CONVENTIONAL AND HIGH-TEMPERATURE KILN DRYING OF SAPWOOD, NORMAL HEARTWOOD, AND SINKER HEARTWOOD OF DIMENSION LUMBER FROM YOUNG-GROWTH WESTERN HEMLOCK

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Introduction

Sinker heartwood of western hemlock causes a wide range in final moisture contents, 8 to 25 percent or more, as shown in studies by Dedman and Van Dusen (1) and Kozlik and Hamlin (5). Nonuniformity of final moisture content makes it difficult for the lumber producers to meet the 19 percent moisture content specification of ALS PS 20-70. Mills endeavor to meet the specification for hemlock dimension lumber by over-drying, which may create additional degrade, increase kiln residence time and drying costs, and reduce total kiln capacity. Those mills cutting true firs (Abies) and redwood visually segregate unseasoned lumber on the green chain according to drying characteristics. Although this method is not common for western hemlock, some mills scan hemlock lumber for moisture content before planing and redrying the wet stock.

Kozlik, et al. (6) concluded from small specimens of old-growth heartwood of western hemlock that the drying rate for sinker heartwood is about 60 percent slower than for normal heartwood. Ethanol or acetone extraction or steaming sinker heartwood before drying improved the drying rate over matched or untreated specimens. Electron microscopy of sinker specimens showed pit membranes encrusted with deposits and heavy deposits on the cell-wall surface adjacent to the lumen which would reduce liquid flow and diffusion through the cell wall.

Ward and Kozlik (7) found that sinker heartwood from young-growth hemlock dried faster than that from old-growth hemlock. Bacteria were found in both young growth and old growth. Ring and pith shake are generally associated with heartwood which may have anaerobic bacteria producing a pectin-degrading enzyme that selectively attacks the compound middle lamella, thus weakening bonds between the wood cells.

Visual, mechanical, or electronic sorting on the green chain by drying characteristics would reduce total drying time and ensure uniform final moisture content. A better understanding of the drying properties of young-growth hemlock is needed before sorting by drying characteristics.

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Procedure

We selected four representative logging sites of young-growth hemlock in the Coast and Cascade Mountains of Oregon. The site location and characteristics are given in Table 1. Sample logs from each site were marked, transported, and sawn at the cooperating mill. Mill-run dimension lumber sawn from the marked logs was pulled from the green chain and classified sapwood, normal heartwood, and sinker heartwood. After sawing and selection, each sample was examined so that a board 6 inches wide and 8 feet long would contain nearly 100 percent sapwood, normal heartwood, or sinker heartwood. A 100-percent sample would have been desirable for each classification but is nearly impossible to secure. After sizing, we required that each board contain at least 75 percent of one wood type. The sapwood or normal did not contain more than 25 percent of another type. Past studies and industrial practice have shown that young- or old-growth sinker board can have 75 percent sinker interspersed with narrow bands of normal heartwood without necessarily retarding the drying rate. Sinker boards had to include wet or sinker areas 1.25 inches or more wide in the tangential and radial directions and at least 72 inches long. Width, depth, and length of the sinker areas had to total 75 percent or more for the sinker type.

Ninety-five percent of the sample boards were end- or side-matched and assigned a conventional or high-temperature kiln charge. The remaining boards were matched by visual appearance, growth rate, and type of cut. All lumber was then processed at the laboratory and was assigned to two kiln charges: one a conventional schedule, dry-bulb temperature not exceeding 180°F., and the other a high-temperature schedule, dry-bulb temperature not exceeding 230°F (Table 2). Each charge consisted of 55 sapwood boards, 58 normal boards, 60 young-growth sinker boards, and 19 old-growth sinker boards. The old-growth sinker boards were selected from a green chain for comparison with results of a past study by Ward and Kozlik (7).

Before drying, boards were surfaced to 1.75 inches by 6 inches and cut 96 inches (± 0.10 inch) in length. Each board was end-coated with neoprene asphalt. The width and thickness were measured at three points along the length of the board to the nearest 0.03 inch, averaged, and recorded to compute the cubic foot per board. Weight of each board was recorded before drying. Boards dried with the conventional schedule were individually weighed every 24 hours. Because high-temperature charges were not allowed to cool in the kiln first, the boards lost moisture in initial drying stages during the weighing period. We therefore assigned two charges, one containing sapwood and normal heartwood and the other containing the young- and old-growth sinker heartwood. Each board was weighed every 12 hours. Total weighing time for the boards was about 30 minutes for the conventional charge and about 15 minutes for each high-temperature charge. The conventional schedule of 120 hours is common in industry for drying hemlock dimension lumber. High-temperature schedules vary from 55 to 84 hours in commercial practice, depending on lumber width, kiln heating capacity, and mill production. We selected a 72-hour high-temperature schedule.

After drying, the boards were equalized in a kiln maintained at 150°F dry-bulb temperature with conditions for 10.3 percent equilibrium moisture-content or a 13°F. wet-bulb depression for approximately 3 months. Each board was weighed, then tested with a resistance moisture-meter with 1-inch insulated electrodes at nine locations about 48 hours after equalizing. The nine meter readings were averaged to determine the calculated oven-dry weight of each board and the moisture content at each weighing period.

Results and Discussion

Table 3 shows the initial moisture content and specific gravity, based on green volume and oven-dry weight, of the sample boards. The average specific gravity of the four board types varied by 0.04. Specific gravity within one type varied most in lumber from Crown Zellerbach, which was harvested from a pre-commercially-thinned mixed stand undergoing commercial thinning. The average moisture content was consistently highest for sapwood boards and lowest for normal boards. Moisture content was lower in young-growth sinker heartwood than in old-growth sinker heartwood.

After drying for 120 and 72 hours with the two schedules, boards continuing to lose 0.5 pounds were loaded back into the dryer. A 0.5 weight loss was selected because it reflected about a 3 to 5 percent change in moisture content at the end of the drying cycle. Many of the sapwood and sinker boards continued to lose more than 0.5 pounds of moisture every 24 hours with the conventional schedule and every 12 hours with the high-temperature schedule. Those in each classification continuing to lose 0.5 pounds at weighing periods after the preset time are shown in Table 4. Drying was stopped at 168 hours with the conventional schedule and 84 hours with the high-tempearture schedule because only a few boards remained in each charge.

Figure 1 shows the average weight loss per cubic foot per hour and Figure 2 the average moisture content loss per hour for the four board types dried with a conventional schedule. Because each figure represents the total average loss of water per hour, the curves for the four board types should be similar. Moisture loss in normal heartwood slowed after the first 48 hours of drying but did not slow in sapwood until after the 96th hour of drying. Moisture content in young- and old-growth sinker heartwood constantly declined over 144 hours of drying in this study. Mean weight loss per cubic foot per hour and mean moisture content loss per hour are shown in Tables 5 and 6, respectively. The curves in Figures 1 and 2 are for the four board types. In no instance during drying was moisture content loss the same for the four types. Normal boards had the same moisture loss in the weighing period at the 72nd and 96th hours, which indicates that fiber saturation point was reached (Figure 3).

The moisture-content loss for sapwood was the same for the first 96 hours (Tables 5 and 6). Before the 120th hour, the fiber saturation point was attained (Fig. 3). Moisture-content loss during the first 96 hours of drying young- and old-growth sinker heartwood was nearly constant. Old-growth sinker heartwood had the slowest rate of moisture loss between 96 hours and removal of the last samples from the kiln at 168 hours.

Figure 4 shows average weight loss per cubic foot per hour and Figure 5 the average moisture content loss per hour for the four board types dried with a high-temperature schedule. The curves for weight loss per cubic foot per hour and moisture content loss per hour are similar. Moisture loss constantly declined in normal boards and drying was completed in 48 hours. Moisture sharply declined after 24 hours of drying in sapwood and young- and old-growth sinker heartwood (Figs. 4 and 5). After 24 hours, these three board types had a constantly declining rate of moisture loss until the end of drying.

Tables 5 and 6 show the same moisture loss for old-growth sinker at the 24th- and 36th-hour and at the 72nd- and 84th-hour weighings. The drying rate for each board type, shown in Figure 6, was fastest with the high-temperature schedule (compare Figures 3 and 6). The approximate drying time to average fiber saturation point, arbitrarily chosen as 30 percent moisture content, and to 15 percent average moisture content is shown in Table 7.

High-temperature drying reduced kiln time from the conventional schedule by one-half or more for all four board types. With either schedule, normal heartwood dried twice as fast as the three other wood types to 30 percent moisture content and 25 percent faster to 15 percent moisture content. In all instances, sapwood and young-growth sinker heartwood dried in similar time. Old-growth heartwood had the longest kiln time, and some boards contained more than 19 percent moisture after extension of the two kiln schedules.

Comparing degrade between the two kiln schedules or among the wood types was not part of this study because 192 mill-run boards were not considered a sufficient sample size. Visual inspection of warp or seasoning degrade in the form of surface checks or knot checks showed the two charges were similar. Collapse, internal checking, and bottleneck checking in hemlock has been observed in other studies and in industrial practice. However, machining has removed evidence of collapse both in the laboratory and industry. Internal checking was present in studies by Kozlik (3, 4) but did not statistically result in lower strength values in static bending or tension parallel to the grain. Figure 7 shows internal checking occurring only in sinker boards dried with the conventional schedule. Extreme internal checking and collapse in sapwood and young- and old-growth sinker boards are shown in Figure 8. The severe collapse in the sapwood dried at high temperature occurred when the charge was pulled after 12 hours of drying for weighing. As the lumber was being removed from the dry kiln, we observed distortion or collapse of several sapwood boards resulting from the combination of high moisture content and thermal contraction of wood. The moisture content of the sapwood averaged 126 percent after 12 hours of drying, the outer shell approaching 10 to 12 percent moisture content and the core remaining near green condition at 179 percent. The wood temperature was at least 210°F and the temperature outside the kiln was 60°F.

When Koehler (2) heated green wood at a maximum temperature of 274°F for 6.25 hours and dried the wood at normal temperature, the tendency of the wood to collapse greatly increased. Therefore, it is difficult to state that the excessive collapse that occurred in our study would occur in commercial high-temperature drying. Sinker heartwood would collapse similarly since moisture-content levels are maintained above fiber saturation point even after the charge has been kiln dried.

Summary

Normal heartwood dried with a conventional or high-temperature kiln schedule has a nearly constantly declining loss of moisture during the drying cycle. It reaches fiber saturation point in one-half the drying time of sapwood or sinker heartwood. Total drying time to a final average moisture content of 15 percent is about 30 percent less with a conventional schedule and 40 percent less with a high-temperature schedule for normal heartwood than for sapwood and young-growth sinker heartwood.

Sapwood and young-growth sinker heartwood have similar drying times with either conventional or high-temperature schedules. However, a few sapwood and sinker boards have areas above 19 percent moisture content after regular kiln drying time. Sapwood has a higher initial moisture content than sinker boards, but the drying rate to fiber saturation point is greatly accelerated. Sinker heartwood has a constantly declining moisture loss through the drying cycle.

Initial moisture content in old-growth sinker heartwood is greater than in young-growth sinker heartwood but lower than in sapwood. Total drying time to 15 percent average moisture content is longer than for sapwood, normal heartwood and young-growth heartwood. Areas of old-growth sinker heartwood have more than 19 percent moisture content even after regular drying times are extended 25 to 40 percent.

Drying time for the four wood types dried at high temperatures is 50 percent less than with a conventional schedule.

High-temperature drying intensifies internal checking and collapse in sapwood and sinker heartwood. However, these defects do not degrade the lumber in industrial practice, and strength properties are not affected.

Hemlock drying may be optimized by segregation of normal heartwood from sapwood, young-growth sinker heartwood, and old-growth sinker heartwood. However, to prevent overdrying of sapwood and sinker types, a mill must recognize the need to redry or to market the lumber with more than 19 percent moisture content as off-grade or green.

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TABLE 1. Location and site characteristics of selected timber.

Location	Elevation (feet)	Forest type	Stand condition	Age	Aspect
Cascade Range, 6.5 miles southeast of Idanha	3,600	About 90 percent hemlock with noble fir and western red cedar	Even age and clear cut	160[a]	Bench with prevailing east wind. Snow in winter.
Cascade Range, 3 miles northeast of Upper Soda	3,000	About 90 percent hemlock with Douglas-fir, Pacific silver fir, western red cedar	Uneven age, previously thinned, and clear cut	100	Slope with prevailing southwestern wind. Snow in winter.
Coast Range, 2 miles east of Rockaway	700	100 percent hemlock	Even age, previously commercially thinned and clear cut	80	Slope with prevailing western wind.
Coast Range, 3 miles south of Wauna	350	60 percent hemlock with 18 percent red alder, 20 percent Douglas-fir and 2 percent western red cedar	Uneven age and commercially thinned	50	Bench with west and east wind along Columbia River. Some snow in winter

[a]First 60 years of growth very slow. This wood was typical of old-growth sinker heartwood with ring shake.

TABLE 2. Conventional and high-temperature kiln schedules.

Time (hrs)	Dry bulb (°F)	Wet bulb (°F)
CONVENTIONAL SCHEDULE		
24	160	150
12	165	150
24	170	150
12	175	150
12	180	150
36	185	150
HIGH-TEMPERATURE SCHEDULE		
24	225	210
24	230	210
24	230	210
24	230	205

TABLE 3. Moisture content (MC) and specific gravity (SG) for four board types collected from the five cooperating sawmills.

	Young growth						Old growth	
	Sapwood		Normal heartwood		Sinker heartwood		Sinker heartwood	
	MC (%)	SG	MC (%)	SG	MC (%)	SG	MC (%)	SG
			COAST RANGE-ROCKAWAY					
Mean	149.1	.41	75.0	.40	117.1	.41		
High	186.2	.50	120.6	.52	182.8	.50		
Low	103.1	.33	50.1	.35	82.0	.35		
CV*	18	14	22	12	27	9		
			CASCADE RANGE-IDANHA					
Mean	151.0	.41	59.7	.40	120.6	.41		
High	181.4	.46	80.3	.42	146.8	.48		
Low	116.3	.37	34.4	.38	85.4	.38		
CV*	16	8	31	5	17	8		
			COAST RANGE-WAUNA					
Mean	178.1	.39	60.8	.39	124.3	.39		
High	285.8	.53	70.5	.53	159.3	.45		
Low	95.7	.30	50.9	.32	81.6	.32		
CV*	29	16	12	19	21	11		
			CASCADE RANGE-UPPER SODA					
Mean	169.0	.39	77.1	.38	96.5	.42		
High	220.7	.47	156.6	.42	126.0	.47		
Low	97.3	.32	42.3	.33	69.9	.35		
CV*	24	11	44	7	17	6		
Mean							146.1	.42
High							184.6	.46
Low							121.6	.37
CV*							21	6

*CV = coefficient of variation expressed in percent.

TABLE 4. Percentage of each board type losing 0.5 pounds of moisture after the preset time with the conventional and high-temperature schedules.

	Young growth			Old growth
Time (hrs)	Sapwood	Normal heartwood	Sinker heartwood	Sinker heartwood
	CONVENTIONAL SCHEDULE			
120	100	24	100	100
144	64	0	48	89
168	2	0	5	47
	HIGH-TEMPERATURE SCHEDULE			
72	58	0	52	95
84	0	0	7	37

TABLE 5. Mean weight loss in pounds per cubic foot per hour computed at each weighing period for four board types kiln dried with conventional and high-temperature schedules[1]

	Conventional schedule (hrs)							High-temperature schedule (hrs)						
	24	48	72	96	120	144	168	12	24	36	48	60	72	84
NORMAL HEARTWOOD														
Mean	.14	.18	.10[a]	.08[a]	.03	--	--	.23	.16	.10	.06	--	--	--
SD*	.07	.04	.03	.02	.01	--	--	.09	.05	.03	.02	--	--	--
SAPWOOD														
Mean	.28[b]	.34[b]	.37[b]	.36[b]	.17	.05	--	.50	.35	.29	.22	.15	.06	--
SD*	.10	.08	.07	.12	.08	.02	--	.12	.09	.08	.08	.07	.05	--
SINKER HEARTWOOD														
Mean	.25[c]	.25[c]	.23[c]	.19	.12	.07	--	.49	.26	.19	.12	.08	.06	--
SD*	.13	.07	.07	.05	.04	.02	--	.13	.07	.05	.04	.03	.02	--
OLD-GROWTH SINKER HEARTWOOD														
Mean	.30[d]	.33[d]	.28[d]	.25[d]	.15	.10[e]	.10[e]	.62	.30[f]	.26[f]	.16	.12	.07[g]	.05[g]
SD*	.11	.06	.06	.05	.05	.04	.04	.09	.10	.09	.04	.02	.02	.01

[1]Superscript letters by the mean indicate values were not significant at the 10 percent level of probability by analysis of variance.

*SD = standard deviation.

TABLE 6. -- Mean moisture-content loss per hour computed at each weighing period for the four board types kiln dried with conventional and high-temperature schedules[1]

	Conventional schedule (hrs)							High-temperature schedule (hrs)						
	24	48	72	96	120	144	168	12	24	36	48	60	72	84
NORMAL HEARTWOOD														
Mean	.61	.77	.42[a]	.37[a]	.13	--	--	1.02	.69	.45	.25	--	--	--
SD*	.32	.24	.17	.11	.07	--	--	.40	.25	.15	.08	--	--	--
SAPWOOD														
Mean	1.35[b]	1.42[b]	1.51[b]	1.51[b]	.70	.23	--	2.11	1.48	1.24	.94	.62	.20	--
SD*	.63	.36	.35	.58	.15	.10	--	.57	.43	.38	.40	.31	.13	--
SINKER HEARTWOOD														
Mean	1.01[c]	1.02[c]	.93[c]	.76	.49	.25	--	2.01	1.05	.76	.50	.32	.23	--
SD*	.54	.32	.29	.22	.15	.09	--	.7	.31	.23	.16	.12	.07	--
OLD GROWTH SINKER HEARTWOOD														
Mean	1.17[d]	1.30[d]	1.11[d]	.98[d]	.60	.38[e]	.37[e]	2.49	1.22[f]	1.05[f]	.64	.46	.26[g]	.20[g]
SD*	.48	.24	.26	.19	.18	.16	.08	.51	.43	.43	.18	.10	.09	.06

[1]Superscript letters by the mean indicate values were not significant at the 10 percent level of probability by analysis of variance.

*SD = standard deviation.

TABLE 7. Approximate hours of drying time to the average fiber saturation point and to an average 15 percent moisture content for four board types kiln-dried with conventional and high-temperature schedules.

Board type	Fiber saturation point		15% moisture content	
	Conventional	High temperature	Conventional	High temperature
Normal	56	22	94	41
Sapwood	102	51	132	64
Young-growth sinker	104	43	134	67
Old-growth sinker	124	51	168	70

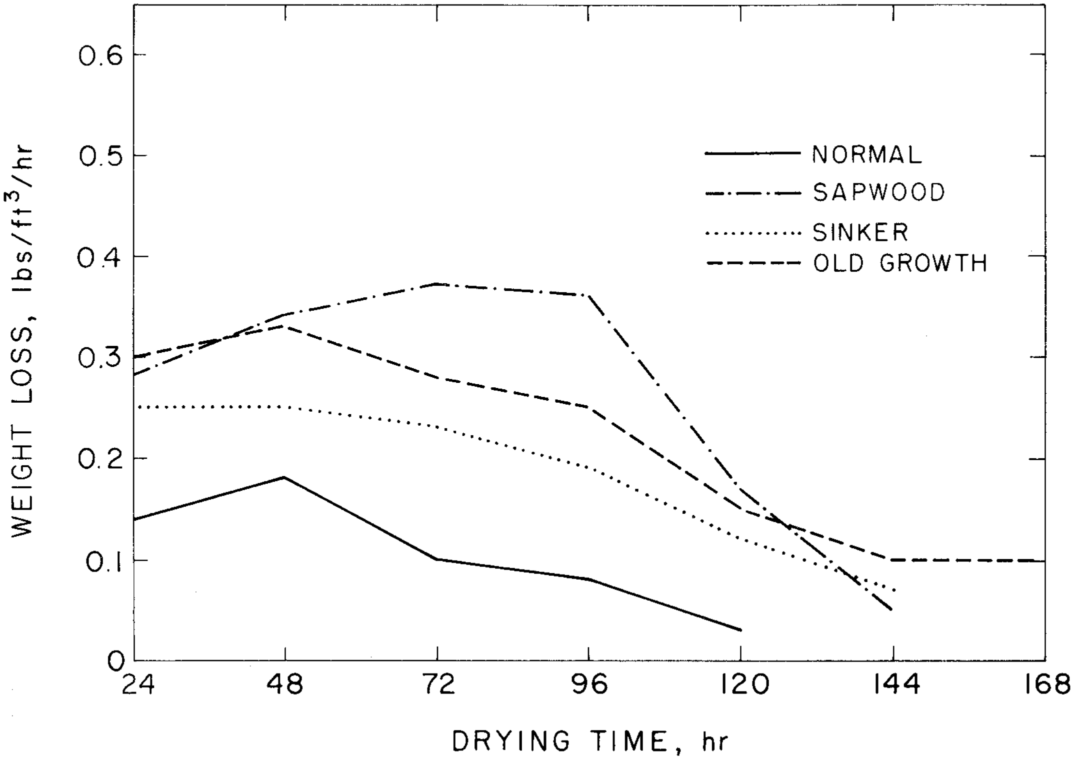

FIGURE 1. Weight loss in pounds per cubic foot per hour for the four board types kiln dried with a conventional schedule.

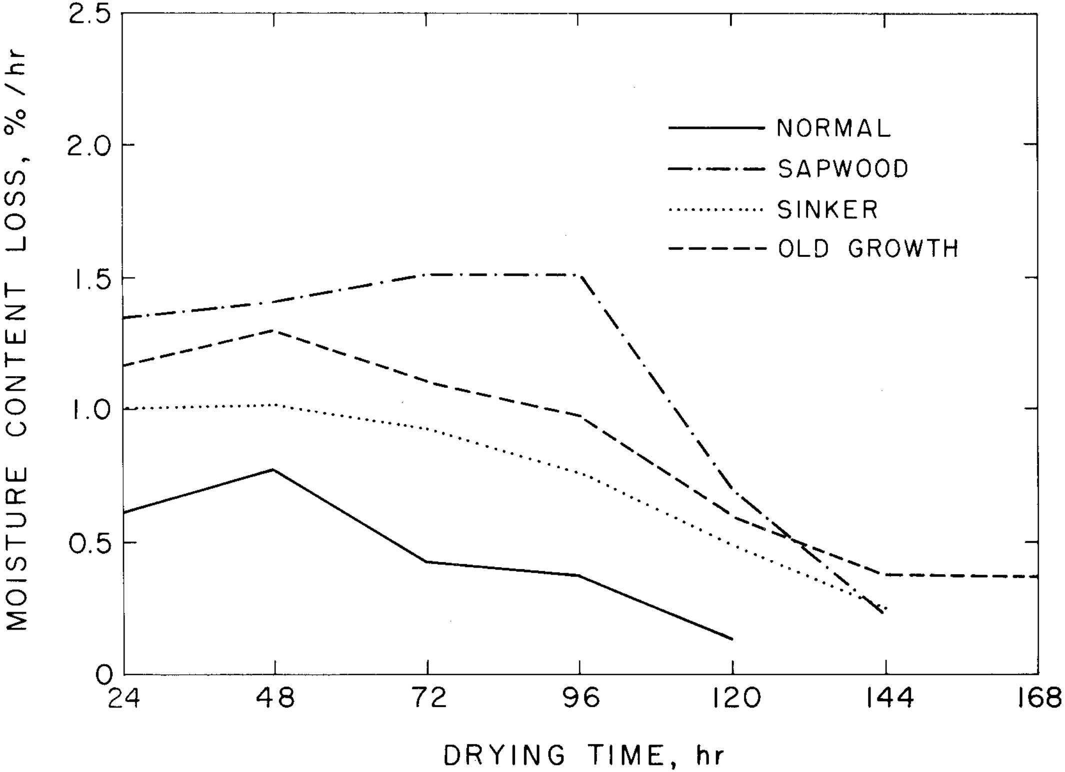

FIGURE 2. Moisture content loss per hour for the four board types kiln dried with a conventional schedule.

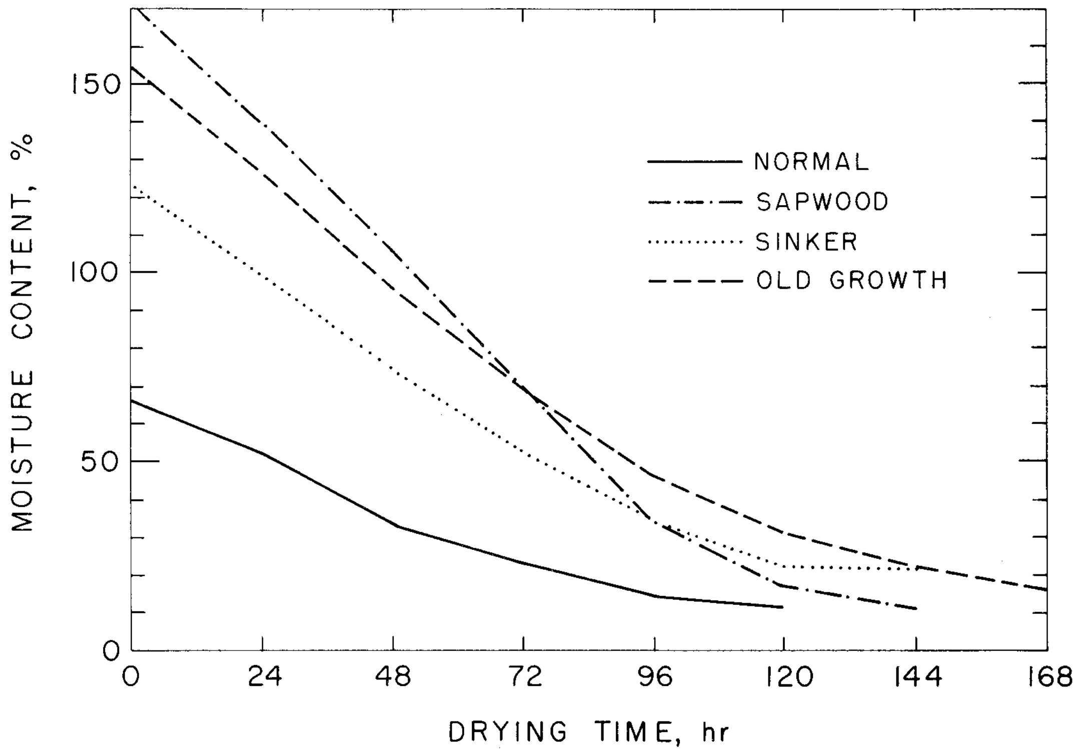

FIGURE 3. Drying rate for the four board types kiln dried with a conventional schedule.

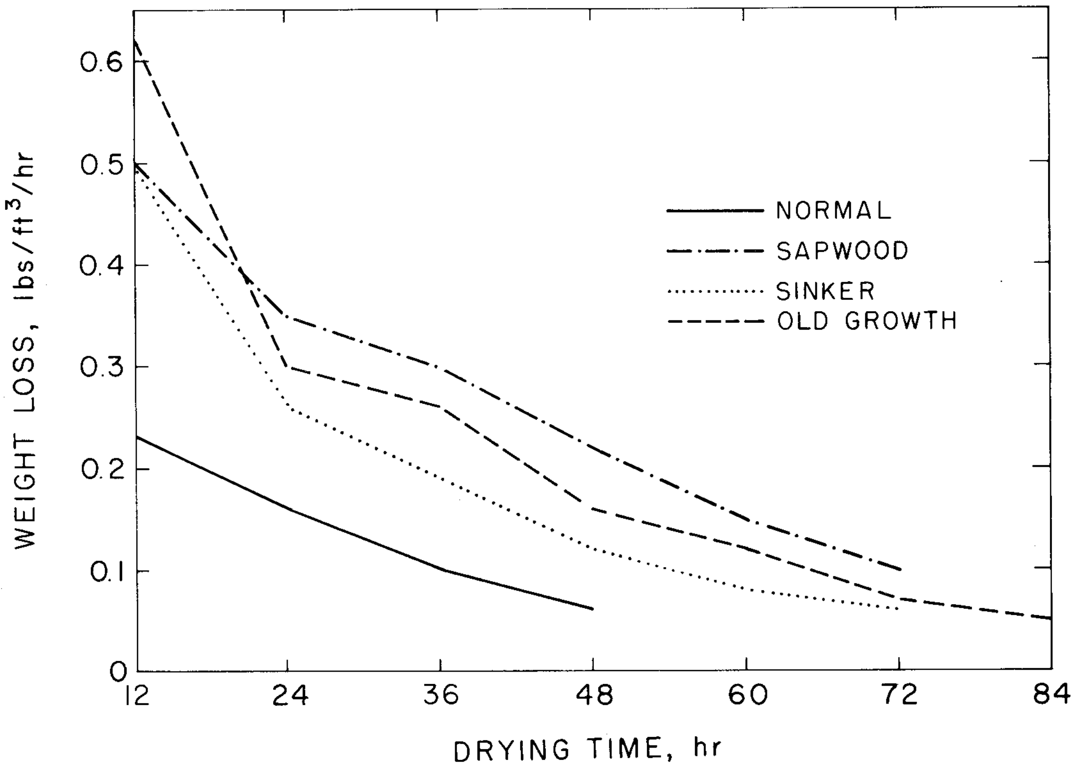

FIGURE 4. Weight loss in pounds per cubic foot per hour for the four board types kiln dried with a high-temperature schedule.

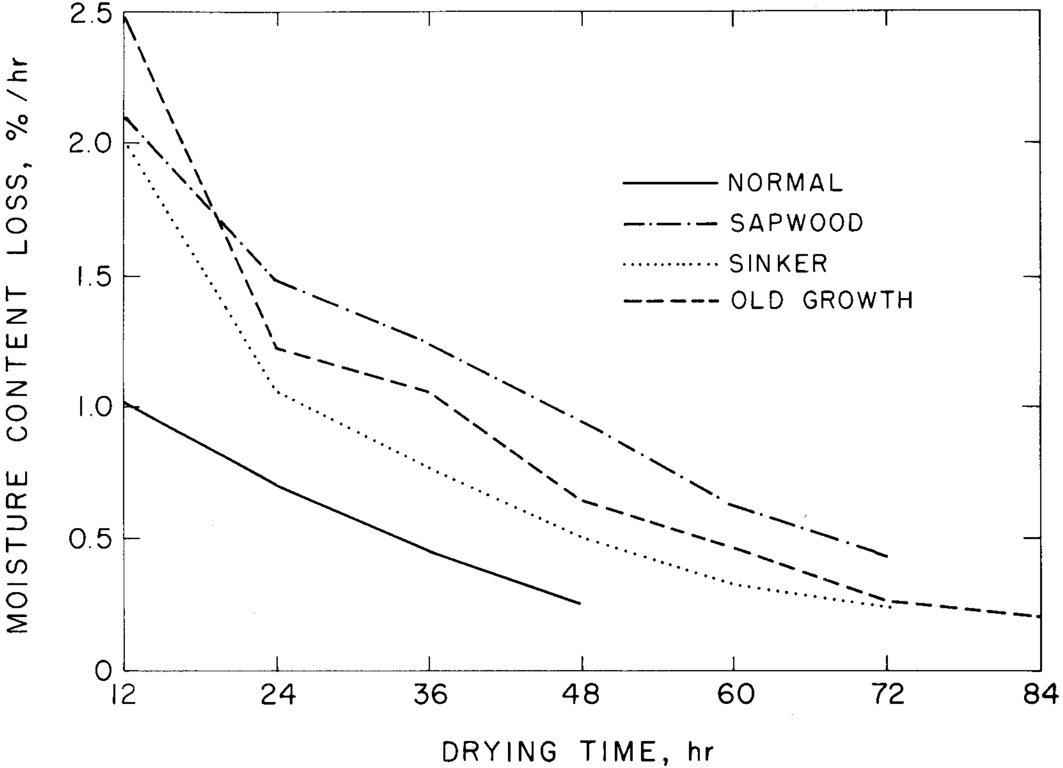

FIGURE 5. Moisture content loss per hour for the four board types kiln dried with a high-temperature schedule.

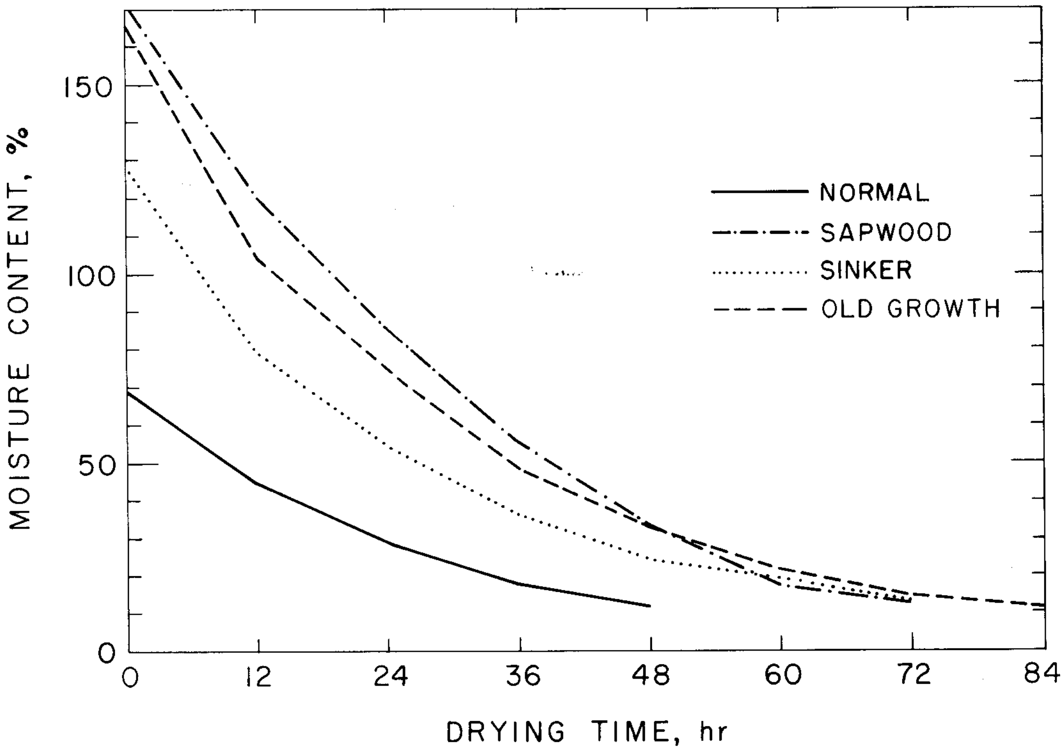

FIGURE 6. Drying rate for the four board types kiln dried with a high-temperature schedule.

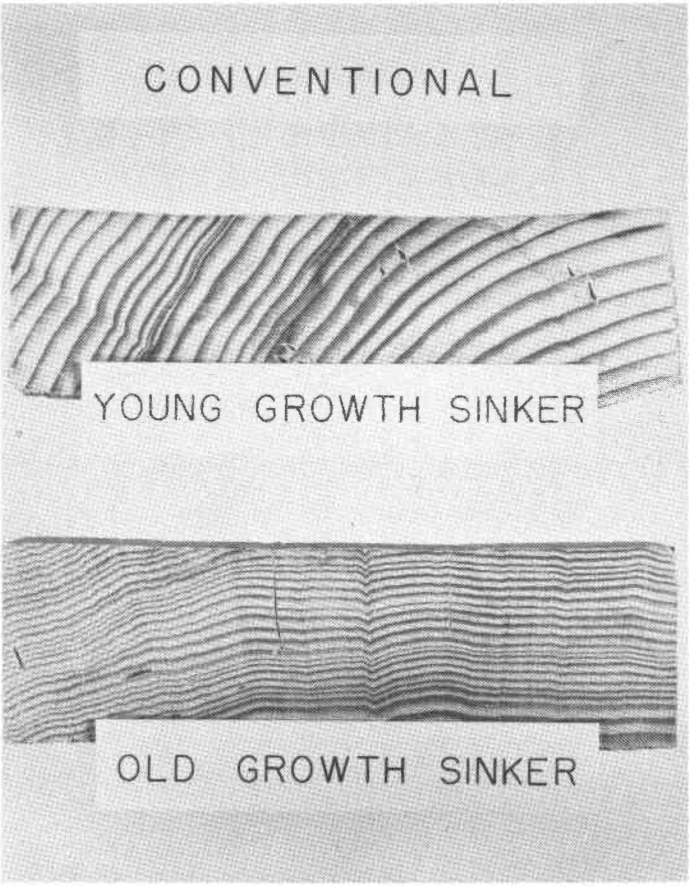

FIGURE 7. Checking in specimens of young- and old-growth sinker heartwood sawn from boards kiln-dried with a conventional schedule.

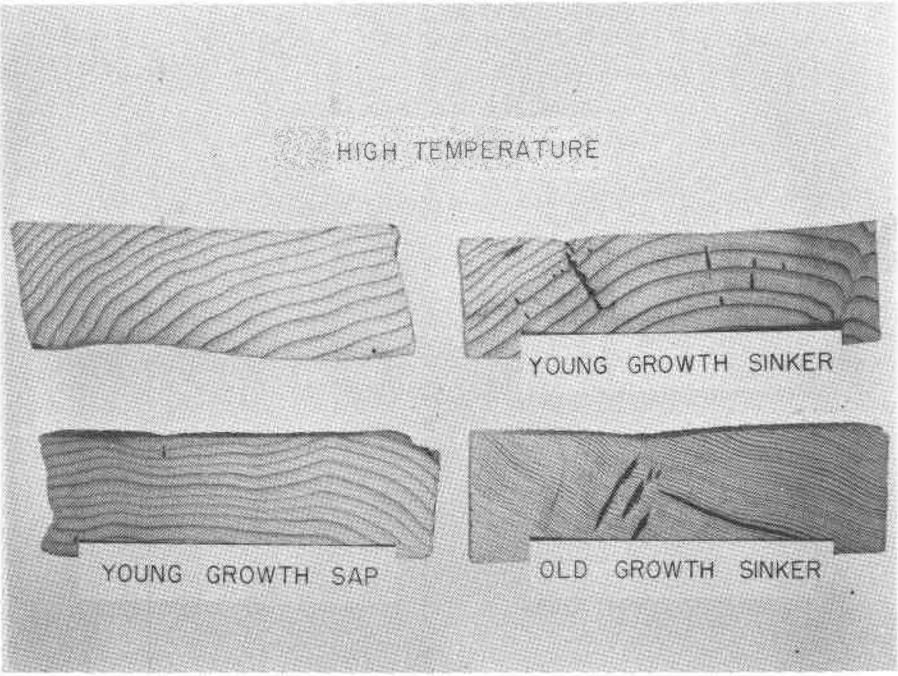

FIGURE 8. Extreme collapse in two young-growth sapwood specimens is shown on the left. Extreme internal checking and collapse in young and old-growth specimens of sinker heartwood is shown on the right.