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Kiln Drying 4/4 American Elm and Sweetgum Lumber With a Combination of Conventional-Temperature and High-Temperature Schedules

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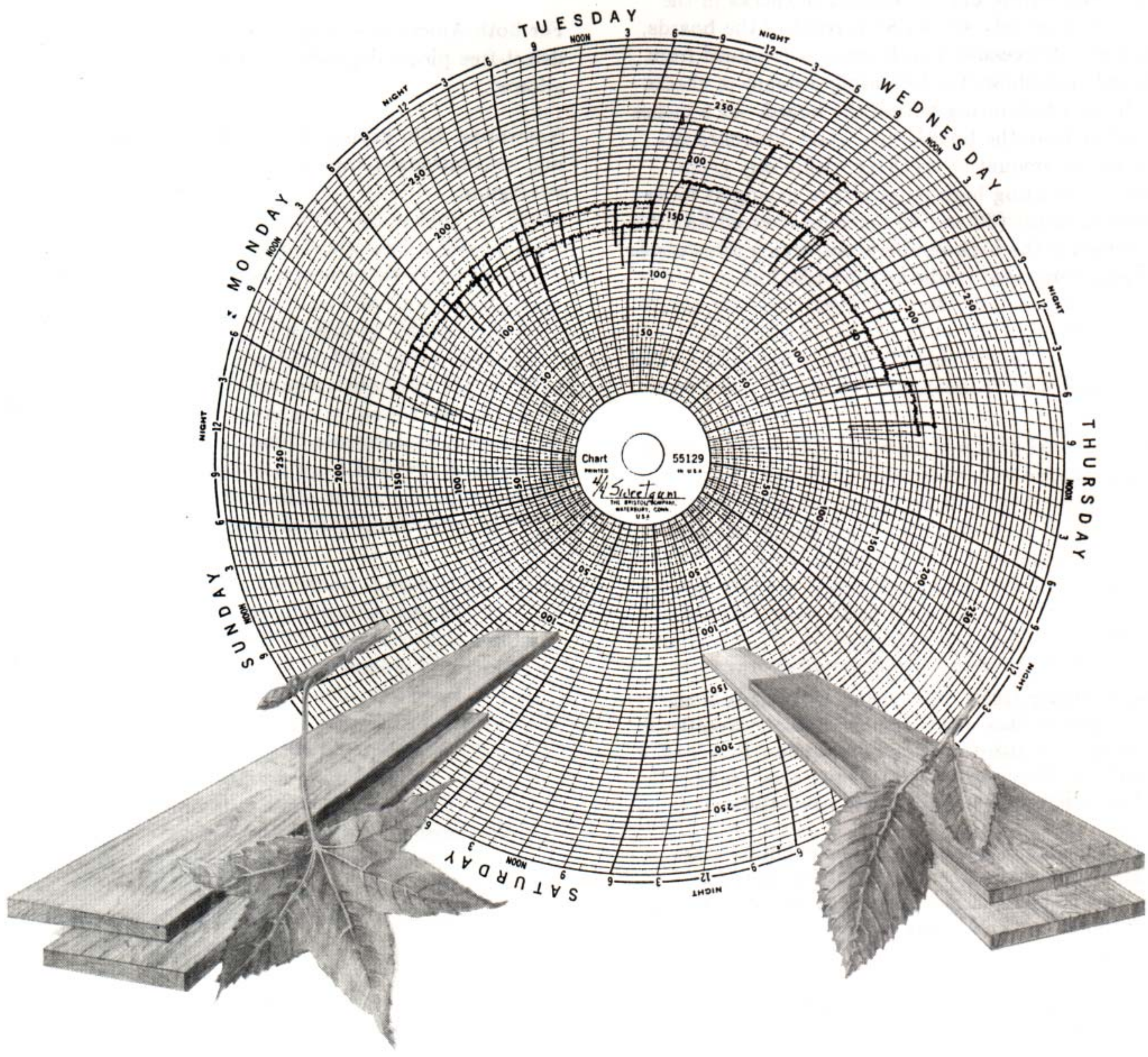

Abstract

American elm and sweetgum lumber were kiln dried by conventional- temperature schedules to average moisture contents of 45, 30, and 20 percent before high-temperature drying at 230°F to final moisture content of 7 percent. Drying degrade was evaluated and compared to that of lumber dried to 7 percent moisture content by straight high-temperature or conventional-temperature drying. The amount and type of warp did not differ between treatments for either species. For elm, 45 percent moisture content at the start of high-temperature drying resulted in checks in the exposed ends and 1 inch from the ends of all boards. However, moisture contents of 30 and 20 percent at start of high-temperature drying resulted in checks in the exposed ends of only 40 and 80 percent of the boards, respectively. Successive 1-inch sections trimmed from the board ends showed a decreasing amount of checks from the end to 5 inches within the board. At 5 inches and farther from the board ends, little difference occurred in the amount of checking within any given treatment. Starting high-temperature drying at lower moisture contents (30 and 20 percent) reduced kiln residence time for the high-temperature drying schedule by 10 percent compared to the control schedule.

For sweetgum, more checks were found on the ends of cross sections cut 1 inch from the exposed ends than on the exposed ends of all treated boards and controls. A much lower percentage of trimmed boards had end checks 3 inches from the exposed ends than 1 inch from the exposed ends. The percentage of trimmed boards with end checks leveled off at ≤10 percent of boards that had a moisture content of ≤45 percent when subjected to high-temperature drying. When boards were subjected to high-temperature drying at 20 percent moisture content, kiln residence time was reduced by about 16 percent, and at 30 and 45 percent moisture contents, kiln time was reduced about 40 percent.

For both American elm and sweetgum, recovery of defect-free pieces depended on the amount of end trim allowed.

Keywords: Kiln drying, lumber, high-temperature drying, conventional-temperature drying, American elm, sweetgum.

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Kiln Drying 4/4 American Elm and Sweetgum Lumber With a Combination of Conventional-Temperature and High-Temperature Schedules

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Introduction

High-temperature drying (HTD) in the range of 230°F to 240°F is attractive to hardwood and softwood lumber processors for the same reason: shorter kiln residence time. Shorter time in the kiln saves energy and provides faster turnover of inventory. Many softwood processors, especially Southern Pine processors, dry all their lumber in high-temperature (230°F to 250°F) kilns with little or no decrease in quality compared to lumber dried by conventional-temperature (maximum 180°F) schedules. However, most hardwoods must be dried more slowly than Southern Pine, using milder schedules and lower temperatures (maximum 180°F).

Research on HTD of 12 hardwood species showed that some low- to medium- density species can be dried green from the saw at 230°F with acceptable results, depending on the end use of the lumber (Boone 1984). For some of these species and others, partial drying by conventional-temperature kiln schedules prior to HTD diminishes the drying degrade but increases the kiln residence time. This combination of initial drying at conventional temperatures and subsequent HTD can reduce kiln residence time by 25 to 60 percent compared to drying exclusively at conventional temperatures (Boone 1986). Thus, the method of combining conventional- and high-temperature schedules is worth serious consideration.

Work by Wengert (1974) and later by Simpson (1982) and Boone (1984) indicated that if the moisture content (MC) is reduced to $\leq$20 percent at temperatures below 180°F, most U.S. hardwoods, even oaks, can be subjected to high temperatures in the later stages of drying without significantly increasing drying degrade. Little is known about the kind and amount of drying defect that occur when HTD is begun at wood MC levels between 20 percent and green from the saw.

A group of studies was started at the Forest Products Laboratory to better understand the responses of three species (red maple, American elm, and sweetgum) to increasing the dry-bulb temperature to 230°F at various levels of MC. These species were chosen based on a comparison of defect-free pieces dried green from the saw and those dried by a combined conventional-temperature/high-temperature schedule in which the temperature was changed to 230°F when the wood reached 20 percent MC (Boone 1984). Each species was dried by conventional-temperature schedules (Table 1) to MC of 45, 30, and 20 percent before changing to HTD to finish drying to 6 to 7 percent MC. For comparison, additional kiln charges were dried entirely by HTD or entirely by a conventional schedule to final MC of 6 to 7 percent. The results of the red maple study have been published (Boone 1986). The study reported here presents the results of the studies on 4/4 American elm and sweetgum lumber.

Materials and Met hods

Table 1—Cokentional-temperature kiln schedules for American elm and sweetgum.

Species and schedule[a]	Moisture content (percent)	Dry bulb (°F)	Wet bulb (°F)
4/4 American elm	>50	120	113
T6-D4	50	120	110
	40	120	105
	35	120	95
	30	130	90
	25	140	90
	20	150	100
	15 to final	180	130
4/4 sweetgum	>70	160	150
(sapmood)	70	160	146
T12-F5	60	160	140
	50	160	125
	40	160	110
	30	170	120
	20	180	130
	15 to final	180	130

[a]Boone and others 1988.

Source and Preparation of Green Lumber

American elm *(Ulmus americana)* lumber was supplied by a Wisconsin furniture manufacturer. Sweetgum *(Liquidambar styraciflua)* logs were obtained from a commercial logging operation in South Carolina. Approximately 1,500 fbm of lumber of each species was used for the study. The logs and lumber were prepared as described in the following sections.

American Elm

The American elm lumber consisted of 1-1/8-in.-thick, random-width, 8-ft-long boards graded No. 2 Common or Better. Boards 4 to 6 in. wide and at least 7 ft long were numbered sequentially for the study. Boards wider than 6 in. were ripped, so that no test lumber was wider than 6 in., and any boards narrower than 4 in. were discarded. All boards were then placed in a pool from which they were randomly assigned to one of the five treatment groups to make up the minimum of 300 fbm per treatment. Material awaiting kiln drying was solid piled, wrapped in a plastic sheet, and stored at 36°F and 82 percent relative humidity. Immediately before stacking in the kiln for drying, each board was end trimmed to 6 ft long, taking approximately equal amounts (12 to 14 in.) from each end. Boards were trimmed to eliminate all visible end checking and splits.

Sweetgum

The 44 sweetgum logs were 8 ft long plus trim allowance; most logs had a scaling diameter of 14 to 16 in., although a 10-in. minimum was permitted. The logs were grade sawn on the circular sawmill at Forest Products Laboratory into 1-1/8-in.-thick random-width boards. All pieces 4 in. wide and 7 ft long and larger were numbered to indicate which log they were cut from and how the pieces were ordered within the log. All pieces graded as less than No. 2 Common were discarded. Unedged pieces were edged and ripped as necessary to produce boards with widths between 4 and 6 in. When two or more usable boards were ripped from one wide board, they were designated as A, B, or C after the board number.

Boards were next systematically sorted into five treatment groups; at least one board from each log went into each group. Where possible, a second board from each log went into each group. The remaining boards were pooled and randomly assigned to each of the five groups to make up the minimum of 300 fbm per treatment. Wrapping, storage, and end trimming immediately before loading in the kiln followed the procedure described for American elm.

Drying of Lumber

We performed all drying treatments in an aluminum, prefabricated, steam-heated dry kiln of 800-fbm capacity. Lumber was stacked on 3/4-in.-thick stickers spaced 18 in. apart, which formed a pile 4 ft wide and 9 to 11 courses high for each load. All loads were top weighted with about 45 lb/ft^2 of iron to minimize warp in the top courses. Air speed through the load averaged 500 ft/min for the conventional-temperature portions of the kiln run and 900 to 1,000 ft/min for the high-temperature portion. Fans were reversed every 6 h. Standard sample board procedure was used to monitor MC, using four sample boards per charge, two on each side of the load. Each of the sorted groups was kiln dried by one of the treatments listed in Table 2.

Evaluation of Drying Defects

Following drying and short-term, solid-piled, heated indoor storage, all boards were surfaced to 25/32-in. thickness on a single-surface planer, removing approximately equal amounts from both sides. We next measured warp (cup, bow, crook, and twist) over the 6-ft length using calibrated wedges and a flat-surfaced platform to measure deflection to the nearest 1/32 in.

In this study, we did not distinguish between end checks and honeycomb. To evaluate the amount and extent of end checking and honeycomb, we

1. counted visible checks on exposed ends of boards,
2. trimmed cross sections from boards at l-in. intervals for the first 12 in. from each end and counted end checks in each section (including checks around knots) (Fig. 1),
3. trimmed additional cross sections at 2-in. intervals for another 12 in. and counted end checks, and
4. cross cut boards at their original center and counted checks.

Table 2—Kiln drying treatments for American elm lumber and sweetgum logs.

	Conventional temperature		High temperature	
Species and treatment no.	Drying schedule[a]	Lumber MC (percent)	Kiln condition (dry bulb/wet bulb, °F)	Lumber MC (percent)
American elm				
1	—		230/180	(Green) to 7
2	T6-D4	(Green) to 45 ± 2	230/180	45 to 7
3	T6-D4	(Green) to 30 ± 2	230/180	30 to 7
4	T6-D4	(Green) to 20 ± 2	230/180	20 to 7
5[b]	T6-D4	(Green) to 7		
Sweetgum				
1	—		230/180	(Green) to 7
2	T12-F5	(Green) to 45 ± 2	230/180	45 to 7
3	T12-F5	(Green) to 30 ± 2	230/180	30 to 7
4	T12-F5	(Green) to 20 ± 2	230/180	20 to 7
5[b]	T12-F5	(Green) to 7		—

[a] Complete kiln schedules are described in Table 1. All kiln charges were equalized to 5 percent equilibrium moisture content (EMC) for the required time and stress-relieved or "conditioned" at 10 percent EMC.
[b] Control.

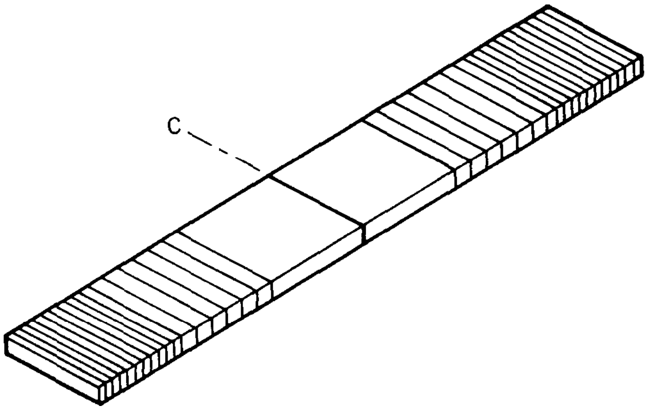

Figure 1 —To count checks, boards were cross cut at I-in. intervals for the first 12 in. from each end and at 2-in. intervals for the next 12 in. Boards were also cross cut at their original center (C). (ML 89 5519)

Results and Discussion

Drying Time

Time required to dry the American elm lumber from green to 7 percent ranged from 41 h for lumber dried entirely at 230°F (treatment 1) to 150 h for the control (treatment 5) (Table 3). The time the lumber was exposed to 230°F dry-bulb temperature ranged from 23 to 0 h. We met our target MC of 6 to 7 percent fairly closely as measured by sample board averages. The combined time for equalizing and conditioning varied from 13 to 20 h for treatments 1 to 4. Adequate stress relief was achieved with 8 h of conditioning for these treatments. The control treatment required no equalizing, but boards were conditioned for 10 h. Total drying time for treatment 4 was shorter than expected. The boards dried to 20 percent MC more quickly than expected, perhaps because their initial average MC was lower than that of boards in the other treatments. Total drying time for treatment 3 was longer than expected. Time to dry to 30 percent MC was somewhat longer than anticipated, and equalizing ran 3 to 4 h longer than equalizing in other treatments of elm.

Less time was required to dry the sweetgum lumber from green to 7 percent MC compared to the elm; drying time ranged from 41 h for lumber dried entirely at 230°F (treatment 1) to 126 h for the control (treatment 5) (Table 3). The time the lumber was exposed to 230°F dry-bulb temperature ranged from 20 to 0 h. In treatments 1 to 3, the average final MC of the sample boards was higher than our target of 6 to 7 percent. This was due in each case to high MC in one sample board containing heartwood. Heartwood of sweetgum dries more slowly than sapwood, and if appreciable amounts of heartwood are present in the stock, combining a high-temperature schedule with the conventional schedule is not advisable. Total equalizing and conditioning times varied little (20 to 25 h) for treatments 1 to 4. The control run required no equalizing, but boards were conditioned for 8 h. Adequate stress relief was achieved in all treatments with 8 h conditioning.

Drying times for the various treatments of sweetgum and elm were about the same as for red maple (Boone 1986), which ranged from 50 h to dry from green to 6 percent MC at 230°F to 150 h to dry the control by the conventional-temperature schedule. Total drying time for the sweetgum control was less than that for the red maple or American elm controls because no equalizing was required for this particular kiln run.

Table 3—Moisture content, processing times, and drying temperatures for kiln-drying 4/4 American elm and sweetgum lumber.

Species and treatment no.	Average MC[a] of green sample boards (percent)	Time at ≤180°F (h)	Average MC when temperature raised to 230°F (percent)	Time at 230°F (h)	Time for equalizing and conditioning[b] (h)	Final average MC of sample boards (percent)	Total drying time (h)
American elm							
1	100		100	23	18	8.4	41
2	113	91	45	19	13	7.0	123
3	111	115	27	12	20	7.5	147
4	89	102	18	8-1/2	14-1/2	6.4	125
5[c]	99	140	—	—	10	7.6	150
Sweetgum							
1	101	—	101	20	21	10.1[d]	41
2	115	36	49[d]	14	25	8.7[d]	75
3	116	43	37[d]	12	21	9.8[d]	76
4	114	78	16	8	20	7.3	106
5[c]	111	118	—	—	8	6.2	126

[a] Moisture content.
[b] Conditioning time averaged 8 h in all treatments except treatment 5 of American elm (10 h).
[c] Control.
[d] High average MC due to high MC in one sample board containing heartwood.

More typically, an equalizing period of several hours would likely be required.

Warp

All four forms of warp (cup, crook, bow, and twist) were measured. Measurable cup was so slight and found in so few boards (all boards were between 4 and 6 in. wide) that the data were not meaningful for either the elm or the sweetgum. The other three forms of warp were measured over the 6 ft length of the boards (Table 4).

Although there were statistical differences (0.05 level) between treatments in American elm for the amount of crook and bow, there were no clear trends. For twist, there was no statistical difference between treatments and no apparent trends. These data support earlier observations that if the lumber is properly stacked, HTD does not increase warp and may even reduce it.

No clear trends were apparent between treatments in sweetgum for the amount of crook, bow, or twist. Analysis of variance showed no statistical difference (0.05 level of significance) between the five treatments. However, it is interesting to note that for crook and bow, the control (treatment 5) showed the most warp, and for twist, the control showed the second highest value.

End Checking and Honeycomb

All boards were freshly end-trimmed and inspected just before stacking on the kiln truck to ensure the absence of end checks. Any end checks or honeycomb detected after drying could then be attributed to the particular drying treatment.

As described earlier, the end checks and honeycomb were counted at specific intervals from both ends of the boards and at the middle of the boards. We counted all visible checks and honeycomb on the end surfaces. This included any surface checks, end checks not extending to the wide surface of the board, so-called bottleneck checks, and true honeycomb. Figures 2 and 3 show some examples of end checking and honeycomb.

Table 4—Warp in kiln-dried American elm and sweetgum boards.[a]

Species and warp type	Treatment number[b]	Sample size	Average warp (1/32 in.)	Standard deviation (1/32 in.)	Maximum warp (1/32 in.)
American elm					
Crook	1	73	8.99	5.02	21
	2	81	7.68	5.35	25
	4	85	6.54	6.24	46
	5	80	8.05	5.31	27
	3	79	6.61	4.81	29
Bow	2	73	4.71	3.58	17
	4	81	3.16	2.75	11
	1	85	3.78	3.24	17
	3	80	3.11	2.63	11
	5	79	5.11	3.52	15
Twist	1	73	2.20	2.35	14
	2	81	2.17	2.69	12
	3	85	2.48	2.36	9
	4	80	2.30	2.55	10
	5	79	2.15	2.50	12
Sweetgum					
Crook	1	107	5.77	4.30	25
	2	103	5.69	3.58	17
	3	102	5.24	3.72	16
	4	103	5.92	4.06	25
	5	115	6.55	4.53	24
Bow	1	107	3.82	2.88	19
	2	103	4.48	2.84	15
	3	102	4.52	3.16	16
	4	103	4.08	2.93	14
	5	115	4.58	3.10	17
Twist	1	107	4.13	4.34	22
	2	103	5.53	5.02	21
	3	102	4.49	4.62	19
	4	103	4.64	4.22	17
	5	115	5.30	6.39	37

[a] Boards were 6 ft long, 4 to 6 in. wide, and surfaced two sides to 25/32 in. thick.
[b] Multiple comparisons (Tukey). Treatments with a common bar are not statistically different at the 0.05 level. Treatment 5 was the control.

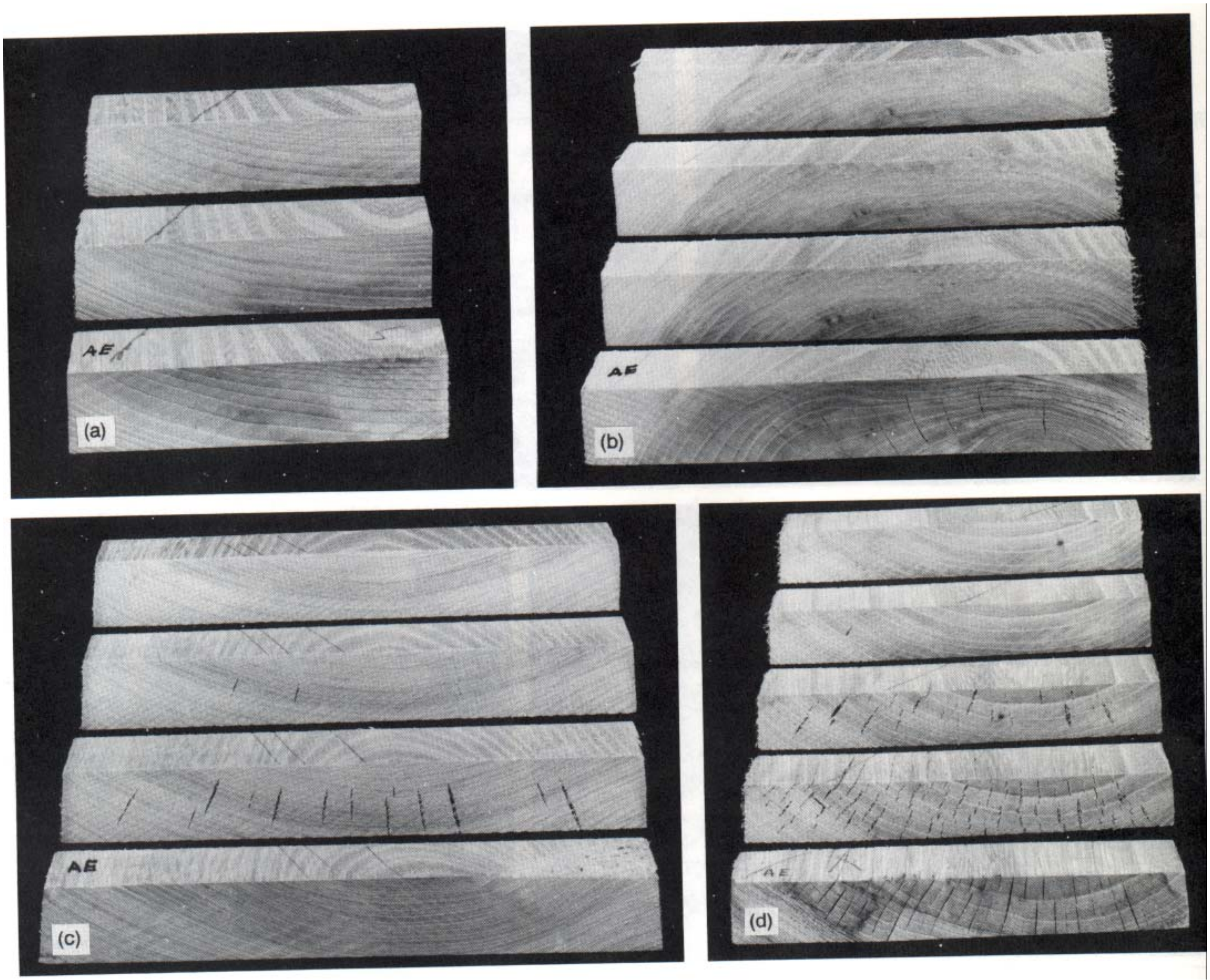

Figure 2 – Checks and honeycomb in exposed ends and at l-in. intervals from ends of American elm boards. (a) No end checks; (b) checks on exposed end only; (c) checks 1 in. and 2 in. from exposed end only; (d) end and surface checks on exposed end. Note that number of checks decreases further into board. (M87 0339, M87 0334, M87 0336, M87 0348)

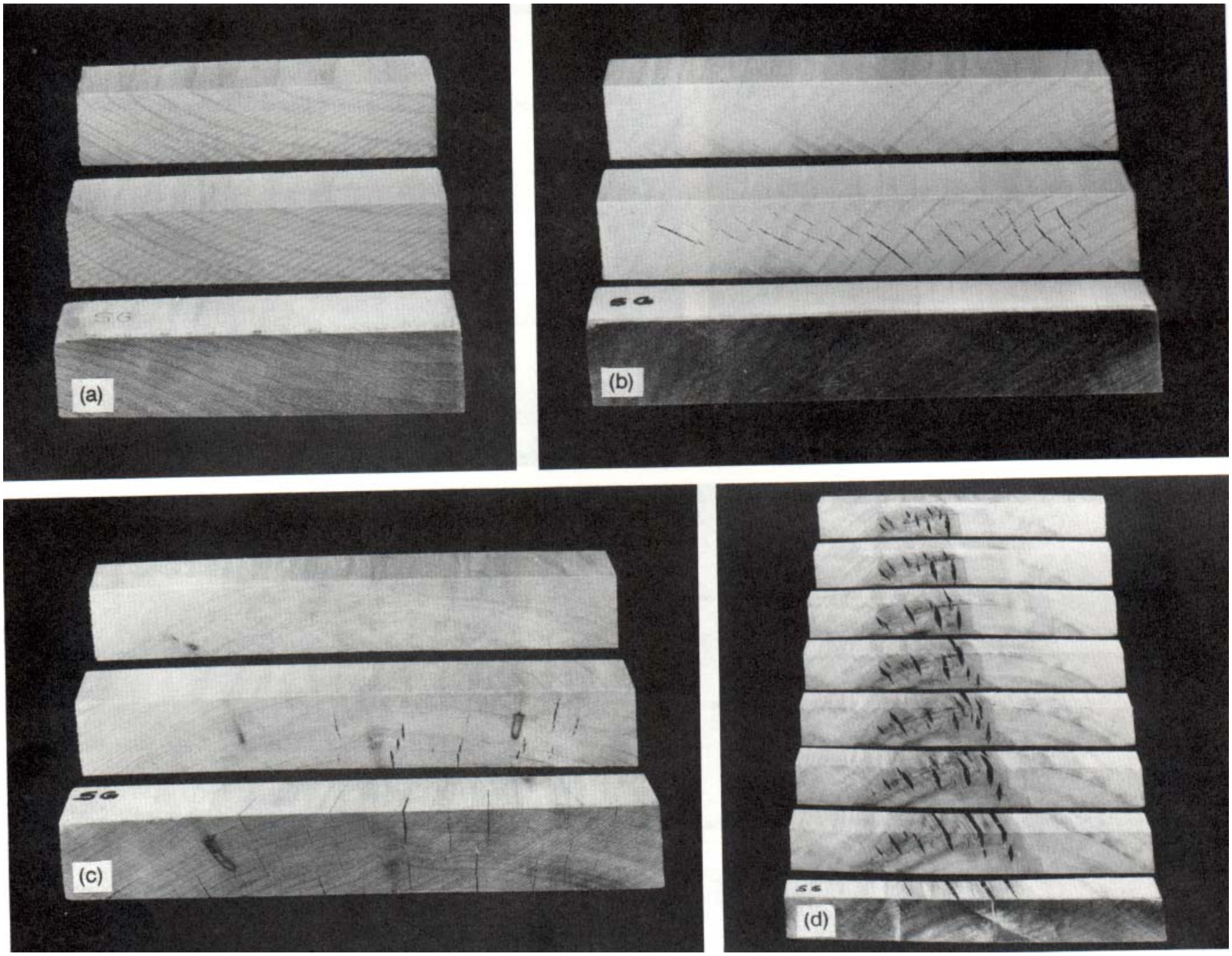

Figure 3 – Checks and honeycomb in exposed ends and at l-in. intervals from ends of sweetgum boards. (a) No end checks; (b) checks 1 in. from end of board only; (c) end and surface checks on exposed end and 1 in. from end; (d) honeycomb associated with heartwood. (M87 0345, M87 0352, M87 0353, M87 0338)

American Elm

End checking data for American elm are shown in Figure 4. The data fell into two groups: (a) boards subjected to HTD at MC ≥45 percent (treatments 1,2) and (b) boards subjected to HTD at MC ≤30 percent (treatments 3 to 5). With treatments 1 and 2, virtually all boards had one or more checks on the exposed ends and also 1 in. from the ends. In treatment 1, almost all the boards had end checks 2 in. from the exposed ends, but far fewer boards had end checks between 2 and 4 in. from the exposed ends; this decline in the percentage of boards with end checks tapered off 6 in. from the exposed ends. In treatment 2, the percentage of boards with end checks dropped sharply beyond 1 in. from the exposed ends; at 4 in. from the ends to the center of the board, only 15 to 20 percent of the boards had end checks. The boards in treatments 4 and 5 also had the maximum number of checks on the exposed ends (between 50 and 80 percent); the percentage of boards with end checks dropped sharply to around 30 percent at 1 in. from the ends and leveled off to ≤15 percent at 3 in. from the ends. About 45 percent of the boards in treatment 3 showed checks on the exposed ends; at 1 in. from the ends, the percentage of boards with checks increased slightly before dropping to ≤10 percent and leveling off between 3 and 4 in. from the end. It should be noted that treatment 5, the control, did not have the lowest percentage of boards with checks on the exposed ends. Moreover, the percentage of control boards with end checks at 1 to 3 in. from the exposed ends was in-between that of boards in treatments 1 and 2 and treatments 3 and 4. Treatments 3 and 4 had the lowest percentage of boards with end checks on the exposed ends and 3 to 4 in. from the exposed ends.

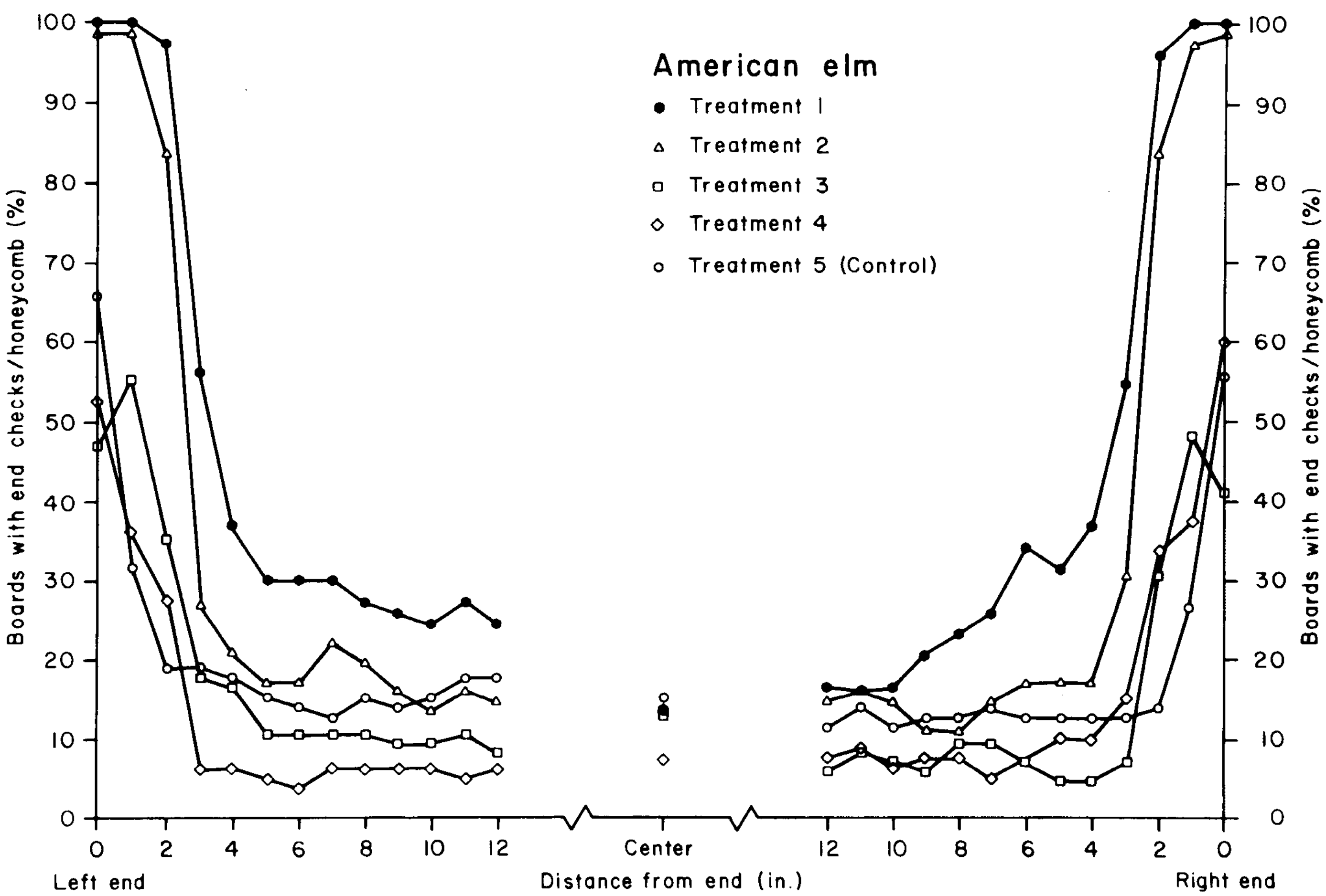

Figure 4 – Percentage of treated and control American elm boards with checks at various distances from ends of board. (ML89 5523)

Sweetgum

The pattern of end checking in the sweetgum boards was similar to that of American elm boards in treatment 3 and of previously described red maple boards in treatments 1 to 3 (Boone 1986). In all treatments of sweetgum boards, a higher percentage of boards had end checks 1 in. from the exposed ends than on the exposed ends themselves (Fig. 5). Unlike the pattern of end checking in elm and maple boards, sweetgum data were not grouped according to MC of wood when subjected to HTD. Seventy to 80 percent of sweetgum boards in treatments 1, 2, 3, and 5 showed checks on the exposed ends. These percentages increased about 15 percent (85 to 95 percent) at 1 in. from the ends, fell sharply between 1 and 2 in. from the ends, and by 3 in. from the ends, had fallen to between 5 and 15 percent and remained at this level. Only 20 percent of treatment 4 boards showed checks on the exposed ends. At 1 in. from the exposed ends, the percentage of boards with end checks rose to 50 percent; at 2 in., the percentage fell to fewer than 10 percent and remained at that level. At $\geq$3 in. from the exposed ends, $\leq$10 percent of boards in treatments 2 to 5 showed end checks. In treatment 1, where boards were dried entirely at high temperature, about 15 percent of the boards had end checks $\geq$3 in. from the exposed ends.

Incidence of end checking and honeycomb between 12 and 24 in. from the ends of the boards followed essentially the same pattern as that between 6 and 12 in. for all treatments of both species (data not shown). Internal checks seen on cross-cut sections taken at the center of the 6-ft boards were generally continuations of previously seen checks or honeycomb in the particular board. The exceptions were when a knot or patch of discoloration occurred near the middle of the board but not near the ends.

Perhaps the major attraction to using HTD or combining HTD with a conventional-temperature kiln schedule is the kiln residence time saved. The questions then be-

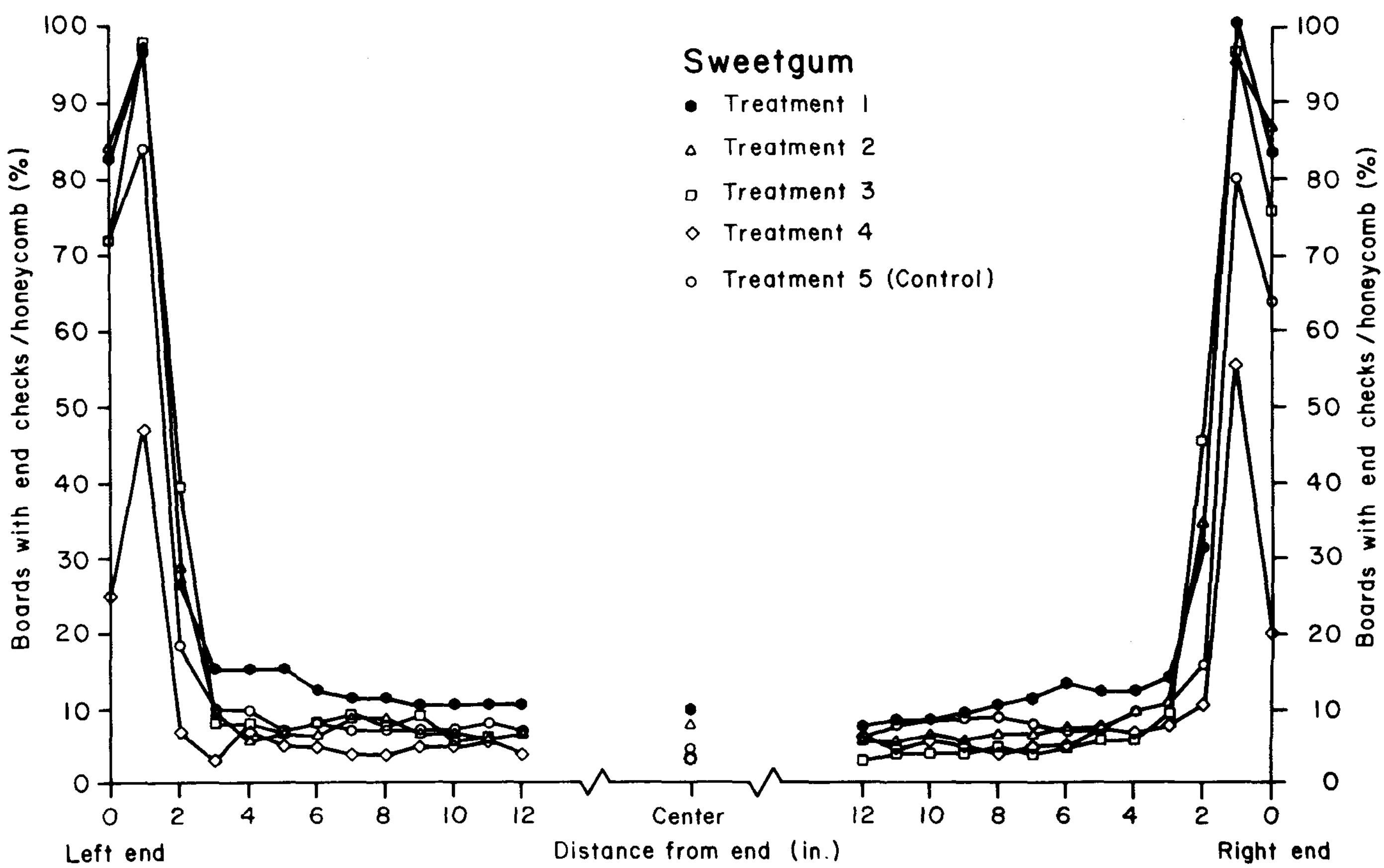

Figure 5 – Percentage of treated and control sweetgum boards with checks at various distances from ends of board. (ML89 5522)

come, Do we sacrifice drying quality to save kiln time? If so, how much? Is the increased amount of drying degrade tolerable for a particular operation? We conducted experiments using the same drying treatments for three different species. Not surprisingly, we found differences in the way the different woods responded to the same drying treatments.

Defects and Drying Time

Knowing the pattern of end check formation and extension from Figures 4 and 5, What pattern emerges when comparing percentages of boards with no drying defects by treatment and species over time in the kiln? Data are shown in Figure 6 for American elm and Figure 7 for sweetgum.

American Elm

No untrimmed boards in treatments 1 and 2 were free of defects (Fig. 6), which is not surprising since a very high percentage of boards in these treatments had checks on the exposed ends. About 15 percent of the boards in treatments 3 to 5 had no drying defects. In the control treatment, only 17 percent of the boards had no drying defects. This differs considerably from the previously reported results with red maple where treatments 1 to 3 produced between 0 and 8 percent defect-free boards; treatment 4, 70 percent; and treatment 5 (control), 77 percent. In the study reported here, kiln residence time of treatments 3 and 4 and the control cannot be easily compared because the drying time for elm in treatment 3 was longer than expected and that in treatment 4 was shorter than expected. The treatments apparently reduced drying time by about 10 percent. As in the red maple study, the data reported here show the percentage of defect-free boards after 2 and 3 in. were trimmed from each end of the boards (Fig. 6). The removal of end trim increased the percentage of defect-free boards, but the grouping between treatments 1 and 2 and treatments 3 to 5 apparently persisted. Even when 3 in. were removed from each end, only 66 percent of the controls were defect free. Boards in treatments 3 and 4 were in the 55 to 60 percent defect range. Because subjecting boards to HTD at 30 or 20 percent MC reduced kiln residence time by only 10 percent and caused a 10 percent loss in defect-free boards, combining HTD with conventional schedules may not be desirable for most operations drying American elm.

Sweetgum

The results of plotting percentage of untrimmed boards with no drying defects over time in the kiln show that the control had only 4 percent defect-free boards (Fig. 7); thus, these results more closely resemble the results with American elm than the previously reported results with red maple. In contrast, the percentage of defect-free boards in treatment 4 was considerably higher for sweetgum (25 percent) than for the other two species. Data for treatments 1 to 3 and 4 to 5 are grouped to some extent, a pattern that persisted for the trimmed sweetgum boards (Fig. 7). For boards trimmed 2 in. from each end, treatment 4 had a higher percentage of defect-free boards (75 percent) than treatment 5 (70 percent), the control. For boards trimmed 3 in. from each end, the percentage of defect-free pieces was essentially the same for treatments 4 and 5 (about 80 percent). Treatment 4 should be considered an alternative schedule since it saved about 16 percent of kiln residence time and gave equal or better results than drying by the conventional-temperature schedule (control) at all trim allowances. Using treatments 2 or 3 saved about 40 percent kiln time compared to treatment 5, but the percentage of defect-free pieces was lowered from 80 to 70 percent.

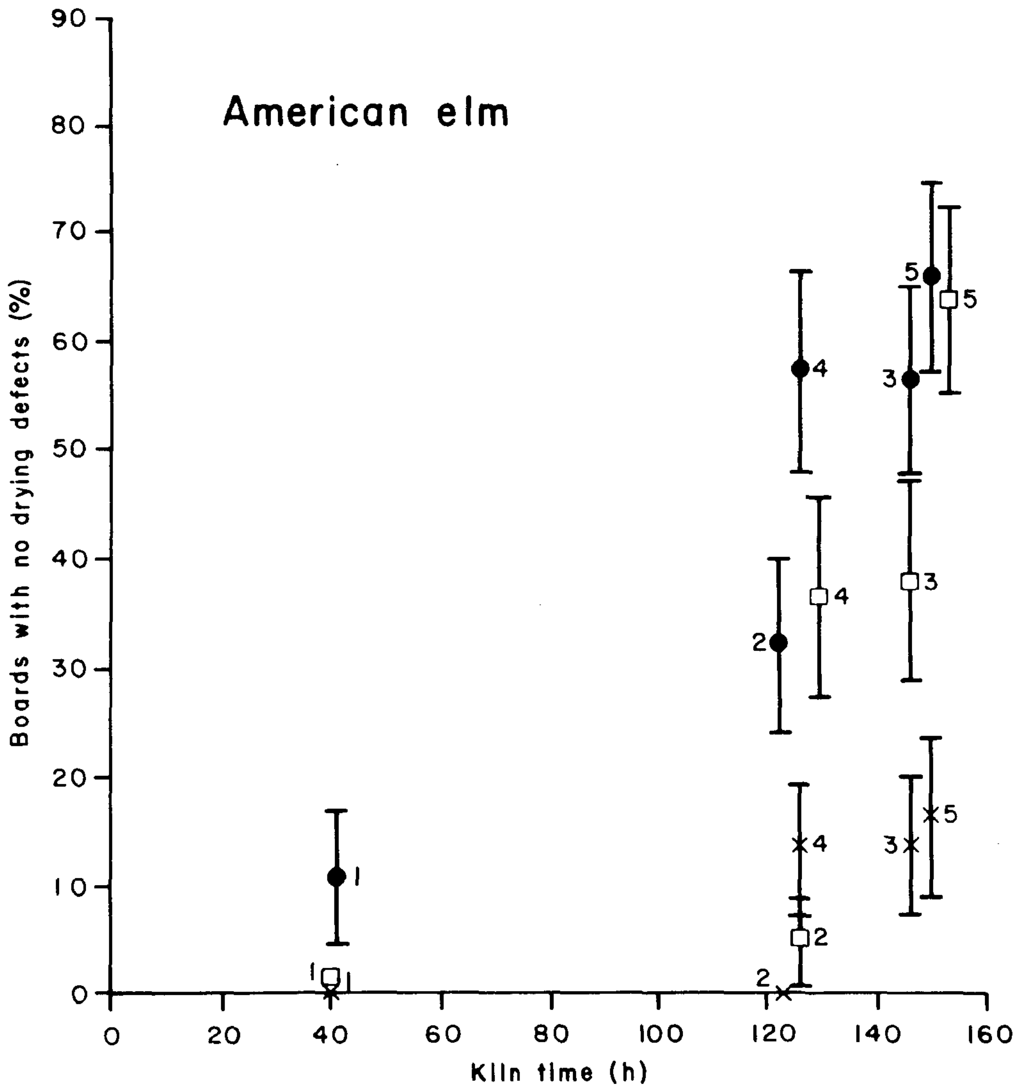

Figure 6 – Percentage of trimmed and untrimmed American elm boards with no defects by treatment. x untrimmed boards; ☐ 2 in. cut from each end of board; • 3 in. cut from each end of board. Numbers designate treatments. Bars indicate standard deviation (±2). (ML89 5521)

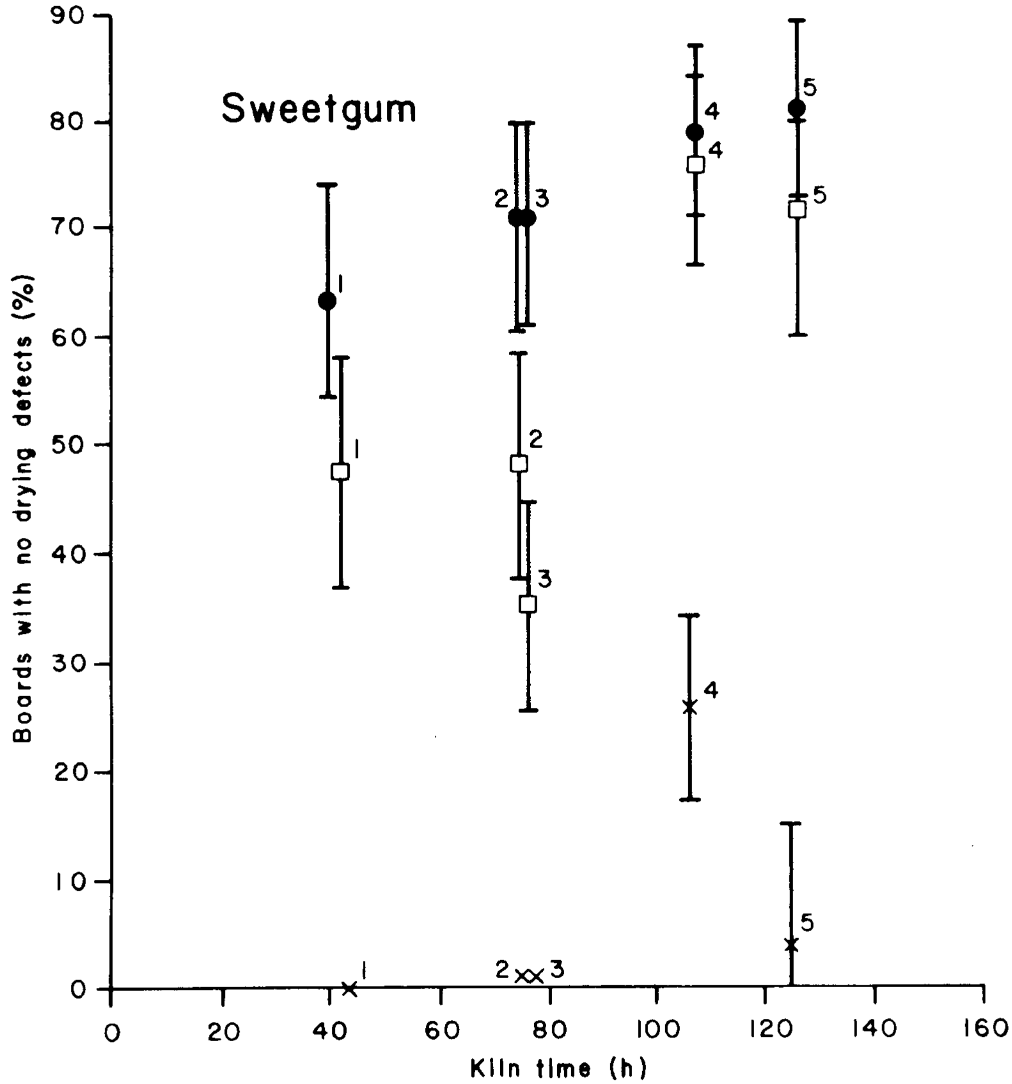

Figure 7 — Percentage of trimmed and untrimmed sweetgum boards with no defects by treatment. x untrimmed boards; ☐ 2 in. cut from each end of board; • 3 in. cut from each end of board. Numbers designate treatments. Bars indicate standard deviation (±2). (ML89 5520)

Concluding Remarks

We found that drying by any kiln schedule generated new end checks in boards. The incidence of checks dropped rapidly with the distance from the ends of the board and became fairly constant at 3 to 5 in. from the ends. End trimming of dried lumber was necessary to reduce the number of end checks, but depending on species, end checks and honeycomb occurred beyond 3 to 5 in. in 5 to 15 percent of control boards dried by a conventional-temperature schedule.

Initial drying at conventional temperatures followed by drying at high temperatures offered savings in kiln residence time that varied with species. The tradeoff of increased drying degrade for savings in kiln time varied by species and by the level of moisture content in the wood when subjected to the high-temperature schedule.

Of the three species dried in our studies to date, red maple (Boone 1986) offers the most promise for combining conventional-temperature and high-temperature schedules. Processors who dry sweetgum sapwood should consider the tradeoff of increased drying degrade for 40-percent reduction in drying time when combining conventional-temperature and high-temperature schedules. Drying of American elm with combined temperature schedules seems least promising.

When American elm lumber was subjected to HTD at MC $\geq$ 45 percent, all boards subsequently had end checks in the exposed ends and 1 in. from the ends. The percentage of boards with end checks dropped sharply between 2 and 4 in. from the ends and leveled off at around 30 percent at about 5 in. from the ends. In drying elm lumber, subjecting boards to HTD at MC levels of 30 and 20 percent saved about 15 percent kiln residence time compared to the control; the percentage of defect-free boards was reduced 5 percent for untrimmed boards and 10 percent for boards trimmed 3 in. from each end. Although statistical differences (0.05) occurred between treatments for the amount of crook and bow, no clear trends were apparent. No statistical difference between treatments and no apparent trend occurred for twist.

In drying sweetgum, more end checks were found 1 in. from the ends than on the exposed ends of the board in all treatments, including the control. In our previous study, we also had found more end checks 1 in. from the ends than on the exposed ends in red maple. The percentage of sweetgum boards with end checks dropped rapidly between 1 and 3 in. from the ends, leveling off at $\leq$10 percent in all treatments where boards were subjected to HTD at $\leq$45 percent MC. For the most severe treatment, in which boards were green from the saw when subjected to HTD, $\leq$15 percent of the boards had end checks beyond 3 in. from the exposed ends. Thus, for this severe treatment, fewer sweetgum boards had end checks beyond 3 and 4 in. than American elm boards. If trimming 3 in. from each end of the board is acceptable, then subjecting boards to HTD when MC is 20 percent can save about 16 percent in kiln residence time at no loss in defect-free pieces; subjecting boards to HTD at 30 or 45 percent MC can save about 40 percent in kiln time at the expense of reducing the number of defect-free pieces by 10 percent. No statistical difference between treatments in the amount of warp was observed in sweetgum.

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