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ACCELERATING THE KILN DRYING OF OAK.(U)
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Accelerating the Kiln Drying of Oak

Abstract

Reducing kiln-drying time for oak lumber can reduce energy requirements as well as reduce lumber inventories. In this work, 1-inch northern red oak and white oak were kiln-dried from green by a combination of individual accelerating techniques—presurfacing, presteaming, accelerated and smooth schedule, and high-temperature drying below 18 percent moisture content. Results were compared with those achieved by conventional kiln drying. Drying time in the combined techniques procedure was reduced by more than 50 percent. The results for quality of the lumber were mixed. In most of the material, the quality was acceptable, but enough honeycomb was present to be of concern.

p-1

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Research
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Accelerating the Kiln Drying of Oak

By
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Introduction

Research in kiln-drying 4/4 oak lumber has shown individual accelerating techniques such as presurfacing and the schedule acceleration it allows, presteaming, schedule smoothing, and high-temperature drying below 18 percent moisture content, can reduce drying time of oak lumber without loss of quality to the lumber. These techniques have been investigated mainly on an individual basis, although Wengert and Baltes *(19)*[2] studied some combinations of individual techniques. The combination of all of these techniques might offer a dramatic reduction in drying time yet maintain acceptable quality lumber. One of the most significant benefits of reduced kiln-drying time is reduced energy requirements. Heat losses from a kiln are directly proportional to drying time; thus a reduction in drying time will cut heat losses. Reduction in lumber inventory is another substantial benefit of reduced drying time.

The concept of surfacing oak lumber before drying dates back to the work of Gaby reported in 1963 *(2)*. Gaby showed that lumber produced by circular sawing has many surface tears and fractures, and that by planing as little as 1/32 inch from the surface the tears could be eliminated. Furthermore, he showed that lumber dried with these surface tears and fractures was more susceptible to surface checking than lumber that was planed to remove the torn surface layer. The implication is that the tears and fractures are concentration points for drying stresses and they open up much more easily than does an undamaged surface. In 1964, Leney *(3)* and in 1966, Rietz and Jensen *(9)* confirmed this reduced tendency of surfaced lumber to check during drying.

The significance of this observation on surfacing lumber before drying is the potential to accelerate kiln-drying oak lumber. Reducing the tendency to surface check should allow the use of more severe (and faster) drying schedules without causing surface checking. McMillen *(4)* explored this potential on northern red oak and developed an accelerated schedule estimated about 30 percent shorter than the previously recommended kiln schedule for 4/4 northern red oak. In 1972, McMillen and Baltes *(5)* reported on further work on northern red oak and on white oak. They confirmed the 30 percent estimate for northern red oak and developed an accelerated schedule for white oak. The white oak schedule reduced drying time by an estimated 22 percent without increasing degrade.

Rice *(10)* tested McMillen's accelerated schedule for northern red oak on a larger scale—6,000 board feet loads. He dried two presurfaced loads and found 9 percent and 23 percent reductions in kiln time compared to that of a rough load and no increase in surface checking. Cuppett and Craft *(1)* compared the kiln-drying time of rough and presurfaced red and white oak in mixed loads, and found a 50 percent reduction in kiln time of the presurfaced loads compared to that of the rough load, again with no increase in defects.

Presteaming is another pretreatment that shows promise for accelerating drying. In 1975, Simpson *(12)* reported steaming wood at 212° F in saturated conditions before drying increased subsequent drying rate of several species. Increases were largest for oak. Beyond the time necessary to heat the wood to the steaming temperature, the increase in

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
[2] Numbers italicized in parentheses refer to Literature Cited at end of report.

Table 1.—Drying schedules for 11 experimental dry kiln runs

Kiln run[1]	Drying curve	Drying schedule	Species
		PRELIMINARY EXPERIMENTS	
1[a]	Figure 3	Conventional	Red Oak
2[a]	Figure 3	Accelerated	Red Oak
3[b]	Figure 4	Conventional	Red Oak
4[b]	Figure 4	Accelerated	Red Oak
		ADDITIONAL EXPERIMENTS	
5[c]	Figure 5	Conventional	Red Oak
6[c]	Figure 5	Accelerated (steaming at 190° F)	Red Oak
7[c]	Figure 5	Accelerated (steaming at 212° F)	Red Oak
8[d]	Figure 6	Conventional	White Oak
9[d]	Figure 6	Accelerated (steaming at 190° F)	White Oak
10[d]	Figure 6	Accelerated (steaming at 212° F)	White Oak
11		Accelerated (steaming at 190° F)	Mixed Red/ White Oak

[1] Superscripts of same letter denote end-matched material.

drying rate was found independent of steaming time. In 1976 Simpson *(13)* reported results of tests on 4/4 oak lumber dried by a conventional schedule. The lumber was steameu at 185° F for 2 hours, then kiln-dried. A 17 percent reduction in drying time was observed. The effect of steaming temperature on the reduction in drying time has not been determined.

Wengert and Evans *(19)* explored the idea of automating dry kiln control. An advantage of their automation scheme is any desired wet- or dry-bulb temperature changes can be made automatically at any moisture content desired. This suggests the possibility for schedule "smoothing"— many small changes in kiln conditions instead of the large step changes in a conventional, manually controlled schedule. The changes can be made small enough to approach a smooth, continuous change over the entire drying schedule. The hypothesis is that relatively large, abrupt changes in equilibrium moisture content conditions in a conventional kiln schedule subject a wood surface to abrupt and steep moisture gradients that tend to aggravate or cause surface checking. If these changes were smaller and more numerous, lumber should be less susceptible to surface checking. Furthermore, if the tendency toward surface checking were reduced, it should be possible to make these smaller changes in kiln conditions a little earlier in the drying schedule and thus effectively accelerate the schedule. Wengert and Baltes *(18)* have compared kiln-drying time of 4/4 northern red oak lumber dried with a conventional, stepwise, manually operated schedule to that dried by a schedule smoothed to continuous changes, and found an 18 percent time savings.

High-temperature (230° F to 240° F) kiln drying is being used successfully in some softwood drying processes, and results in significant time and energy savings. The suitability of high-temperature kiln drying for hardwoods has not been fully tested. The literature does not contain much information on whether or not high-temperature drying can be used without causing excessive degrade in hardwood lumber. The technical feasibility will very likely depend on species and initial moisture content of lumber when high temperature is applied. Success (lack of drying defects) has been noted for several species that have been partially air-dried before high-temperature drying. Wengert *(16)* has reviewed the literature on high-temperature kiln drying of hardwoods and has discussed what little is known about the factors causing success or failure. In addition, Wengert *(17)* conducted some exploratory research on high-temperature drying of hardwoods, and observed that drying defects were negligible in red oak predried to below 20 percent moisture content before application of high temperature.

The objective of this investigation was to determine the technical feasibility of one approach to reduce kiln-drying time of 4/4 oak lumber. In the approach a number of individual accelerating techniques are combined into one drying process. The individual techniques are the following:

1. Presurfacing
2. Presteaming
3. Accelerating kiln schedule
4. Schedule smoothing
5. High-temperature drying below 18 percent moisture content

The specific objectives were:

1. To determine the reduction in kiln-drying time for 4/4 red oak and white oak lumber by applying the combination of the five accelerating techniques and to determine the effect of the presteaming temperature on the reduction in drying time.
2. To compare the amount of surface and internal checks that develops in lumber dried under these accelerated techniques with the amount that develops when lumber is dried by conventional means.

Experimental

The research included a total of 11 kiln runs. After four preliminary runs the results were promising enough to continue with further tests, an additional seven kiln runs. The drying schedules of the 11 experimental kiln runs are given in table 1.

Drying Time

Preliminary experiments—Four kiln runs (1-4) were conducted from two groups of experimental material. Each two paired runs was a comparison of the response of lumber dried by the combination of techniques with that of end-matched lumber dried conventionally. Northern red oak logs 8-1/2 feet long were obtained from southern Wisconsin and sawed into lumber 1-1/8 inches thick. Each 8-1/2-foot board was cut into two equal lengths. One length was to be kiln-dried by the combination of techniques; the other, conventionally. Of the two paired kiln loads, one set contained 25 boards; the other, 51 boards.

The conventional method of drying was by the kiln schedule recommended for 4/4 red oak by Rasmussen

(7), and is shown in table 2. The combination of techniques was as follows:

1. Presurface lumber to 1-1/32 inches thick.
2. Presteam lumber at 190° F—3 to 4 hours to attain 190° F and 2 hours at constant 190° F. This was accomplished in a 1000-board-foot experimental kiln with only the spray line on and an air speed as low as could be obtained, about 100 feet per minute (ft/min).
3. Use of an accelerated and smoothed schedule. The allowable schedule accelerations that McMillen (4) and McMillen and Baltes (5) found acceptable for northern red oak and white oak after presurfacing are given in table 3. Without kiln automation, in which very small changes in conditions can be made very often, the real potential of schedule smoothing cannot be realized. However, the same philosophy can be applied manually to make some smaller schedule changes earlier and accomplish some of the benefits of smoothing. Figure 1 shows the accelerated schedule for northern red oak listed in table 3. The change points in the schedule are connected by straight lines in a manner that results in more severe drying conditions (higher temperature-lower EMC) at any given moisture content point in the schedule. Condition changes at every 5 percent moisture content were taken from these straight lines to construct the kiln schedules for this work (table 4). Air speed was 600 ft/min.
4. Drying at 230° F, no wet-bulb control, below 18 percent moisture content.

Additional experiments—Additional kiln runs (5-10) were almost the same as the preliminary runs except they included white oak as well as red oak, and each 8-1/2-foot board was cut into three 30-inch sections to allow three matched comparisons: The combined techniques with steaming at 212° F, the combined techniques with steaming at 190° F, and conventionally dried material. The relevant kiln schedules are shown in tables 2 through 4 and figures 1 and 2. Steaming at 212° F was in a separate steam chamber because the kiln could not attain steaming temperatures above 190° F.

Enough excess material from the logs provided about 300 board feet of red oak and an equal amount of white oak to dry as full-length lumber by the accelerated techniques. It was dried as mixed red and white oak by the smoothed, accelerated red oak schedule (kiln run 11) (table 4). No conventionally dried control group was included.

Table 2.—Kiln schedules recommended by Rasmussen for 4/4 northern red oak and white oak

Moisture content	Dry-bulb temperature	Wet-bulb temperature
Pct	°F	°F
NORTHERN RED OAK (T4-D2)		
50+	110	106
50	110	105
40	110	102
35	110	96
30	120	90
25	130	80
20	140	90
15	180	130
WHITE OAK (T4-C2)		
40+	110	106
40	110	105
35	110	102
30	120	106
25	130	100
20	140	90
15	180	130

[1] Agric. Handb. 188 (7).

Table 3.—Accelerated schedules for northern red oak and white oak

Moisture content	Dry-bulb temperature	Wet-bulb temperature	EMC[1]
Pct	°F	°F	Pct
NORTHERN RED OAK			
55+	115	111	17.5
55	115	110	16.2
45	120	112	13.4
38	130	116	10.0
30	130	94	4.6
24	140	90	2.6
18	180	130	3.3
WHITE OAK			
42+	115	111	17.5
42	115	110	16.2
37	120	112	13.4
30	130	116	10.0
26	130	94	4.6
21	140	90	2.6
16	180	130	3.3

[1] EMC, equilibrium moisture content.

Results

Drying Time

Preliminary experiments—Drying time curves for the two sets of comparisons are shown in figures 3 and 4. In one comparison (runs 1, 2), the red oak dried conventionally from 87.5 percent moisture content to 7 percent in 24.5 days, whereas the matched material dried by accelerated techniques required only 11 days to dry from 96 to 7 percent moisture content—a 55.1 percent reduction in time (fig. 3). In the other comparison

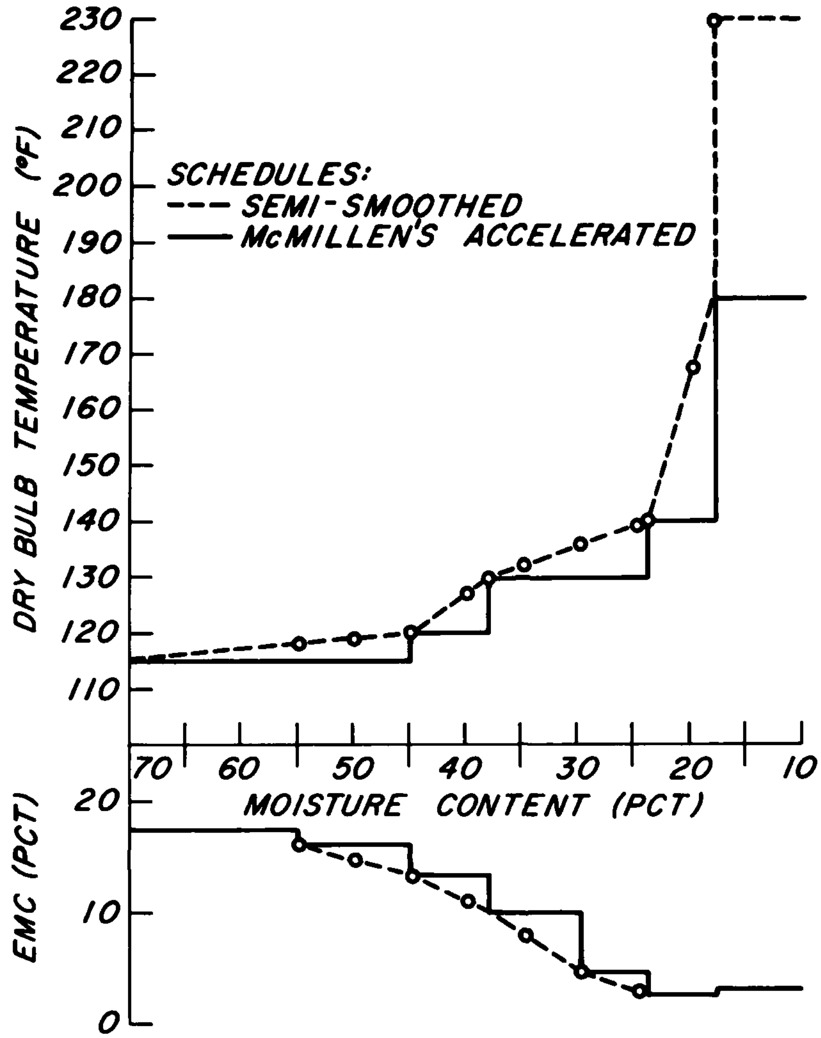

Figure 1.—Construction of smoothed-accelerated schedule for northern red oak.

M148 923

(runs 3, 4), conventional drying required 27.5 days from 89.5 to 7 percent moisture content, and the accelerated drying techniques required 12 days from 88 to 7 percent moisture content—a 56.4 percent reduction in time (fig. 4).

Additional experiments—Drying time comparisons for red oak (kiln runs 5-7) are shown in figure 5. Conventional drying required 31 days from 80.5 to 10 percent moisture content. Accelerated drying with steaming at 212° F required 8.8 days, from 81.5 to 10 percent moisture content; with steaming at 190° F, 8.1 days were required to dry from 80.5 to 10 percent moisture content. These time reductions approach 70 percent.

The results for white oak (kiln runs 8-10) are shown in figure 6. Conventional drying required 22 days from 68 to 9 percent moisture content. Accelerated drying with steaming at 212° F required 9.7 days from 69 to 7 percent moisture content, and when steaming was at 190° F, 10 days were required to dry from 68 to 6 percent moisture content. These are time reductions of about 55 percent.

Figures 5 and 6 show no practical difference in drying time in the accelerated techniques between steaming at 190° F and 212° F.

The lumber in full 8-1/2-foot lengths dried from 90.9 to 6 percent moisture content in 12 days.

Quality of Dried Material

The reductions in drying time are obviously highly significant and will lead to reduced drying costs if quality of dried lumber is maintained.

Preliminary experiments—In one comparison (kiln runs 1, 2), amount of honeycomb was evaluated. Each board was crosscut into three pieces, and honeycomb observed at each half of each fresh cut. Of 51 boards in the conventionally dried control, only one board contained honeycomb, and there were only two individual honeycomb checks. Of the 51 boards dried by accelerated techniques, seven contained honeycomb, and there were 37 individual honeycomb checks.

In the other preliminary comparison (kiln runs 3, 4), the number and total length of both surface and honeycomb checks were compared. No honeycomb was found in either the control or the accelerated group. Of the 25 boards in the control group, 13 had surface checks after drying, and the total length of the surface checks was 98.5 inches. Of the 25 boards in the accelerated group, 7 had surface checks, and the total length of the surface checks was 70 inches.

Additional experimental—The honeycomb and the surface checking comparisons of the 25 boards in each group of the red (kiln runs 5-7) and the white oak (kiln runs 8-10) lumber are given in table 5 (three crosscuts as before).

The boards dried full-length (kiln run 11) and with no conventionally dried control were end trimmed to exactly 8 feet, and cut into two 4-foot pieces to expose honeycomb on internal surfaces (fig. 7). The number of honeycomb checks on what were the ends and centers of the 8-foot boards was recorded; the results are tabulated as follows:

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Accelerating the kiln drying of oak, by William T. Simpson, Madison, Wis., For. Prod. Lab., 1980. 9p. (USDA For. Serv. Res. Pap. FPL-378).

Results and subsequent advantages are given of kiln-drying northern red oak and white oak from green condition by a combination of individual accelerating techniques. The techniques include presurfacing, presteaming, accelerated and smoothed schedule, and high-temperature drying below 18 percent moisture content.

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Number of honeycomb checks	Percent of exposed ends—	
	(End of 8-ft board)	(Center of 8-ft board)
0	72.1	85.5
1	12.9	7.8
2	4.9	4.4
3	1.5	1.0
4	3.0	0
5 or more	5.6	1.0

Discussion of Results

Based on the results of this work, the accelerated schedule can dry oak from green to 6 percent moisture content in a range of 9 to 12 days. This is about one-half the time normally required by conventional schedules. Heat losses would therefore be reduced by about one-half; because heat losses account for 20 to 33 percent of the energy consumed in kiln drying *(11)*, a net reduction of approximately 10 to 15 percent (minus steaming requirements) may be realized by utilizing the accelerated schedules.

The results of comparisons for quality are not as clearly defined as those for drying time. Some comparisons for quality showed no apparent significant detrimental effect resulted from the accelerated drying; other comparisons did show a detrimental effect. Some oak apparently will tolerate this type of rapid drying and maintain good quality, and some oak will not tolerate it without developing surface and interval checks.

Although the results of this research indicate the percentage of boards with drying defects may not be too large, the uncertainty of the quality and the high value of oak lumber warrant caution in applying these accelerated schedules.

In 1970 Rietz *(8)* also observed that 4/4 oak could be dried rapidly with a minimum of degrade. In kiln-drying from green to 7 percent moisture content in 12-1/2 days, he noted only minimal surface checking and honeycomb. Conversely, those in touch with industrial drying of oak are aware that honey comb is sometimes observed even after kiln drying by relatively mild conventional schedules.

Why does this contradictory behavior occur? Is it considered just "natural variability" of a material of biological origin or will it be possible to define causes of some of this variability and thus reduce it? This research does not answer these questions; it does show that substantial reductions in the drying time of 4/4 oak lumber may be nearer to realization than has been thought and can provide added impetus to define the wood characteristics that separate unacceptable from acceptable quality.

Ward *(14, 15)* and McMillen, Ward, and Chern *(6)* are making significant progress with this natural variability approach to oak drying. Their research is finding a correlation between an infection of certain bacteria in the living tree and the occurrence of honeycomb and ring failure during drying. If this infected oak lumber can be identified and segregated by a method that is practical on a production basis some of the "natural variability" will be reduced, and each segregation can be dried according to the limits of its tolerance.

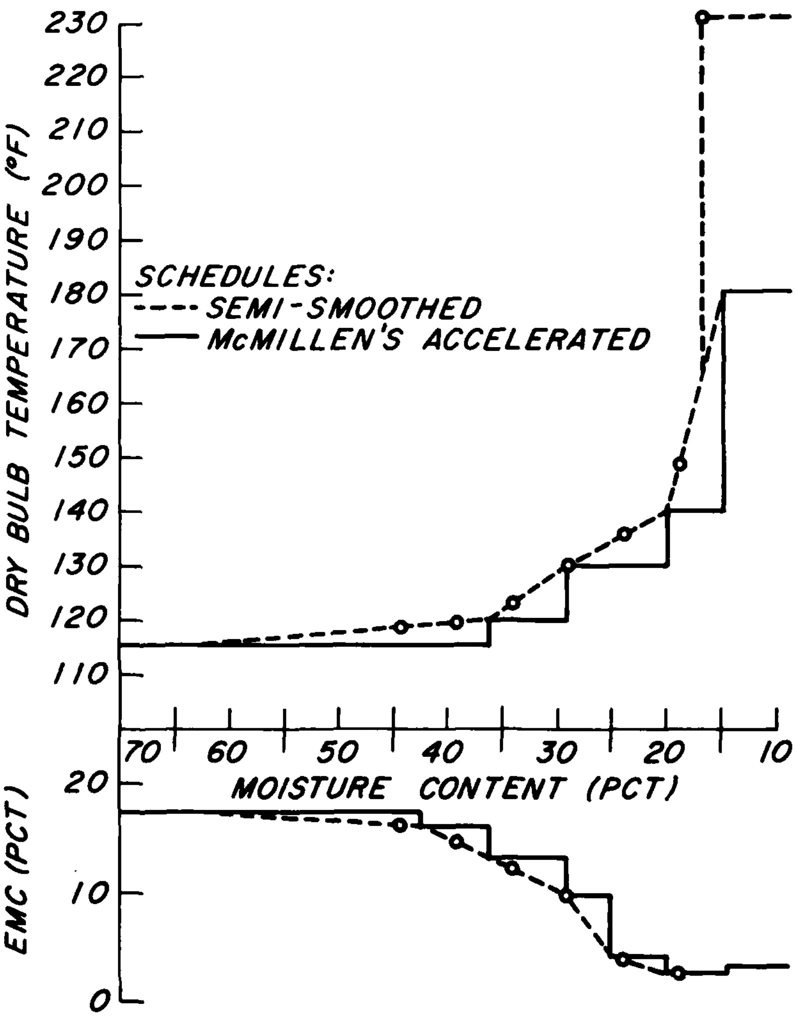

Figure 2.—Construction of smoothed-accelerated schedule for white oak.

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Table 4.—Smoothed, accelerated schedules for northern red oak and white oak

Moisture content	Dry-bulb temperature	Wet-bulb temperature	EMC[1]
Pct	°F	°F	Pct
	NORTHERN RED OAK		
55+	115	111	17.5
55	117	112	16.2
50	119	113	15.1
45	120	112	13.4
40	127	115	11.0
35	132	112	8.0
30	136	98	4.3
25	139	89	2.6
20	166	116	3.2
18	230	—	—
	WHITE OAK		
45+	115	111	17.5
45	118	113	16.2
40	120	114	15.1
35	123	114	12.7
30	130	116	10.0
25	136	96	4.0
20	148	98	2.9
18	230	—	—

[1] EMC, equilibrium moisture content.

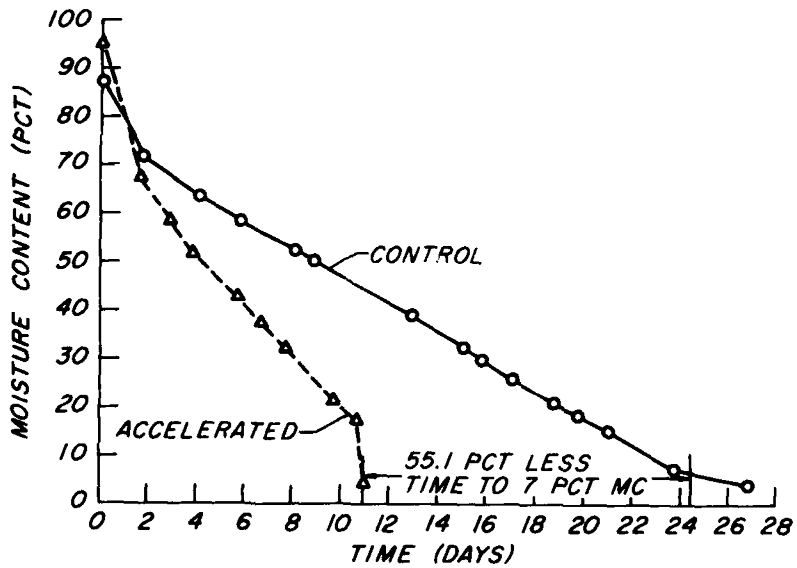

Figure 3.—Comparison of drying time of 4/4 northern red oak dried by conventional schedule and by accelerated techniques (presurfaced, presteamed, accelerated- smoothed schedule, high-temperature dried below 18 percent MC).

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Summary

Several observations are apparent from the results of this research. Drying of some 4/4 oak lumber can be accelerated to a point at which it can be kiln-dried from green to 7 percent moisture content in approximately 9 to 12 days; this represents an approximate 50 percent reduction in kiln time compared with that for conventional kiln schedules. Equally apparent is the fact that some 4/4 oak lumber will not tolerate the rapid drying without excessive surface checking and honeycomb. This typifies the perverse nature of oak drying characteristics, and leads to the conclusion there must be some basic properties or conditions inherent in the lumber that must account for this wide variation in tolerance to rapid drying. Future work in identifying these particular properties or conditions might well prove fruitful and allow for acceleration of schedules.

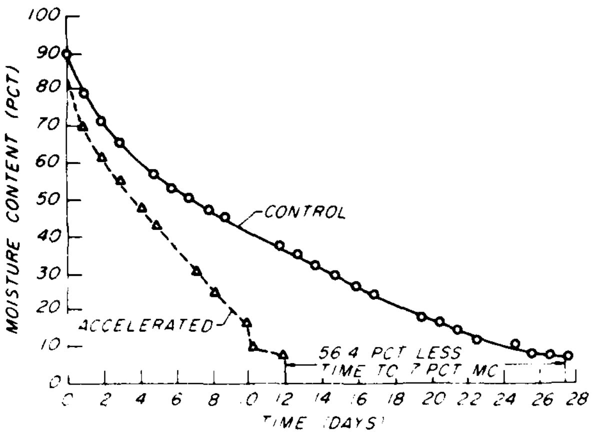

Figure 4.—Comparison of drying time of 4/4 northern red oak dried by conventional schedule and by accelerated techniques (presurfaced, presteamed, accelerated-smoothed schedule, high-temperature dried below 18 percent MC).

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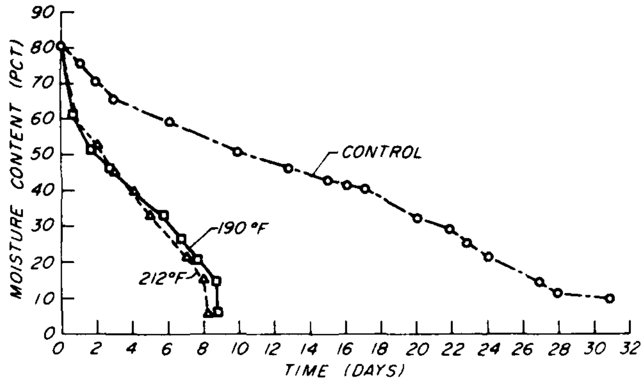

Figure 5.—Comparison of drying time of 4/4 northern red oak dried by conven tional schedule and by accelerated techniques (presurfaced, presteamed at either 212° or 190° F, accelerated-smooth schedule, high temperatures below 18 percent MC).

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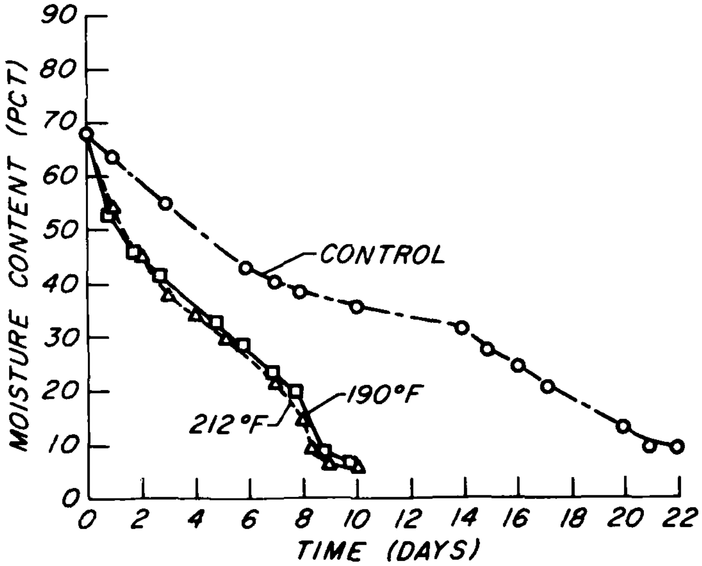

Figure 6.—Comparison of drying time of 4/4 white oak dried by conventional schedule and by accelerated techniques (presurfaced, presteamed at either 212° or 190° F, accelerated-smooth schedule, high temperature dried below 18 percent MC).

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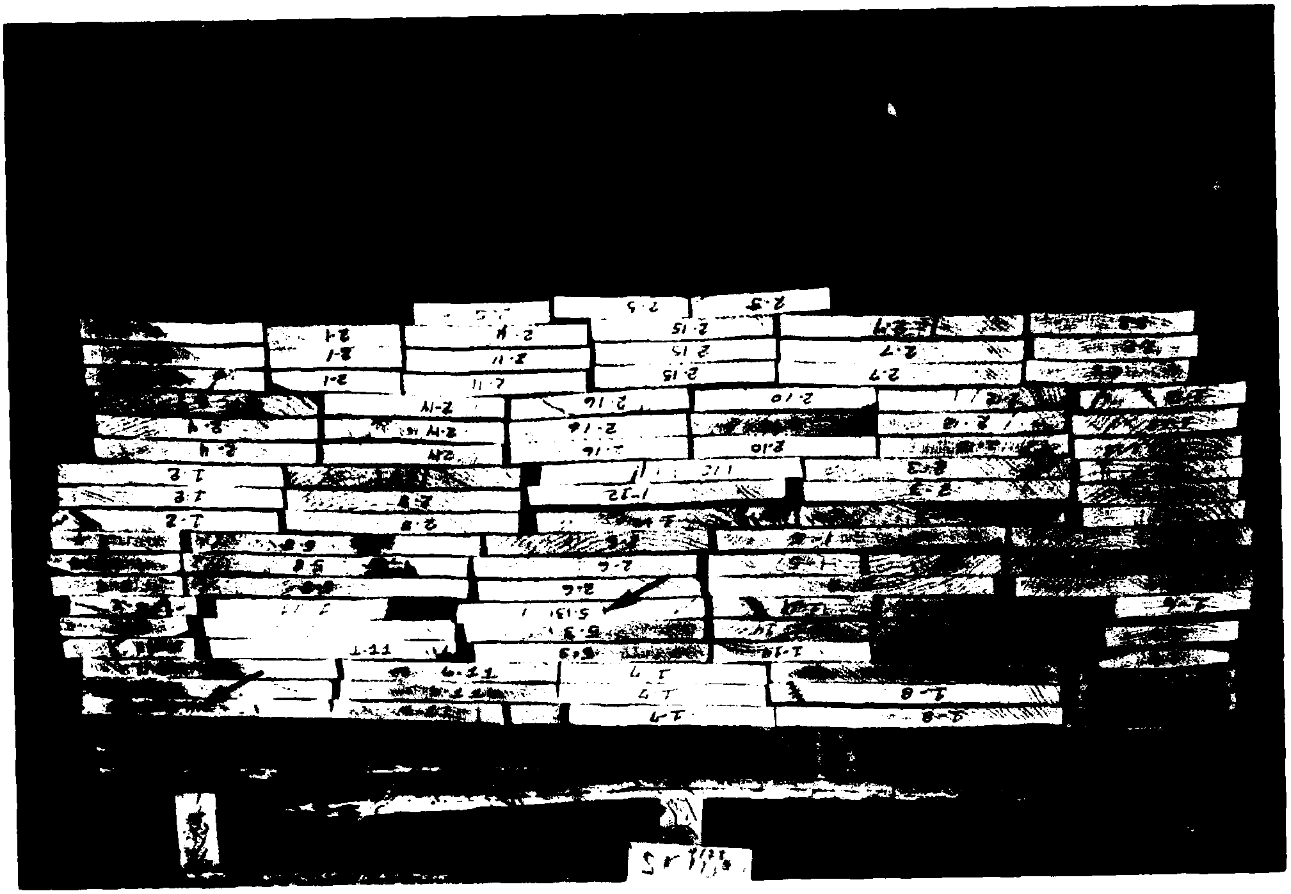

Figure 7.—Ends of oak lumber show honeycomb (arrows indicate typical examples) after accelerated kiln drying.

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Table 5.—Comparisons of the surface checking and honeycomb in 25 boards of red oak and white oak lumber

Steam at	Surface checks		Honeycomb	
	Number of checked boards	Total check length	Number of honeycombed boards	Total check length
		In.		In.
		RED OAK		
212°F	3	11.9	10	26.5
190°F	9	59.5	7	11.2
Control	4	23.6	4	8.0
		WHITE OAK		
212°F	1	38.9	2	5.2
190°F	5	20.4	1	0.8
Control	3	37.9	1	2.2

3.0-9-10/80

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