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KILN-DRYING SCHEDULES FOR 1-INCH LAUREL, MADRONE, TANOAK, AND CHINQUAPIN

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KILN-DRYING SCHEDULES FOR 1-INCH LAUREL, MADRONE, TANOAK, AND CHINQUAPIN

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Introduction

Seasoning is considered to be one of the principal obstacles to satisfactory utilization of Western hardwoods. Air seasoning, if the lumber is carefully piled and protected, can be counted upon to give fairly good results, but a great deal of time is required and the final moisture content is very apt to be too high for most use requirements. Air seasoning followed by kiln drying is a very common and satisfactory procedure for slow-drying and refractory items because, after being air seasoned to a moisture content of 20 to 25 percent, lumber can be kiln dried in a relatively short period of time without much danger of additional checking. In the Southern States, the average weather conditions are usually such that oak can be air seasoned without excessive surface checking. For these reasons, practically all southern oaks are air seasoned before kiln drying. A hot, dry climatic condition, on the other hand, may cause excessive checking.

In many cases, kiln drying green from the saw would be a desirable procedure provided satisfactory schedules are known. The standard kiln-drying schedues of the U. S. Forest Products Laboratory, as given in Technical Note No. 175, do not include schedules for most of the western hardwoods. To obtain data for developing such schedules, the Laboratory has conducted kiln-drying experiments on 4/4 boards cut from laurel, madrone, tanoak, and chinquapin logs from Sonoma County, California.[1] Selection, logging, and shipping of these logs were done in cooperation with the U. S. Forest Utilization Service at the California Forest and Range Experiment Station, the California State Forest Service, and the Farm Forester at Santa Rosa, California.

Test Material

Logs

The logs were cut in March, 1946, shipped immediately to the Laboratory, and sawed during July of the same year. Table 1 and figures 1 to 4 describe and illustrate the log sizes and their general character.

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[1] Approved forest service names of the species used in the tests herein described are: California laurel (*Umbellularia californica*), Pacific madrone (*Arbutus menziesii*), tanoak (*Lithocarpus densiflorus*), and golden chinquapin (*Castanopsis chrysophylla*).

Figures 1 to 4 show one log cross section of each species. The sapwood and heartwood areas show well in the laurel and chinquapin, but the distinction is not clear in the madrone and tanoak. The madrone, however, is mostly sapwood and the tanoak mostly heartwood.

Test Boards

The logs were sawed into random-width boards that were as flat-grained as permitted by their positions in the log and by the log sizes. The boards were then skip-dressed to an even 1-inch thickness and cut into 30-inch test specimens. After end coating and weighing, they were stored in a low-temperature and high-relative-humidity room until needed for the various experimental drying tests. During the storage period some drying took place and the moisture content values at the beginning of the drying experiments were somewhat less than the original green values shown in table 2.

The average specific gravity of each species, based on oven-dry weight and green volume, was as follows: laurel, 0.59; madrone, 0.54; tanoak, 0.56; and chinquapin, 0.43.

Pilot Tests to Determine Critical Initial Temperatures and Relative Humidities

In developing a kiln schedule for green stock, the first and most important consideration is the initial drying conditions. The use of too high temperatures may cause honeycombing, and too low humidities may cause surface checking. The problem is to find initial conditions that give maximum drying rate without excessive seasoning defects.

To determine such optimum conditions, various initial conditions shown in table 3 were tried.

For each species, the actual number of tests made varied, and was limited to those that were thought necessary to determine the critical conditions. Drying in each of the runs made, however, was continued under relatively mild conditions to a final moisture content of about 7 percent in order to determine the full effect of the initial conditions.

Laurel

The laurel developed no serious defects under any of the conditions shown, but in an extra run at an initial condition of 160° F. and 71 percent relative humidity it checked and honeycombed rather badly. As all results were not entirely consistent, a temperature of 130° F. and a relative humidity of 81 percent were selected as being a suitable and safe initial condition for this species.

Madrone

The madrone checked and honeycombed more readily and, in some cases, showed some degree of collapse. Here again the results were somewhat inconsistent, due, no doubt, to the material variable. For instance, rather small and sometimes inconsistent differences in the number of inches of surface checking were found despite big differences in relative humidity. The indications were, however, that 145° F. causes some honeycombing and that a high relative humidity of 85 to 90 percent would be best to minimize surface checking. An initial condition of 120° F. and 88 percent relative humidity was selected as satisfactory on the basis of the defects observed, but evidently increases in severity of drying conditions are not so critical as might be the case with a species such as oak.

Tanoak

Practically all tanoak boards surface checked and honeycombed under the conditions given in table 3. These defects, however, were found to be much less in two additional runs when an initial temperature of 105° F. was used together with a relative humidity of 90 percent. In no case, was the honeycombing in this species particularly severe -- it appeared to have been confined mainly to the extension of the larger surface checks. Some degree of collapse occurred in each run, but was least under the lower temperatures. As 105° F. is about the lowest temperature and 90 percent is about the highest relative humidity that can be maintained under control in a commercial dry kiln, this initial condition was selected for this species.

Chinquapin

The outstanding characteristic of the chinquapin was variability between individual pieces. The amount of collapse in a few pieces was sufficient to produce a shrinkage in thickness of 40 percent under the more severe of the conditions shown in table 3. The surface fibers of this type of material collapsed enough to cause wide, shallow surface checks at the very beginning of drying under conditions as mild as 100° F. and 90 percent relative humidity. Other pieces, however, dried exceptionally well with no defects of any kind even under the more severe conditions. The remainder of the boards were classifiable as between these two extremes, varying considerably in the amount of checking, honeycombing, and collapse. The conclusion reached was that initial kiln conditions should be as mild as practicable. Consequently, a temperature of 105° F. and a relative humidity of 90 percent were selected as was done for the tanoak.

Selection of Intermediate and Final Conditions

Having selected the initial conditions, the next step was to determine how quickly the conditions could be changed (temperature increased and relative humidity dropped). This was done not only by observing the development of defects in the pilot tests, but from past experience in the kiln drying of refractory species. The proper procedure is to start lowering the relative humidity only after the surface and near-surface fibers have passed through the stage of maximum tension that occurs with drying. As drying proceeds, this tension stress gradually lessens and changes to compression, after which all danger of surface checking is passed. Such changes in stress can be followed through the drying process by progressively cutting strips 1/8 inch thick from the two sides of a short cross section of a board. The relative length of the strips immediately upon cutting and before a change in moisture content takes place represents the degree of stress. A short strip denotes that it was in tension before cutting.

The same general picture can be obtained by watching the progress of surface checks. When they start to close, it is safe to lower the humidity, slightly at first and then more rapidly after the checks are closed. Observations and tests have indicated that there is a great deal of variation between species and between individual boards of a species. In many cases the critical stage is passed after boards have lost about 30 to 40 percent of their original moisture content. It is not particularly uncommon, however, to find checks occurring even when 50 percent of the moisture has been evaporated.

The intermediate relative humidities for these species were selected mainly on the basis of the appearance and apparent disappearance of the surface checks, particularly in the case of the madrone, tanoak, and chinquapin, in which some checking occurred even under the mildest of the conditions used. It seemed desirable to reach a final relative humidity of 30 percent when the laurel, madrone, and tanoak reached a moisture content of 20 percent. This final humidity for the chinquapin, however, was reached at a moisture content of 30 percent because checks close at a higher moisture content when the original green moisture content is high.

Temperatures that are critical for green wood remain somewhat critical until all the free water is gone or, in other words, until all the wood is below 30 percent moisture content. Below that, the temperature danger, within kiln temperature limits, disappears rapidly. A final temperature of 180° F. has been found safe and practical for other refractory hardwoods after a moisture content of 20 percent is reached. This was found to be true also for these species. The decision to use a temperature as high as 180° F. at a moisture content of 20 percent or less is based on the assumption that an accelerated type of schedule is desired. At this moisture content, the individual boards of a kiln charge vary a great deal, particularly if the kiln is poorly designed and equipped. In such cases, it is safer to use a much lower temperature or to be particularly careful that the wettest of the boards are below 20 percent moisture content before high temperatures are used.

Optimum Schedules and Results

The schedules selected and shown graphically and in table form in figures 5, 6, 7, and 8 are called optimum with certain reservations. They follow, in general, the proper pattern of drying conditions. While it would be expecting too much, from the limited tests made, to assume that each step represents the optimum and that no other combination of conditions would be so satisfactory, the schedules were found to work reasonably well. The variable material, as well as the fact that what might be called an optimum in one kiln may be far from an optimum in another kiln, also conspires against the derivation of a true optimum schedule. Although no kiln conditions seemed entirely satisfactory, further refinements may not be justified until the practicality of kiln drying these species green from the saw is weighted against air drying followed by kiln drying. Such information could be obtained best by actual experience in the field under commercial operating conditions.

Drying Time

The drying curves shown on these charts are those that might be expected in a fan kiln having an air velocity of between 200 and 300 feet per minute through the load. Because of the relatively few pieces in each test group, these drying rates represent best the drying rate of the lumber on the entering-air side of a commercial kiln charge or that of kiln samples located on the entering-air side of the load. Lumber farthest away from the entering-air side would dry considerably more slowly because of the temperature drop caused by the evaporation that takes place across the intervening boards. For this reason the drying time is greater if the schedule is followed by means of leaving-air instead of entering-air kiln samples. Where critical temperatures are involved, however, the use of leaving-air samples is the safest procedure in a full kiln charge, so that all boards are sufficiently dried before a temperature change is made. Under reversible circulation, both sides of the kiln are alternately entering- and leaving-air sides, and the problem becomes less important because of the more uniform drying.

Checking and Honeycombing

The results of drying under the conditions shown on the charts are illustrated by the cross-sectional photographs in figures 9, 10, 11, and 12. As surface checks usually close tightly during the latter stages of drying, they are practically invisible on the cross sections except where they had opened up in the interior as a honeycomb. The amount of checking in the laurel and madrone was very slight, but about one-half of the tanoak and chinquapin boards surface checked sufficiently to indicate the importance of high initial relative humidity. In general, the checks in the chinquapin boards were more severe than those in the tanoak boards.

Shrinkage

A small number of shrinkage measurements were taken to learn a little about what shrinkage allowances should be made in thickness and width when sawing out the green boards. These results are shown in table 4.

Because of the curvature of the annual rings, the shrinkage values in thickness and width do not represent, respectively, radial and tangential shrinkage as would be the case if the annual rings were parallel to the board faces. The cupping of the madrone and tanoak, however, was sufficient to indicate a rather high ratio of tangential to radial shrinkage.

Although some of the chinquapin had the highest maximum shrinkage values, some also had the lowest ones. Its average shrinkage was relatively low and 90 percent of the pieces had a shrinkage of 15 percent or less in thickness and 12 percent or less in width. The laurel had the least variation, but its average shrinkage was about the same or a little higher than that of the chinquapin. The average shrinkage in width and thickness of the madrone and tanoak was 12 to 13 percent, about 3 to 4 percent higher than the average shrinkage of the laurel and chinquapin.

On the basis of these data, an average allowance of 3/16 inch in thickness and 1 inch in width would be necessary to take care of the shrinkage of 90 percent of boards having a nominal size of 1 by 6 inches.

A general idea of the relative amounts of shrinkage is given in figures 9, 10, 11, and 12. The relative amounts of cupping are also shown.

Cupping

The cupping of the chinquapin boards was exceptionally small as compared to most species. The cupping of the tanoak boards, on the other hand, was exceptionally bad. Based on actual measurements of the pieces shown in figures 9, 10, 11, and 12, the computed amount of cupping in a board 6 inches wide would be approximately as follows: laurel, 1/8 inch; madrone, 3/16 inch; tanoak, 5/16 inch; and chinquapin, 1/16 inch. As these boards were practically unrestrained during drying, cupping would be less in a large pile where the weight of the stock above would have some effect in reducing the amount of cupping. Weights placed on top of the pile would help to reduce cupping in the top layers.

Because of cupping, as well as collapse and local shrinkage in thickness as high as 20 percent, it may be difficult to use tanoak boards as dried without a great deal of loss in planing. It may be necessary to rip them to widths that will produce a satisfactory yield. For instance, when a board is ripped in two, the amount of cupping in each of the two halves will be approximately 1/4 that of the original board. In many cases it will be less than that because cupping is often concentrated in a relatively narrow central portion where the annual rings are parallel to the board faces. Some madrone boards may also have to be treated in this manner.

Conclusions

Laurel, madrone, tanoak, and chinquapin are sufficiently refractory to require considerable care in seasoning. To dry them green from the saw, a kiln must be so equipped as to provide good control of temperature and relative humidity and a brisk rate of air movement through the loads. Poor operation during the initial stages of drying would be sure to result in excessive degrade, particularly in the tanoak and chinquapin.

A relative humidity of 90 percent is about as high as can be maintained satisfactorily in a lumber dry kiln. An initial condition somewhat lower than this will cause no surface checking in laurel and only a slight increase in checking in madrone. In drying tanoak and chinquapin, however, an initial relative humidity as high as 90 percent is necessary to prevent serious checking even when low kiln temperatures are used.

Honeycombing is caused by excessive temperatures while the wood is above the fiber-saturation point (30 percent moisture content). Usually honeycomb develops from end checks and surface checks that progress inwardly and open up in the interior under excessive temperatures. Under moderate kiln temperatures, such occurrences were very little in evidence in the laurel and only slightly more in the madrone. The tanoak, however, required lower temperatures, and many chinquapin boards honeycombed rather badly even when the kiln temperature was 105° F., which is considered to be about as low as can be maintained under control in most dry kilns.

The possibility of success in kiln drying laurel and madrone green from the saw is very good. The madrone should be sawed somewhat thicker than the laurel to take care of greater shrinkage and cupping. Even then some boards may have to be ripped to obtain a satisfactory yield. The degree of success would probably be less in drying tanoak because it is more susceptible to honeycombing and collapse under kiln temperatures. Its tendency to cup badly when unrestrained is also a problem that must be considered in devising a satisfactory seasoning and manufacturing procedure. By using low initial temperatures and high initial relative humidities and by ripping the excessively cupped boards, the yield of usable stock would, no doubt, be sufficient to warrant consideration of kiln drying green from the saw. The yield of good chinquapin boards is apt to be even less, not so much from cupping as from collapse, excessive shrinkage, and honeycomb.

The probability that preliminary air seasoning might be less conducive to seasoning defects than kiln drying green from the saw was investigated to the extent of drying some tanoak and chinquapin boards under temperatures and relative humidities that simulated, in a general way, desirable air-seasoning conditions. The relative humidity was lowered gradually from 87 to 57 percent while drying from a green condition to about 30 percent moisture content and then more rapidly from 57 to 20 percent in drying to a final moisture content of 6 percent. An initial temperature of 80° F. was maintained during the early stages, but this had to be increased gradually to about 100° F. as a means of attaining the low final relative humidities. Although only a few pieces were dried, the indications were that the amount of collapse and honeycomb was less than that which occurred under temperatures more usual in kiln operation.

One possible danger in air seasoning is that the humidities during the early stages of drying might be considerably less than the 85 to 90 percent that is required to prevent extensive surface checking. Suitable climatic conditions would be necessary and the stock should be completely protected from sun and rain.

Where lumber is air seasoned, it may be desirable to complete the drying in a kiln to a moisture content suitable for heated indoor use. Although no actual data were collected on the kiln drying of previously air-seasoned stock, the schedules suggested in tables 5 and 6 are based on general experience and research in drying of refractory species as well as on the drying experiments described in this report.

On the basis of moisture content, the relative humidities given in tables 5 and 6 appear to be somewhat inconsistent, but the purpose is to use a relatively high humidity until a moisture gradient is established within the wood. The drying stresses in the surface fibers would then be less severe and more evenly distributed through the piece at the time when the low final relative humidity of 30 percent is established. The necessity for such a procedure, of course, is much less for laurel and madrone than for tanoak and chinquapin.

Table 1.--Data on logs used in kiln-drying experiments

Species	Number of logs	Number of trees represented	Diameters Average	Diameters Range	Size and quality for area where cut
			Inches	Inches	
Laurel	8	8	12	8-16	Average
Madrone	13	8	14	9-19	Average or better
Tanoak	10	4	11	8-16	Below average
Chinquapin	11	4	13	10-17	Average or below

Table 2.--Green moisture content (based on oven-dry weight of wood) of logs used in kiln-drying experiments

Tree numbers	Moisture Content: Laurel	Madrone	Tanoak	Chinquapin
	Percent	Percent	Percent	Percent
1	60.5	89.4	90.5	139.4
2	59.8	78.0	98.6	166.4
3	62.7	78.4	83.9	117.8
4	62.5	90.1	85.1	123.7
5	63.9	85.8	--	--
6	65.2	93.0	--	--
7	67.2	87.4	--	--
8	63.1	75.2	--	--
Average	63.1	84.7	89.5	136.8

Table 3.--Pilot kiln runs used to test initial conditions for drying

Kiln run number	Initial conditions			
	Temperature		Relative humidity	Equilibrium moisture content
	Dry-bulb	Wet-bulb		
	° F.	° F.	Percent	Percent
1	115	110	85	16.2
2	115	106	74	12.7
3	115	101	61	10.0
4	130	125	86	16.0
5	130	121	76	12.7
6	130	116	64	10.0
7	145	140	87	15.7
8	145	136	77	12.5
9	145	131	67	10.0

Table 4.--Amount of shrinkage[1] in kiln drying to a moisture content of 6 percent (percent of green dimensions)

Species	Average	Minimum	Maximum	Number of pieces that might be expected to have less than the indicated amount of shrinkage (Percent of total number) 30	60	90
	Percent	Percent	Percent	Percent	Percent	Percent
			Shrinkage in thickness			
Laurel	10	5	16	6	11	15
Madrone	13	7	22	10	13	15
Tanoak	12	6	21	7	11	15
Chinquapin	8	2	28	3	7	15
			Shrinkage in width			
Laurel	9	5	12	7	9	11
Madrone	12	9	18	10	12	15
Tanoak	13	7	16	11	13	14
Chinquapin	9	5	23	6	8	12
			Shrinkage in cross-sectional area[2]			
Laurel	17	11	25	13	17	23
Madrone	23	16	34	19	22	28
Tanoak	24	17	29	20	24	28
Chinquapin	18	7	30	12	19	27

[1] Based on 10 pieces each of laurel, madrone, and tanoak dried under respective schedules shown in figures 5, 6, and 7; and on a mixed lot of 41 heartwood and sapwood pieces of chinquapin dried under schedule shown in figure 8.

[2] Obtained by planimetering the cross-sectional outline of the dried material.

Table 5.--Suggested kiln schedule for 4/4 lumber previously air seasoned to a moisture content of about 25 percent

Drying time	Temperature		Relative humidity
	Dry-bulb	Wet-bulb	
	° F.	° F.	Percent
2 days	130	114	60
2 days or more until the moisture content is below 20 percent	130	103	40
To a final moisture content of 6 to 7 percent	180	135	30
Conditioning treatment for approximately 1 day	180	168	75

Table 6.--Suggested kiln schedule for 4/4 lumber previously air seasoned to a moisture content below 20 percent

Drying time	Temperature		Relative humidity
	Dry-bulb	Wet-bulb	
	° F.	° F.	Percent
2 days	180	165	70
2 days	180	152	50
To a final moisture content of 6 to 7 percent	180	135	30
Conditioning treatment for approximately 1 day	180	168	75

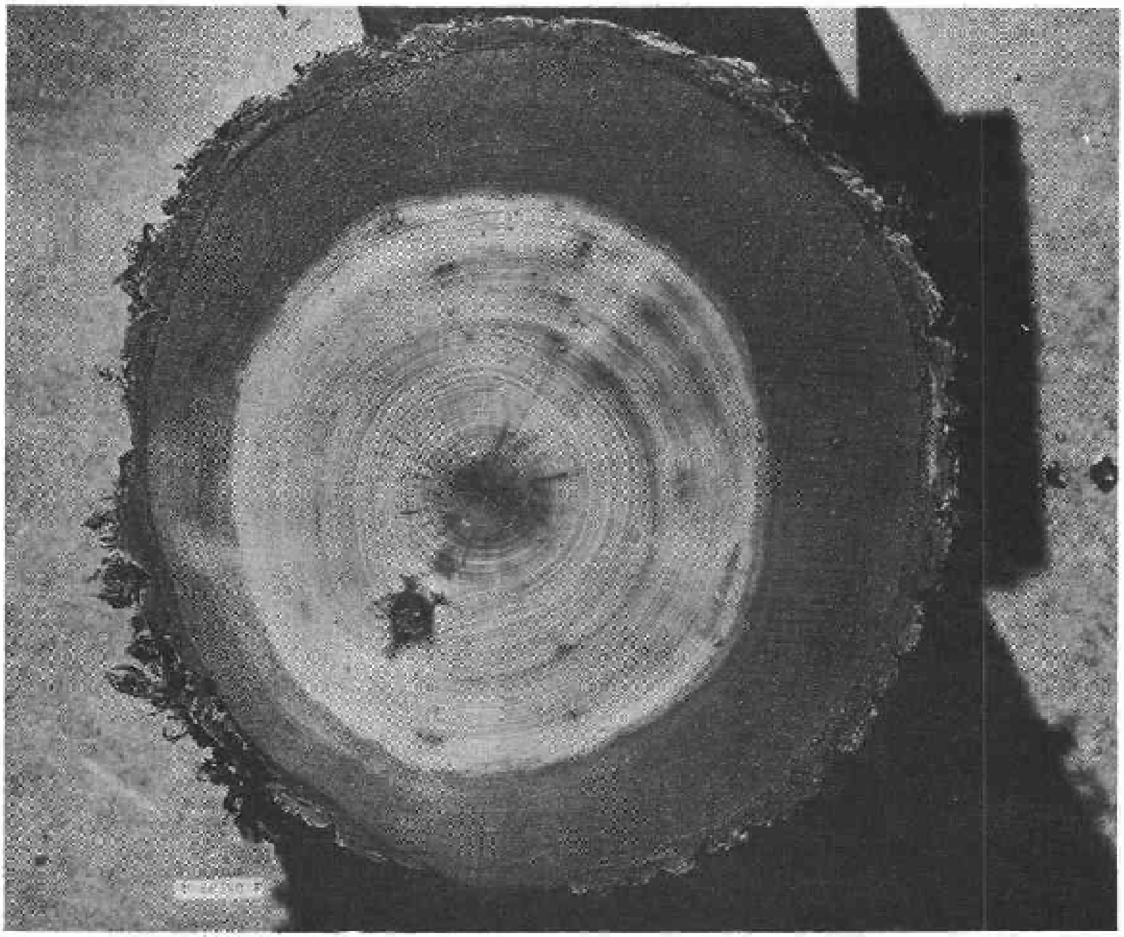

Figure 1.--Cross-sectional view of a laurel log used in kiln-drying experiments.

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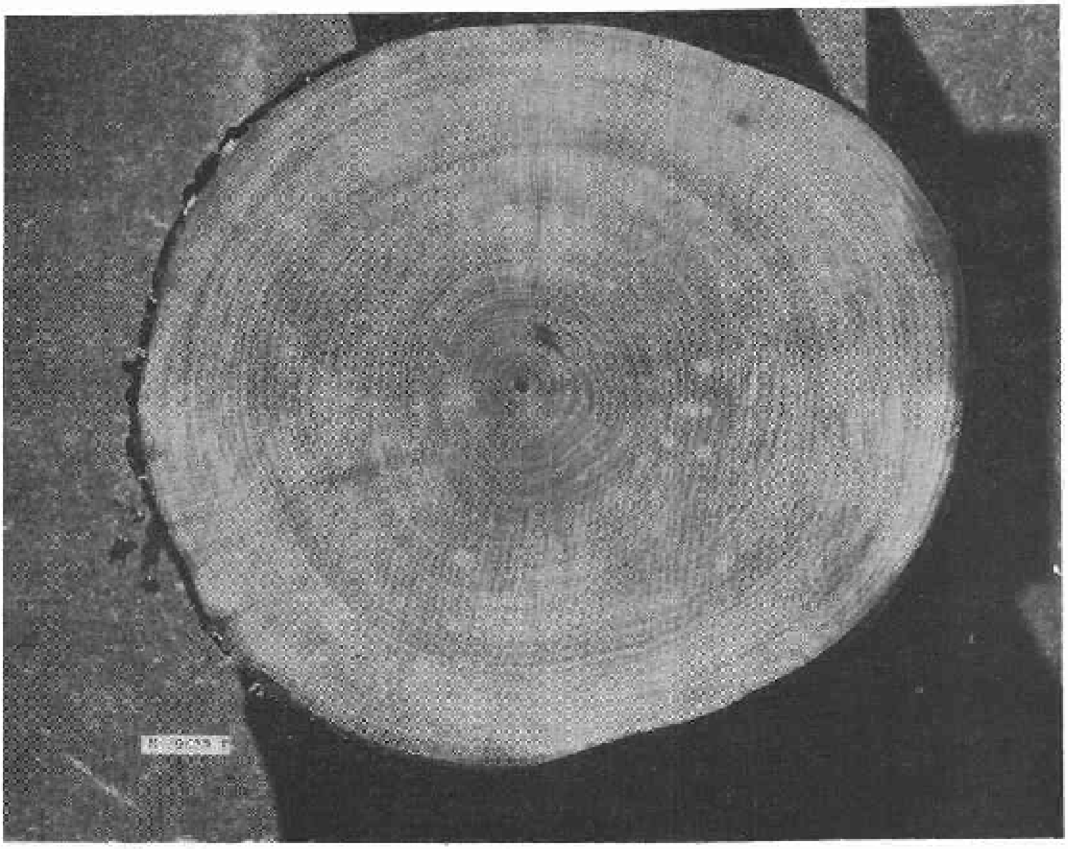

Figure 2.--Cross-sectional view of a madrone log used in kiln-drying experiments.

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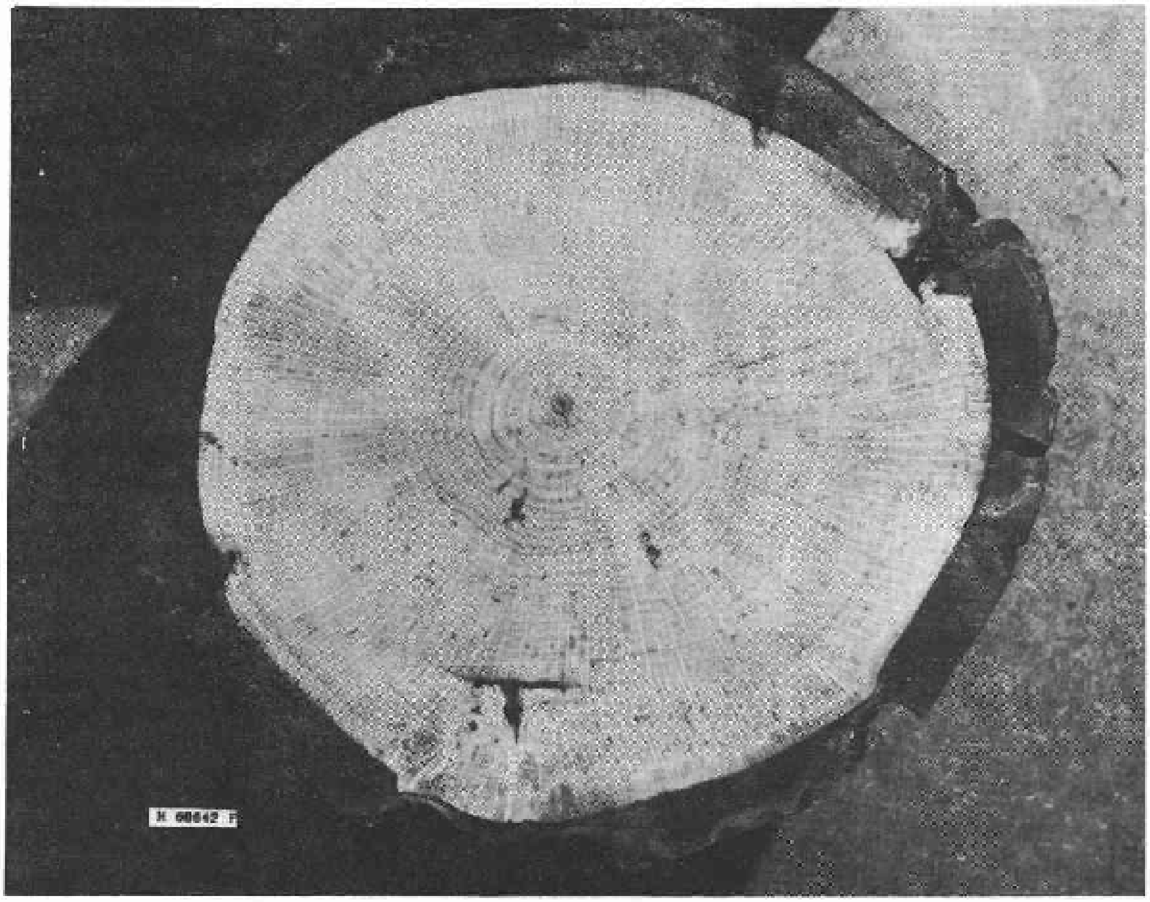

Figure 3.--Cross-sectional view of a tanoak log used in kiln-drying experiments.

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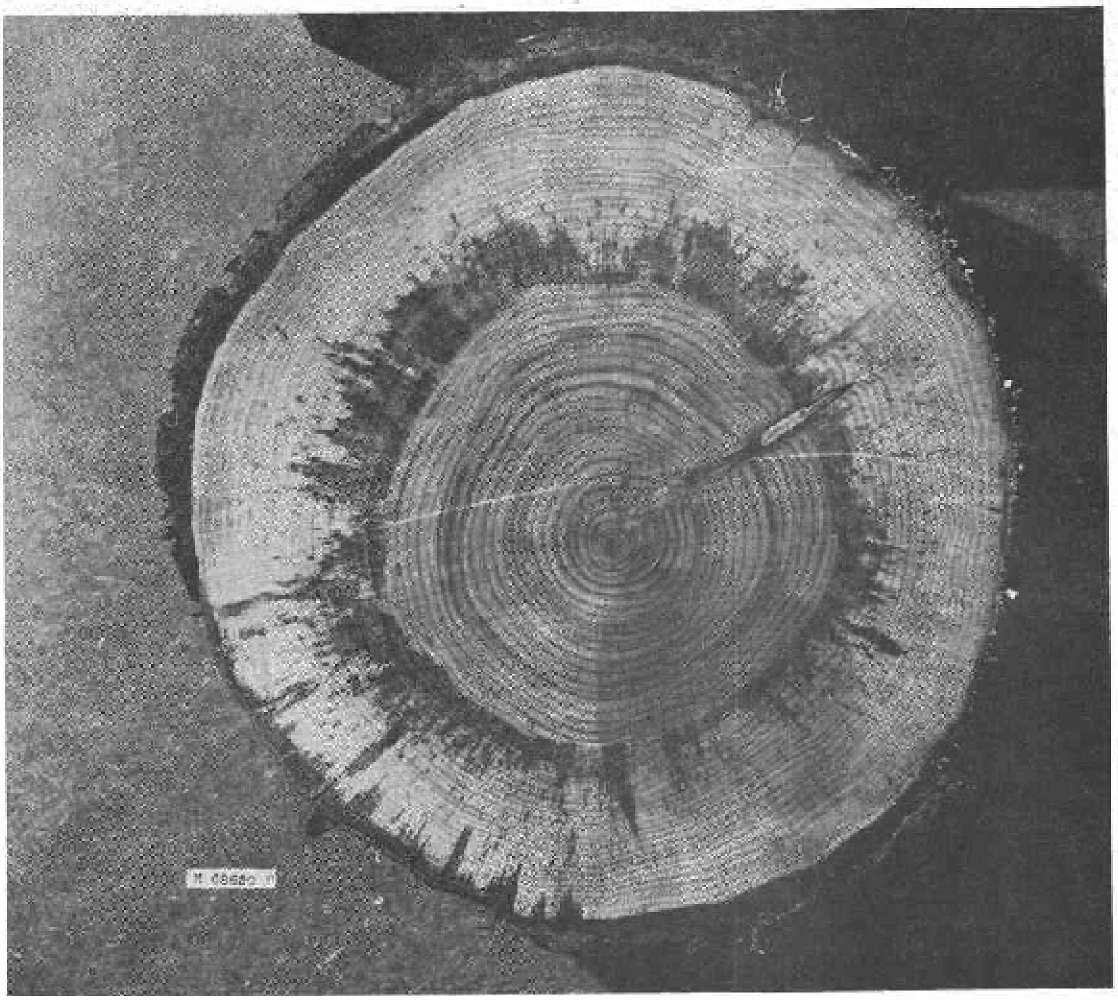

Figure 4.--Cross-sectional view of a chinquapin log used in kiln-drying experiments.

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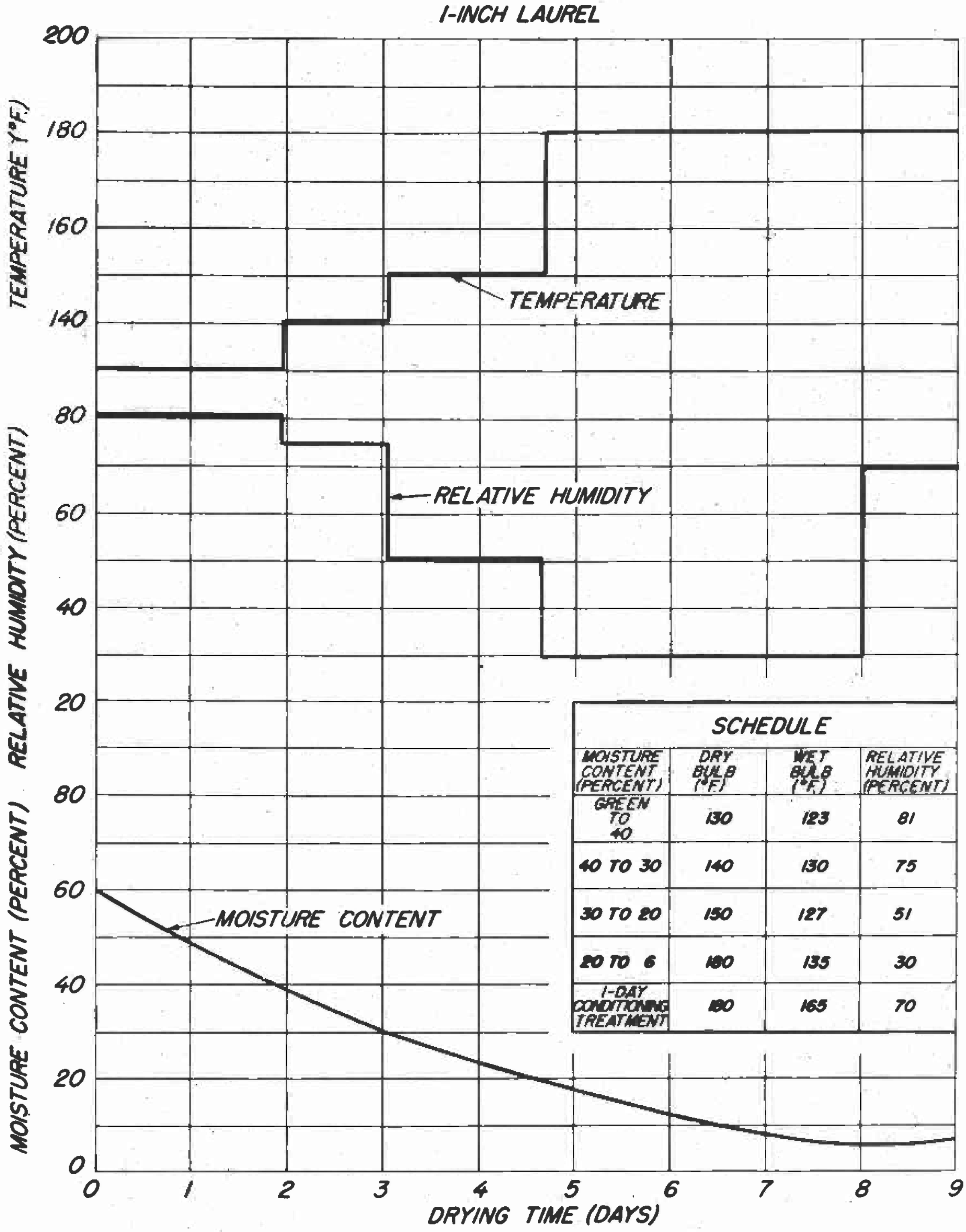

MOISTURE CONTENT (PERCENT)	DRY BULB (°F.)	WET BULB (°F.)	RELATIVE HUMIDITY (PERCENT)
GREEN TO 40	130	123	81
40 TO 30	140	130	75
30 TO 20	150	127	51
20 TO 6	180	135	30
1-DAY CONDITIONING TREATMENT	180	165	70

Figure 5.--Temperature and relative humidity schedule for 4/4 laurel. The resulting drying time shown is that of a small lot of boards when dried in a small experimental kiln having a fast rate of air circulation.

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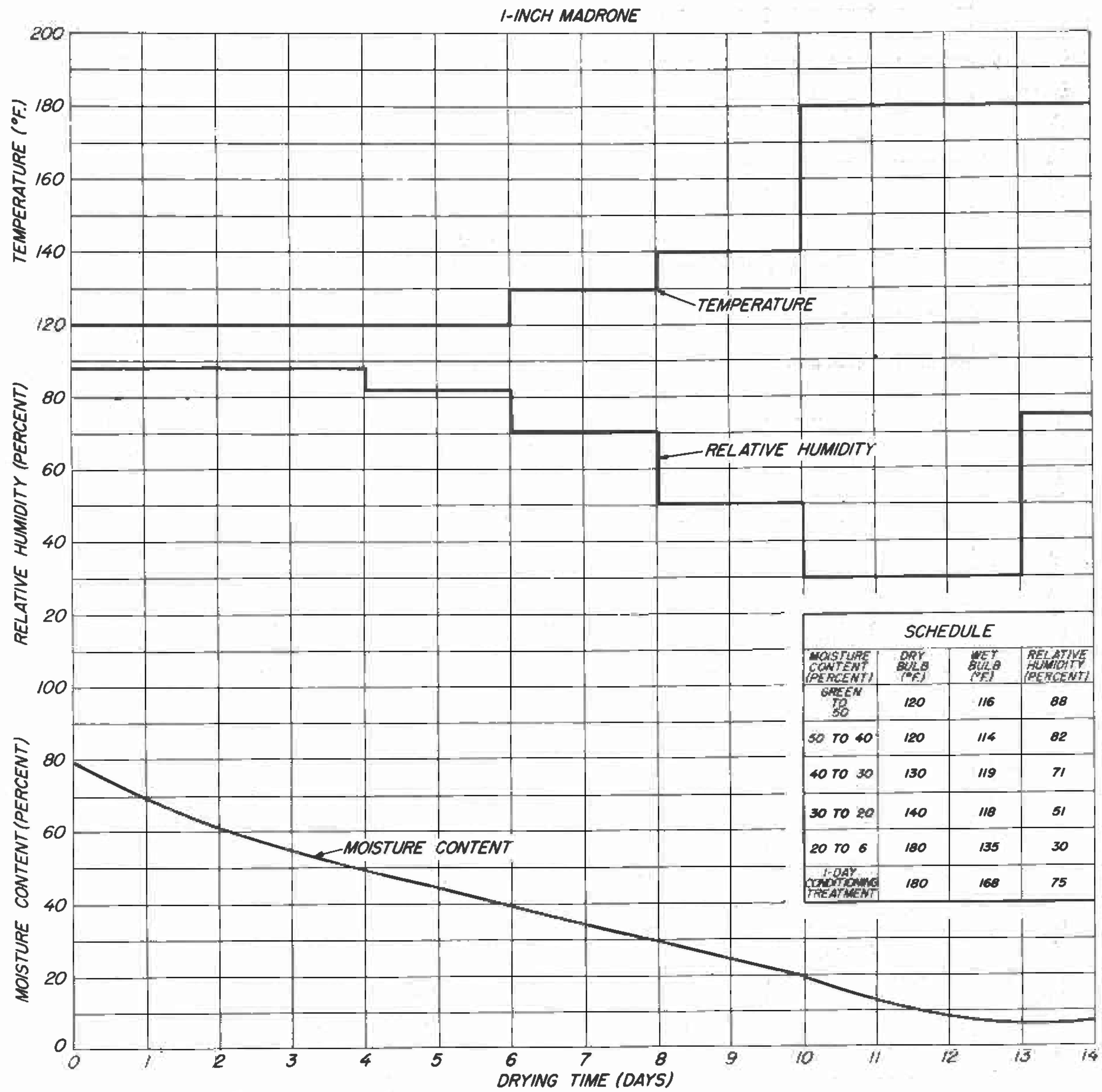

SCHEDULE

MOISTURE CONTENT (PERCENT)	DRY BULB (°F.)	WET BULB (°F.)	RELATIVE HUMIDITY (PERCENT)
GREEN TO 50	120	116	88
50 TO 40	120	114	82
40 TO 30	130	119	71
30 TO 20	140	118	51
20 TO 6	180	135	30
1-DAY CONDITIONING TREATMENT	180	168	75

Figure 6.--Temperature and relative humidity schedule for 4/4 madrone. The resulting drying time shown is that of a small lot of boards when dried in a small experimental kiln having a fast rate of air circulation.

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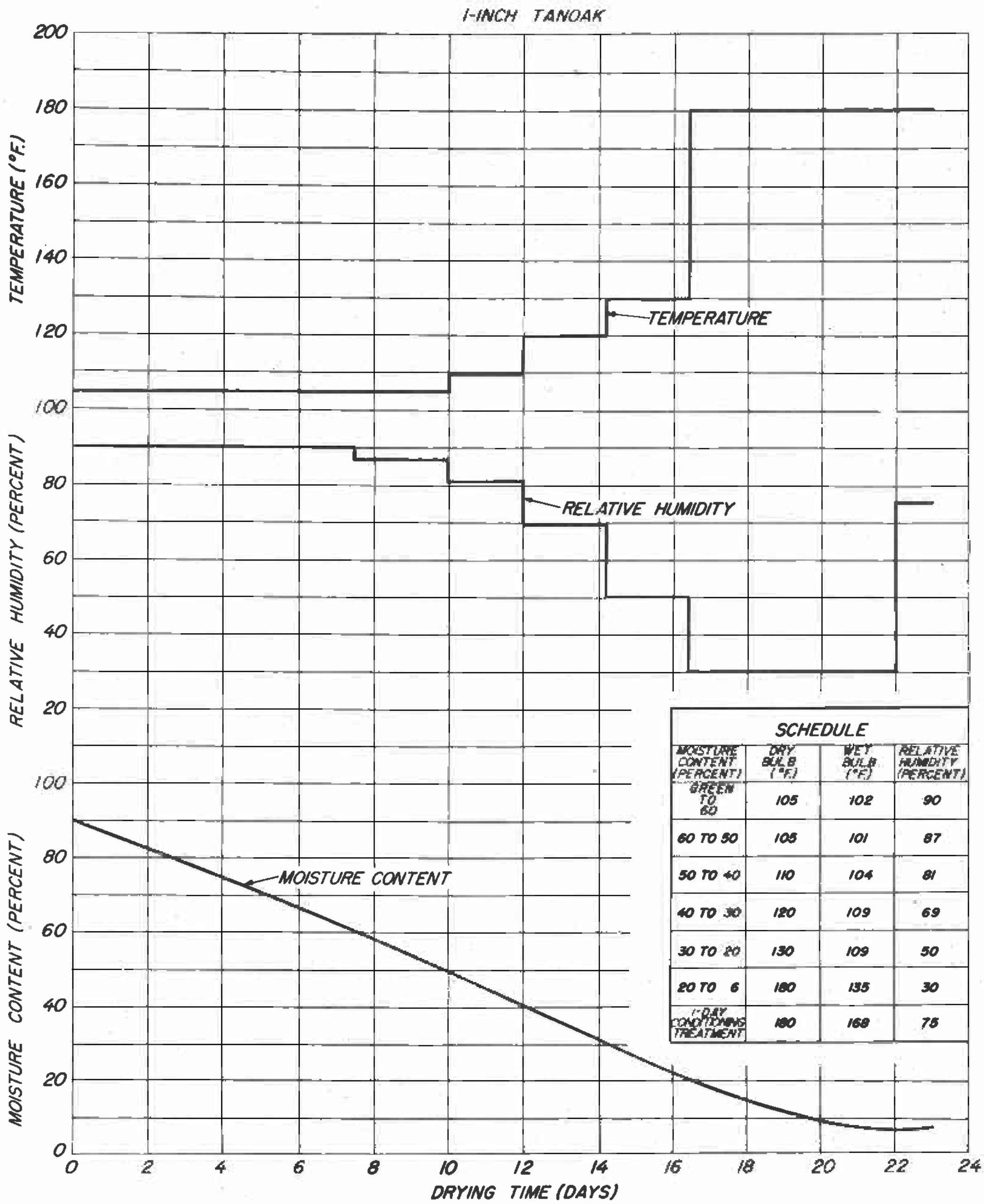

SCHEDULE

MOISTURE CONTENT (PERCENT)	DRY BULB (°F.)	WET BULB (°F.)	RELATIVE HUMIDITY (PERCENT)
GREEN TO 60	105	102	90
60 TO 50	105	101	87
50 TO 40	110	104	81
40 TO 30	120	109	69
30 TO 20	130	109	50
20 TO 6	180	135	30
1-DAY CONDITIONING TREATMENT	180	168	75

Figure 7.--Temperature and relative humidity schedule for 4/4 tanoak. The resulting drying time shown is that of a small lot of boards when dried in a small experimental kiln having a fast rate of air circulation.

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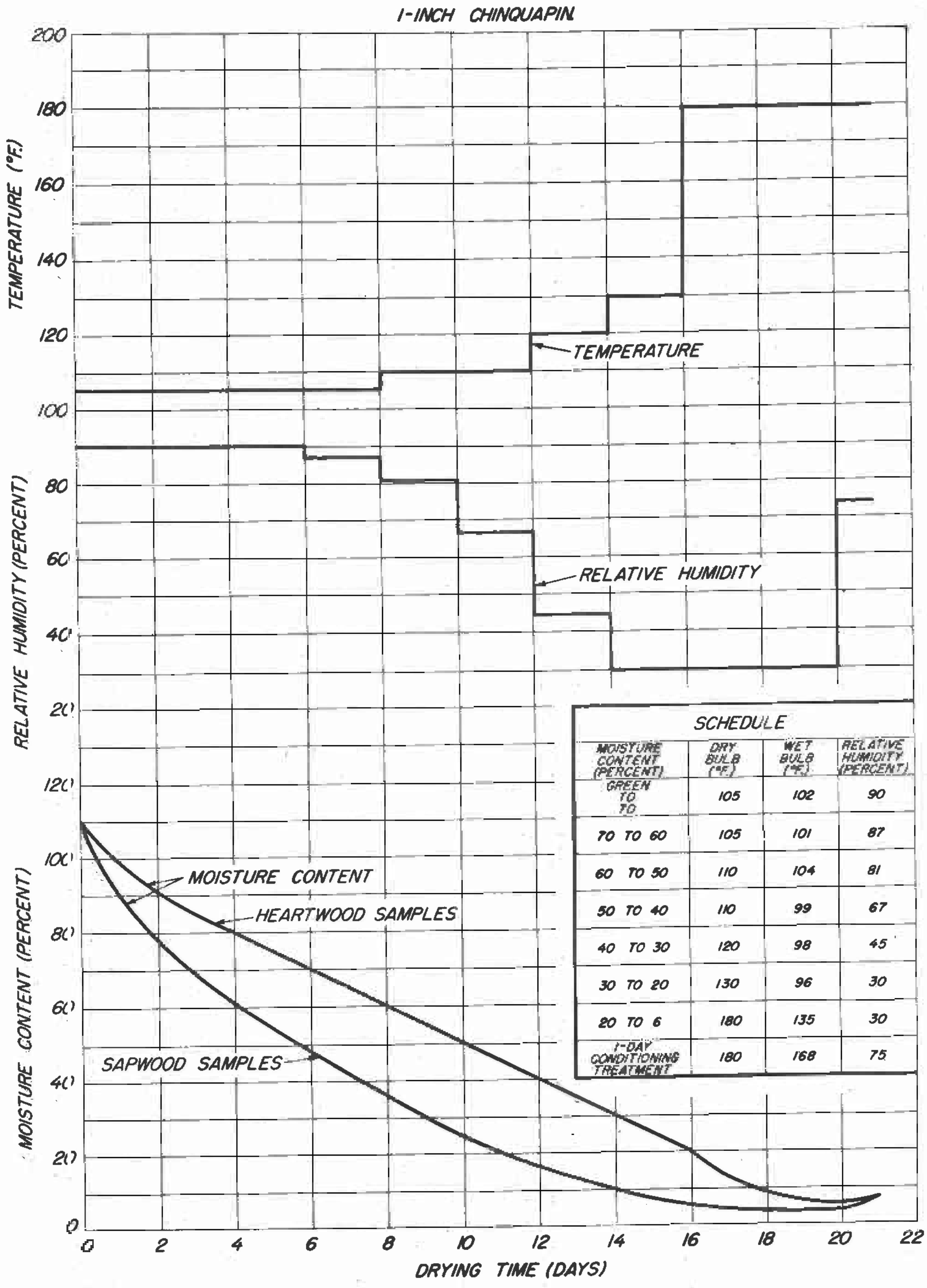

MOISTURE CONTENT (PERCENT)	DRY BULB (°F.)	WET BULB (°F.)	RELATIVE HUMIDITY (PERCENT)
GREEN TO 70	105	102	90
70 TO 60	105	101	87
60 TO 50	110	104	81
50 TO 40	110	99	67
40 TO 30	120	98	45
30 TO 20	130	96	30
20 TO 6	180	135	30
1-DAY CONDITIONING TREATMENT	180	168	75

Figure 8.--Temperature and relative humidity schedule for 4/4 chinquapin. The resulting drying time shown is that of a small lot of boards when dried in a small experimental kiln having a fast rate of air circulation.

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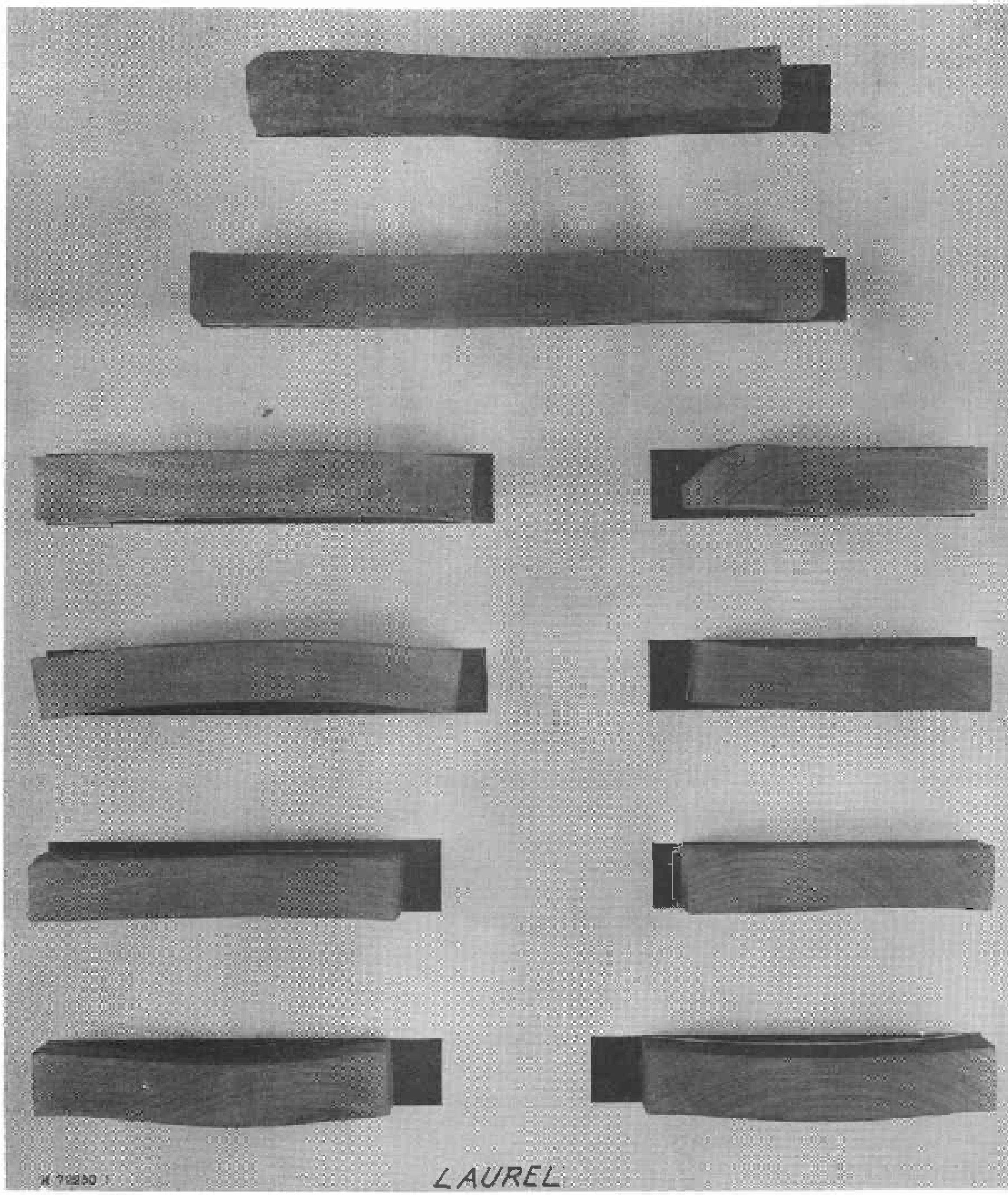

Figure 9.--Cross-sectional views of 4/4 laurel kiln dried under the Forest Products Laboratory's optimum test schedule. The black background represents the green dimensions.

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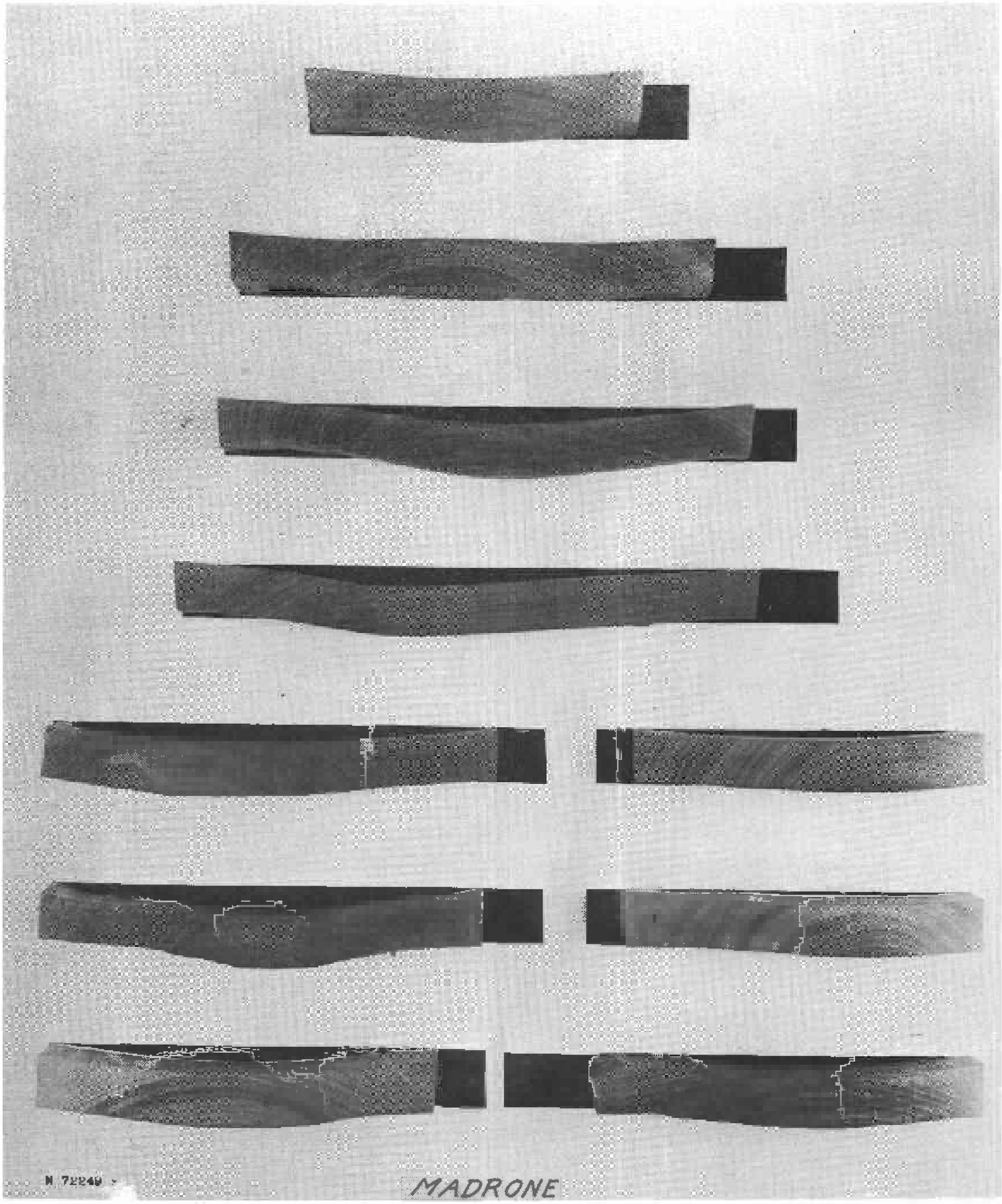

Figure 10.--Cross-sectional views of 4/4 madrone dried under the Forest Products Laboratory's optimum test schedule. The black background represents the green dimensions.

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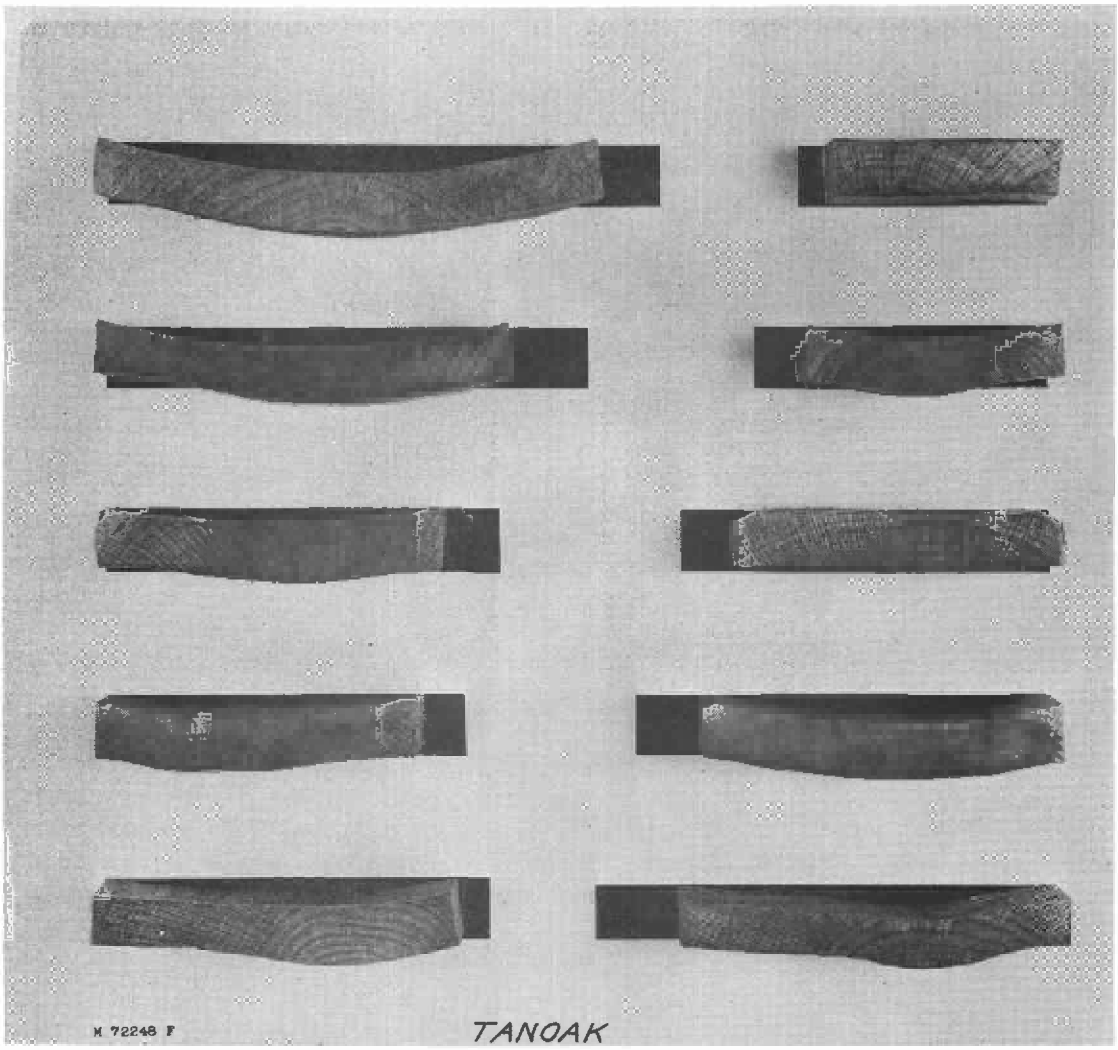

Figure 11.--Cross-sectional views of 4/4 tanoak dried under the Forest Products Laboratory's optimum test schedule. The black background represents the green dimensions.

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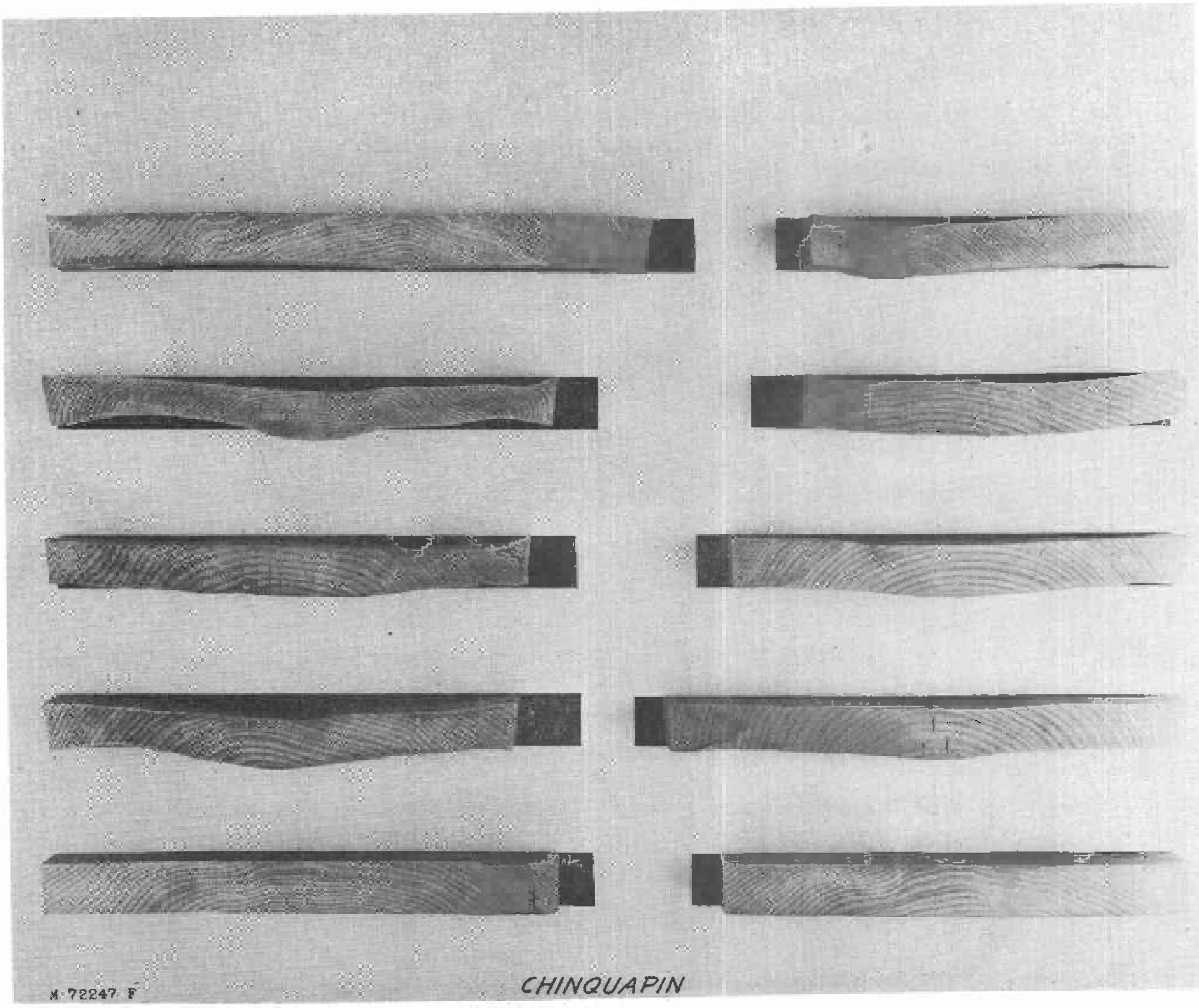

Figure 12.--Cross-sectional views of 4/4 chinquapin dried under the Forest Products Laboratory's optimum test schedule. The black background represents the green dimensions.

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