent to drying of discolored wood and adjacent normal sapwood.

PROCEDURES

Trembling aspen and balsam poplar logs were randomly selected in a sawmill yard in Slave Lake, Alberta, and from thirty logs of each species a 2-ft section was discarded from the butt end and the next 3-ft bolt was sawn off and taken to the laboratory. The 3-ft bolts were then wrapped in plastic and stored under water sprays until used. Three weeks elapsed between selecting the bolts at the mill and the commencement of sample-block preparation at the laboratory.

Moisture contents distributions were ob-

TABLE 3. *Overall (unadjusted) means of percentage volumetric shrinkage values of normal and discolored wood samples of trembling aspen and balsam poplar dried at different temperatures*

Variable	Shrinkage (%)	
	Trembling aspen	Balsam poplar
Normal wood	5.89	7.05
Discolored wood	7.34	10.35
Low temperature	6.77	8.52
High temperature	6.46	8.88

Analysis of Variance

Source	Trembling aspen			Balsam poplar		
	DF	MS	F	DF	MS	F
T	1	1.4980	<1	1	2.1143	<1
W	1	33.6841	5.70*	1	174.9326	11.5*
TW	1	3.4165	1.28	1	0.9053	<1
B	7	8.5265	1.44	7	17.5951	1.11
TB	7	0.6264	<1	7	2.6179	1.32
WB	7	5.9082	2.21	7	15.1881	7.66**
TWB	7	2.5086		7	1.6554	
E	32	2.7074		32	2.0548	

T = Temperature, W = Wood type, B = Bolt, * = Significant at P = 0.05
** = Significant at P = 0.01

TABLE 4. *Overall (unadjusted) means of compressive strength perpendicular-to-the-grain of normal and discolored wood of trembling aspen and balsam poplar at three temperatures*

	Stress at proportional limit (p.s.i.)			
	Trembling aspen		Balsam poplar	
Variable	Radial	Tangential	Radial	Tangential
Normal wood	146.9	215.3	118.4	178.4
Discolored wood	108.6	153.1	70.8	102.5
70 F	171.3	244.3	124.9	190.1
130 F	124.7	185.1	94.3	149.3
180 F	87.3	122.7	56.1	81.9

Analysis of Variance

	Trembling aspen					
	Radial			Tangential		
Source	DF	MS	F	DF	MS	F
T	2	66043	35.8**	2	183995	59.6**
W	1	54065	40.0**	1	125814	8.72*
TW	2	396	<1	2	3083	1.00
B	7	20573	8.62**	7	28652	1.99
TB	14	1923	2.10*	14	1702	<1
WB	7	1387	1.51	7	14422	4.67**
TWB	14	281		14	2611	
E	93	1012		101	3152	

	Balsam poplar					
	Radial			Tangential		
Source	DF	MS	F	DF	MS	F
T	2	47884	104.1**	2	164363	217.1**
W	1	73916	125.1**	1	221875	44.9**
TW	2	1696	4.37*	2	7715	12.8**
B	6	1538	2.32	6	6590	1.29
TB	12	460	1.19	12	757	1.26
WB	6	591	1.52	6	4945	8.21**
TWB	12	117		12	783	
E	100	421		120	584	

T = Temperature, W = Wood type, B = Bolt, * = Significant at P = 0.05
** = Significant at P = 0.01

tained by measuring the oven-dried MC of small blocks sawn in four quadrants from eight bolts of each species, as illustrated in Fig. 1A. The diameter strips were located so that at least one included apparently wet or discolored wood in the inner sapwood or transition zone.

Shrinkage of this discolored wood and of adjacent normal white sapwood was determined in blocks sawn from the above-

TABLE 5. *Specific gravity of normal and discolored wood of trembling aspen and balsam poplar*

Species	Wood type	No.samples	Specific gravity (mean)
Trembling aspen	Normal	150	0.379**
	Discolored	140	0.335
Balsam poplar	Normal	151	0.357
	Discolored	153	0.356

** Indicates significant difference between means at the 0.01 level of probability.

mentioned 16 bolts. The sampling procedure is illustrated in Fig. 1B. From each bolt, two 10-inch-long strips containing adjacent normal wood and discolored wood were sawn. Each strip was further sawn to give two pairs of ¾ by ¾ by 4 inch-long test blocks, each pair thereby consisting of a normal wood block and the adjacent discolored-wood block. Two pairs from each bolt were allocated to high-temperature drying (240 F dry bulb with 180 F wet bulb) and the other two pairs to intermediate-temperature drying (180 F dry bulb and 130 F wet bulb). Each block was measured to the nearest 0.001 inch at three points in the radial and tangential directions, when green and at all subsequent MCs to which they were conditioned. After the blocks were sealed to allow drying in the transverse directions only, they were kiln-dried and conditioned to 15% MC, steamed at 212 F for 2 h to try to recover excessive shrinkage due to collapse, re-equilibrated to 15% MC, and finally oven-dried at 215 F.

During drying, considerable transverse stresses are developed in wood due both to normal shrinkage and collapse if it occurs. Kauman (1960) demonstrated that collapse could be related to the limit of proportionality in compression perpendicular-to-the-grain. Strength in compression perpendicular-to-the-grain was, therefore, measured with green blocks at room temperature or heated to the wet-bulb temperature of the above two drying schedules, namely 180 F or 130 F.

Eight further bolts of each species were sawn to provide matched discolored and adjacent normal blocks for measuring compression perpendicular-to-the-grain. The sawing pattern was essentially as already described for the shrinkage tests except that the strips were 20 inches long to provide six ¾ by ¾ by 4 inch-long blocks of each wood type from each bolt. Within each group of six, blocks were randomly allocated to each of the six treatment combinations of radial or tangential direction of stress at 70, 130 or 180 F. Prior to testing at 130 and 180 F, those blocks were sealed in aluminum foil and heated to their test temperature in a water-saturated atmosphere. Compression perpendicular-to-the-grain was applied with a 1-inch-square brass block on the middle inch of the 4-inch-long specimens. A heating element in the

TABLE 6. *Comparisons of means of E-values at three times for normal and wet-discolored trembling aspen and normal and wet-discolored balsam poplar wood*

Elapsed drying time (hr)	Trembling aspen		Balsam poplar	
	Normal (8)	Wet-discolored (8)	Normal (11)	Wet-discolored (11)
12	0.270	0.436**	0.247	0.393**
36	0.053	0.143**	0.028	0.090**
60	0.010	0.043**	0.007	0.019**
Green m.c. (%)	58.1	72.3	79.7	110.5

**indicates significant difference between means at the 0.01 level of probability.
(Number of samples in parentheses)

brass block maintained the required test temperatures, and, thus, no heat was lost from the wood to the brass block during each test. Appropriate measurements were made on all blocks to calculate specific gravities (green volumes and oven-dry weights) and oven-dried MCs.

The drying behaviour of the two wood types from each species was examined by comparing relative drying rates of matched specimens. From a further eight bolts of each species, two pairs of blocks of discolored wood and adjacent normal sapwood were sawn with dimensions 2.0 inches tangentially, 0.75 inch radially and 18.0 inches longitudinally. The blocks were kiln-dried at conditions of 140 F dry bulb and 110 F wet bulb to equilibrium MC of approximately 5.5%. At regular intervals, all blocks were removed from the kiln and weighed and, finally, after attaining constant weight they were oven-dried for MC determinations. Drying rates were compared using E-values at the given weighing times, where E is the fraction of evaporable water remaining in the specimen at any given time t. It is calculated from the equation $E = (w - c_r)/(c_0 - c_r)$, where w is the MC of the specimen at time t, c_r is the EMC for the drying conditions used, and c_0 is the original MC of the specimen.

RESULTS

Statistical analyses

In all tests except those for MC distribution, any blocks found to contain knots or splits were discarded. As a consequence, the planned balanced factorial design containing a mixture of both random and fixed effects became unbalanced and required a complex analysis. Tables 3 and 4 show the final results. Full details of these analyses are available on request.

Moisture content distribution

The distribution of MCs across two diameters of each of 16 bolts indicated that discolored wood of unusually high MC was encountered in four aspen bolts and in six balsam poplar bolts, as indicated in Table 1. In the remaining six bolts, the MC of the discolored or apparent wetwood did not exceed that of the adjacent clear inner sapwood. Appearance alone, therefore, could not be used as an indicator of high MC wood—that is, wetwood as described by some previous workers. It was for this reason that all subsequent tests were designed to compare discolored wood taken from the inner sapwood with adjacent normal clear wood. As further indication of the lack of correlation between appearance and MC, Table 2 lists the average MCs of samples from the principal described in this study.

Shrinkage

An analysis of variance was carried out to examine the effect of the two drying schedules on volumetric shrinkage to 15% MC (before steaming) of blocks from both wood types of both species. Table 3 shows the results obtained. At both drying conditions, the discolored wood samples had the greater shrinkage, and temperature had no effect.

Steaming and re-equilibration to 15% MC did not yield any increase in radial or tangential dimensions.

Strength

The results of compression tests perpendicular-to-the-grain are shown in Table 4. Discolored wood had consistently lower fiber stress at the elastic limit in both species and at all three temperatures. Stress values for both wood types and both species decreased with increasing temperature.

Specific gravity

Specific gravities of all blocks used in the compression tests were calculated, and a comparison of means of wood types in each species is shown in Table 5. No differences were found between wood types in balsam poplar, but in trembling aspen the discolored wood is significantly lower in specific gravity than the normal sapwood.

Drying behaviour

Drying rates were compared on the basis of E-values at three times during the drying schedule—namely at the 12, 36, and 60-h periods. Results are shown in Table 6. There were no consistent trends when comparisons were made solely between the wood types as they were classified, i.e., discolored versus normal. However, only when those matched pairs where the discolored wood had a higher MC than the normal wood (i.e., wetwood in the strict sense) were segregated out and compared, were there any significant differences between wood types. The wetter discolored wood dried more slowly, on the basis of E-values, than the normal wood.

DISCUSSION

The MC of discolored wood may or may not be higher than that of adjacent normal sapwood, but its shrinkage is significantly greater. In both species this can be directly related to low strength in compression perpendicular-to-the-grain. The high levels of shrinkage have already been shown by others to be a result of collapse, but this study found that recovery could not be achieved by the normal means—i.e. steaming at about 210 F. Wardrop and Dadswell (1948) showed that nonrecoverable collapse is typical of tension wood fibers. The known high incidence of tension wood in poplars, irrespective of leaning stems, demonstrated by Kaeiser (1955) and Isebrands and Bensend (1972), therefore, supports a direct relation here.

Kauman (1960) found a significant increase in total volumetric shrinkage as temperatures were increased from 110 F to 190 F. In his study with eucalypt wood, total volumetric shrinkage comprised normal shrinkage plus collapse, which was later largely recovered by steaming. It would thus appear that in northern aspen the excessive shrinkage occurring in isolated blocks of discolored wood shows some but not all the characteristics of the collapse common to some other hardwoods, including eucalypts and oaks.

Since high temperatures did not increase total volumetric shrinkage, and some workers (Smith 1947) found collapse to be a problem even at 80 F, high-temperature schedules (e.g., Mackay 1974), which can take advantage of the ease of drying of the normal wood, can therefore be used.

A feature common to both species is the slower drying of wet discolored wood relative to normal wood. The result of this is well known to producers of kiln-dried aspen lumber, namely that streaks or pockets of moist wood are present in otherwise adequately dried pieces. Therefore, to reduce the MC of all the wood to required levels means longer kiln residence times, with the possible danger of over-drying the normal wood and increasing degrade.

APPLICATION OF RESULTS

Wood sawn from the area between sapwood and heartwood of trembling aspen and balsam poplar has long been known to cause difficulties during kiln-drying. Some of the reasons for this are clear from the results of this study.

Two of the alternatives that should therefore be considered for the utilization of these species are: Saw dimension lumber from the clear sapwood only, deliberately leaving a center cant of heartwood-inner sapwood, which can be chipped for pulp or composite board. If conventional sawing patterns must be used so that a whole log is converted to lumber, then more than the normal allowance should be made for drying shrinkage. Either a longer time must be expected and allowed to dry the inevitable wet pockets, or wet pieces could be recycled through a further drying cycle.

REFERENCES

CLAUSEN, V. H., L. W. REES, AND F. H. KAUFERT. 1949. Development of collapse in aspen lumber. FPRS Proc. 3:460–468.

HAYGREEN, J. G., AND S.-S. WANG. 1966. Some mechanical properties of aspen wetwood. For. Prod. J. 16(9):118–119.

IRWIN, J. D., AND J. A. DOYLE. 1961. Properties and utilization of Canadian poplars. Can. Dep. For., For. Prod. Res. Branch, Tech. Note No. 24, Ottawa, Ont. 28 p.

ISEBRANDS, J. G., AND D. W. BENSEND. 1972. Incidence and structure of gelatinous fibers within rapid-growing eastern cottonwood. Wood Fiber 4(2):61–71.

KAEISER, M. 1955. Frequency and distribution of gelatinous fibers in eastern cottonwood. Am. J. Bot. 42(3):331–336.

KAUMAN, W. G. 1960. Contribution to the theory of cell collapse in wood: Investigations with *Eucalyptus regnans*. Aust. J. Appl. Sci. 11(1):122–145.

KEMP, A. E. 1959. Factors associated with the development of collapse in aspen during kiln-drying. For. Prod. J. 9(3):124–130.

KNUTSON, D. M. 1968. Wetwood in trembling aspen (*Populus tremuloides* Michx.). Ph.D. thesis, Univ. Minn., Minneapolis. 152 p.

MACKAY, J. F. G. 1974. High-temperature kiln-drying of northern aspen 2- × 4-inch light-framing lumber. For. Prod. J. 24(10):32–35.

SACHS, I. B., J. C. WARD, AND R. E. KINNEY. 1974. Scanning electron microscopy of bacterial wetwood and normal heartwood in poplar trees. Proc. Workshop Scanning Electron Microsc. Plant Sci., I.I.T. Res. Inst., Chicago. Pp. 453–459.

SMITH, H. H. 1947. Seasoning of aspen. USDA For. Serv., Lake States For. Exp. Sta., Aspen Rep. No. 5, St. Paul, Minn. 19 p.

THOMPSON, R. D. 1969. Proc. Aspen Stud Seminar. Sch. For., Univ. Minn., Minneapolis. 104 p.

WALLIN, W. B. 1954. Wetwood in balsam poplar. Univ. Minn., Agric. Exp. Sta., Sci. J. Series, Pap. 3118. 2 p.

WARDROP, A. B., AND H. E. DADSWELL. 1948. The nature of reaction wood. Aust. J. Sci. Res., Ser. B-Biol. Sci. 1(1):3–16.