COMPARISON OF KILN SCHEDULES FOR DRYING SPRUCE*

Marian Salamon
Department of the Environment Canadian Forestry Service
Western Forest Products Laboratory
Vancouver, British Columbia

Spruce (Picea sp.) is Canada's principal softwood and its cut ranks the highest among Canadian woods, accounting for more than 39 percent of all lumber marketed (1). White spruce [Picea glauca (Moench) Voss] and Engelmann spruce (Picea engelmannii Parry) intergrade in the interior of British Columbia, and their respective woods cannot be distinguished. Drying schedules have been developed for these species (2, 3, 4, 5, 6, 7, 8, 9), but associated grade and strength changes for kiln-dried and air-dried lumber processed over a wide range of schedules have not been reported.

The objective of this study was to dry matched spruce charges under different schedules in a small experimental kiln to about 12% moisture content (M.C.) and evaluate the efficiency of the schedules on the bases of drying rate, degrade and possible strength reduction.

Materials and Method

Four shipments of B. C. Interior spruce, each from a different mill, containing 36 to 40 pieces of 2-inch lumber in random lengths up to 22 feet were obtained. Three shipments consisted of 2 x 8-inch common lumber, while one was obtained in widths from 6 to 12 inches.

All shipments were covered with a polyethylene sheet and sprayed with water to prevent their drying until further processing. They were cut into 3-foot-long pieces, taking a section for initial M. C. determination from both ends of each 3-foot-long piece. The average of the two sections per piece was used to estimate the initial M. C. of a board. Basic specific gravity was determined on a cross section of each green piece. A total of 18 charges were assembled, each containing 36 to 40 pieces except for the air-dried parcel, which contained 116 pieces. The charges were randomly assigned to one of six temperature-classification schedules: conventional, low-high, low-variable high, constant high, superheated steam or air-drying. The exact schedule used for each charge is presented in Table 1.

An air-dried charge was stickered in a dry shed and kept until 16 to 17% M. C. was reached, after which the boards were cut up into rough test specimens and conditioned in a humidity cabinet regulated to 12% EMC. The final M.C.s were obtained after at least 12 months of conditioning.

To monitor drying rates in the 3-foot prefabricated, steam-heated aluminum kiln described previously (10), a print-weight balance was added. Through a further modification, air-circulation rates were varied from 250 to 900 fpm.

Because the lumber dried in the experimental kiln was only 3-feet long, it was not practical to grade it under a standard lumber grading rule. With the assistance of qualified lumber graders, however, a method of quality assessment was devised, based on the presence of seasoning checks, splits, warp, loose knots and honeycomb. Table 2 lists these seasoning defects and their potential effect on lumber grade.

Each piece was graded twice, initially in the rough green state and finally in the dried surfaced condition. After drying, the lumber of each charge was divided into three categories (no or slight degrade, medium degrade and severe degrade), based on the number and severity of seasoning defects. Only severe degrade can generally be equated

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Table 1. Drying Schedules of Charges.

Schedule class.	Conventional									Low-high temperature								
Air velocity (fpm)*	250			250			900-250			250			900-250			900-500		
Schedule steps	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.
	170	160	12	168	155	6	170	160	6	170	160	12	170	160	6	170	160	6
	180	160	12	180	155	8	180	160	6	180	160	12	180	160	6	180	160	6
	190	160	24	188	155	24	190	160	24	180	160	7	190	160	6	190	160	6
	200	160	14	200	155	20	200	160	14	232	205	16	232	205	24	232	205	22
	180	160	9	175	155	3	180	170	4	216	208	3						
	180	170	3	175	165	3												
Charge number		1-3		4				5-6			7-8			9-10			11	
Drying time			74			64			54			50			42			40

Schedule class.	Low-varying high temperature						Const. high temperature			Superheated steam			Air drying	
Air velocity (fpm)*	900-250			900-250			250			250			natural	
Schedule steps	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F	hr.	DB°F	WB°F
	-	212	2	170	160	6	232	205	41.5	230	212	40		
	-	-	2	180	160	5								
	170	160	6	190	160	6								
	180	160	8	200	160	6								
	190	160	3	244	200	1/4								
	200	160	3	232	200	3 1/2								
	232	205	4	255	200	1/2								
	235	205	2	242	200	4								
	246	205	4	258	200	3/4								
	252	205	5	252	200	3								
	256	205	1	256	200	3								
	260	205	6	262	200	4								
	265	205	2											
Charge number		12			13			14-15			16-17			18
Drying time			48			42			41.5			40		1 year

*The setting is underlined at which air velocity was changed to lower level.

Table 2. Quality Evaluation Applied to 3-Foot-Long S2S Dried Lumber.

Type of Defect			
Surface check			
small	Less than 4 inches		Slight or medium in combination
medium	More than 4 and less than 10 inches		Slight, medium in combination, severe when through piece
large	Longer than 10 inches		Severe in combination, or severe when through piece
End split			
short	Half width of piece		Slight or medium in combination
medium	Equal to width of piece		Medium or severe in combination
long	More than width of piece		Severe
Ring separation (shake)	When aggravated by drying, treat as split or surface check		
Loose grain			
light	Less than 1/16-inch deep		Slight or medium in combination
medium	1/16 to 1/8-inch deep		Medium or severe in combination
heavy	More than 1/8-inch deep		Severe
Loose knots or holes (regardless of size)	Encased knot		Slight
	Star checked knot with check extended over edge ≤1"		Medium
	Star checked knot with check extended over edge ≥1"		Severe
Warp	Crook	Bow	
	≤1/2"	≤1/2"	Slight
	1/2-7/8"	1/2-7/8"	Medium
	≥7/8"	≥7/8"	Severe
	Cup	Twist	
	≤1/8"	≤3/8"	Slight
	1/8-1/4"	3/8-1/2"	Medium
	≥1/4"	≥1/2"	Severe
Honeycomb	Few checks, closed		Medium
	Several checks, closed		Severe

with a reduction in grade of full-length pieces of dimension lumber.

Within a week after completion of kiln drying, rough mechanical test specimens were cut from the dried boards, which then were placed into a 12% EMC controlled-humidity cabinet to equalize for at least six months. After the equalization period, both air-dried and kiln-dried specimens were processed to final size and tested in static bending and compression parallel to grain following the appropriate ASTM procedure (11, secondary method).

Results and Discussion

Drying rate

A comparison of drying rates achieved with different schedules is realistic only when initial M. C. s are similar and final M. C. s are likewise nearly equal, because the drying rate is faster at high M. C. and much slower below the fiber saturation point. Although some variation does exist in initial M. C. between charges (Table 3), the average initial M. C. s for various classes of schedules (Figure 1) are approximately equal, with the exception of the superheated steam charges. Likewise, average final M. C. s for various schedules (Figure 1) are similar, ranging from 10.6 to 13.1% with the exceptions of the low-varying high schedule (8.0%) and the superheated steam schedule (16.4%). Prior to calculating drying rates in these two instances, drying times were adjusted to the average final M. C. for all charges of 11.4%. These adjustments were achieved by extrapolating or interpolating the relationship between M. C. and drying time to conform to 11.4% M. C.

As shown in Table 3, three conventional charges (no. 1-3) took 74 hours to dry and the other (no. 4) took 64 hours. Their average drying rate was 0.40%/hour at 250 fpm air-circulation rate. The charges which were dried at conventional temperatures, but with circulation rates of 900 and 250 fpm (no. 5 and 6), both took 54 hours to dry at an average rate of 0.53%/hour. On the basis of the average conventional drying rate, this represents an increase of 33% (Figure 1). This emphasizes the gains to be made by employing increased circulation rates, at least during the first part of the schedule, and verifies results presented previously (7, 9). Faster circulation rates reduce the build-up of a humid insulating-boundary layer immediately above a wood surface and increase the heat transfer rate by maintaining a more uniform temperature across a load.

The two low-high temperature charges at 250 fpm air-circulation rate (no. 7 and 8) dried in 51 and 49 hours, respectively, with a corresponding average drying rate of 0.56%/hour to the average final M. C. of 13.1%. The other two low-high temperature charges employing circulation rates of 900 and 250 fpm (no. 9 and 10) were dried in 40 to 44 hours with an average drying rate of 0.73%/hour. The low-high temperature schedule employing somewhat higher air-circulation rates of 900 and 500 fpm (no. 11) increased the drying rate to 0.82%/hours, an increase of 105% over the conventional drying rate (Figure 1).

The two low-varying temperature charges (no. 12 and 13) dried in 48 and 42 hours, the first including 2 hours of steaming and 2 hours of cooling at the beginning of the schedule. The average rate of 0.78%/hour was based on the time needed for the lumber to reach 11.4% final M. C., the average of the other charges. It is interesting to note that the higher circulation rates of 900 and 500 fpm used for charge 11 resulted in a faster drying rate than that obtained in charges 12 and 13, which employed very high temperatures.

The two constant high-temperature charges (no. 14 and 15) dried in 43 and 40 hours, respectively, at 250 fpm with an average drying rate

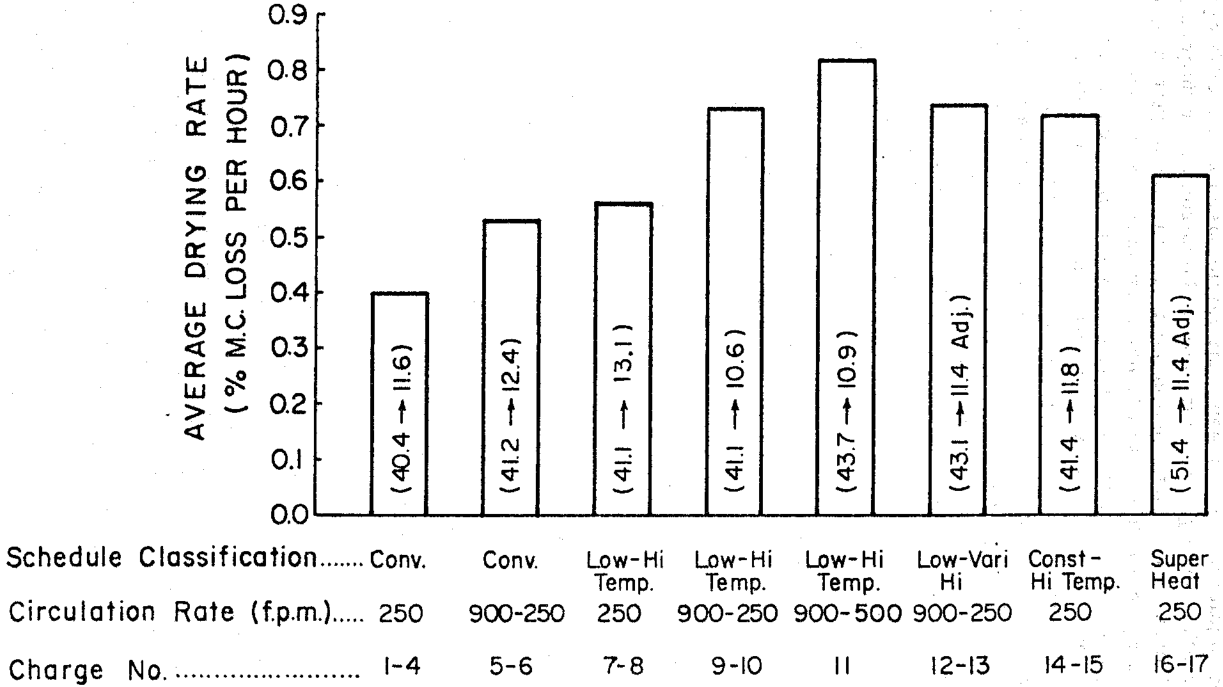

Figure 1. Drying rates for different schedules. Numbers in parentheses represent initial and final M. C. s.

Table 3. Drying Parameters of Each Charge.

Charge no.	Dimension in.	Drying time, hours	Drying rate, % M.C./hr.	Initial M. C. %			Final M. C. %				Schedule class.	Air circ. f. p. m.	Degrade evaluation %		
				min.	ave.	max.	min.	ave.	max.	S. D.			no or slight	medium	severe
1	2 x 8	74	0.30	25.6	34.0	56.8	8.3	11.6	15.3	2.59	Conventional	250	100.0	-	-
2	2 x 8	74	0.33	-	34.8	-	7.9	10.7	14.7	1.44	"	250	97.2	-	2.8
3	2 x 8	74	0.55	30.5	52.4	146.4	7.6	11.4	16.0	2.40	"	250	92.5	2.5	5.0
4	2 x 8	64	0.43	28.5	40.2	82.3	9.1	12.7	20.2	2.61	"	250	95.0	2.5	2.5
5	2 x 8	54	0.52	27.6	39.7	99.7	8.3	11.5	13.7	1.27	Conventional	900-250	95.0	-	5.0
6	2 x 6	54	0.54	29.4	42.7	74.9	10.0	13.3	19.8	2.62	"	900-250	92.5	-	7.5
7	2 x 8	51	0.41	28.6	34.0	55.0	7.8	13.2	20.3	2.32	Low-hi temp.	250	97.2	2.8	-
8	2 x 8	49	0.71	32.8	48.1	170.4	7.3	13.1	21.9	2.33	"	250	97.5	-	2.5
9	2 x 8	40	0.73	31.5	39.4	93.1	5.5	10.1	13.5	1.94	Low-hi temp.	900-250	95.0	2.5	2.5
10	2 x 6-12	44	0.73	30.6	42.9	133.2	6.4	11.0	19.0	2.99	"	900-250	90.0	-	10.0
11	2 x 8	40	0.82	29.3	43.7	86.6	7.3	10.9	24.0	2.87	Low-hi temp.	900-500	95.0	-	5.0
12	2 x 6-12	48	0.74	29.4	43.2	76.1	4.1	7.6	15.2	2.57	Low-varying hi temp.	900-250	67.5	5.0	27.5
13	2 x 6-12	42	0.82	28.9	42.9	121.3	4.4	8.5	14.6	2.78	" "	900-250	60.0	7.5	32.5
14	2 x 6	43	0.53	29.0	32.6	44.6	7.0	10.0	12.9	1.67	Constant hi temp.	250	77.8	-	22.2
15	2 x 8	40	0.92	34.6	50.3	165.2	7.3	13.5	34.7	5.19	" "	250	67.5	22.5	10.0
16	2 x 8	40	0.80	32.4	47.5	171.4	6.8	15.4	49.2	6.49	Superheated steam	250	37.5	22.5	40.0
17	2 x 8	40	0.95	36.5	55.3	138.9	8.9	17.4	43.6	8.31	" "	250	25.0	27.5	47.5
18	2 x 8	*	-	23.4	42.5	173.4	9.7	12.5	13.3	1.09	Air dried	--	N. A.		

*Dried for at least one year.

N. A. = not applicable

of 0.72%/hour. The superheated-steam drying charges were dried in 40 hours, but the final average M.C. was an unsatisfactorily high 16.4%. The drying rate averaged 0.61%/hour when drying time was extrapolated to reach a final M.C. of 11.4%.

Final moisture content distribution

The final M. C. of charges averaged 11.5% and ranged between 7.6% and 17.4%. The average standard deviation was 2.05, with a range of 1.09 (air-dried charge) to 8.31 (a superheated, high-temperature run).

Quality of drying

Table 3 also shows the quality evaluation of the 17 kiln charges. In conventionally dried charges utilizing the lowest air-circulation rate of 250 fpm, a fall-down ranging from zero to 5.0% was indicated from the percentage of severe degrade obtained. The combined air-circulation rate of 900 and 250 fpm with conventional temperatures showed a maximum severe degrade of 7.5%.

Fall-down generally became excessive only in charges 12 to 17. In these instances, moderately high temperatures (230 to 232°F) were employed throughout the schedule, or very high temperatures (up to 265°F) were used for a shorter period of time.

Extensive honeycomb was noted after cross cutting the boards dried at the low-varying high temperature schedules of charges 12 and 13. The constant high temperature and the superheated-steam schedules also produced severe honeycomb in many boards, resulting in unacceptable quality.

Strength comparison

All specimens were stored long enough to attain constant EMC, which varied between 10.5 and 13.5%, depending on severity of drying condition. Those charges exposed to higher temperatures attained the lower EMCs. No attempt was made to adjust individual strength values to a common MC, since the EMC obtained reflect the actual moisture levels expected under service conditions.

Each strength value obtained in testing was adjusted to the average specific gravity of 0.341 based on all test pieces. The following equation was used (12):

$$\frac{S}{S'} = \left(\frac{G}{G'}\right)^n$$

where S is the strength value determined by testing;
S' is the strength value adjusted to the average specific gravity of 0.341;
G is basic specific gravity of a test piece;
G' is 0.341;
n = 1.50 for MOR;
1.25 for MOE and maximum crushing stress

The adjusted values were averaged by each schedule type and the results presented in Table 4. These mean values were compared to the air-dry controls, using Dunnett's test as described by Steel and Torrie (13). The low-varying high temperature treatment gave modulus-of-rupture values which were 8.2% lower than the respective air-dry control. This difference was significant at the 5% level, but no significant difference could be detected among any MOE or maximum crushing-stress values. It should be noted that the test samples were cut in such a way as to avoid honeycomb. The actual strength of low-varying high, constant high-temperature dried and superheated steam-treated specimens might have been lower had the entire board with included honeycomb been tested.

Table 4. Average Strength Properties of Spruce Dried Under Different Schedules.

Charge no.	Schedule	Static bending: Modulus of rupture		Static bending: Modulus of elasticity		Compr. parallel to grain: Max. crushing strength	
		No. tests	psi	No. tests	10^3 psi	No. tests	psi
1 - 6	Conventional, all velocities	139	9958	139	1482	135	5578
7 - 11	Low-hi temp. all velocities	124	10066	124	1513	141	5568
12 - 13	Low-varying hi temp.	51	9557*	51	1461	53	5529
14 - 15	Const. -hi temp.	54	10006	54	1426	52	5536
16 - 17	Superheated steam	41	10166	41	1489	48	5401
18	Air dried	78	10387	78	1458	81	5476

*Significantly different from the air-dried value at the 5% level.

Conclusions

Using a small experimental kiln, several interior spruce charges were successfully dried using conventional kiln temperatures and an air-velocity of 250 fpm. The drying rate was increased by about one-third when a higher circulation was employed in the first half of the schedule or when higher temperatures were introduced during the latter part of the drying schedule. If both higher circulations and temperatures were introduced at the appropriate times in a schedule, drying rates were increased by 75 to 105% without inducing excessive degrade in lumber. However, constant high temperature (max. 232°F), low-varying high temperatures (max. 265°F) and superheated-steam drying schedules produced an excessive amount of honeycomb, therefore precluding their use.

Final M.C. distribution was satisfactory for air dried, conventional and low-high temperature schedules, but other kiln schedules resulted in increased M. C. ranges and high, unacceptable standard deviations.

There was no evidence that modulus of rupture, modulus of elasticity or maximum crushing strength of clear samples cut from specimens were affected by drying conditions, except in one instance where exposure to low-varying high temperatures (max. 265°F) caused a statistically significant reduction of 8.2% in modulus of rupture.

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