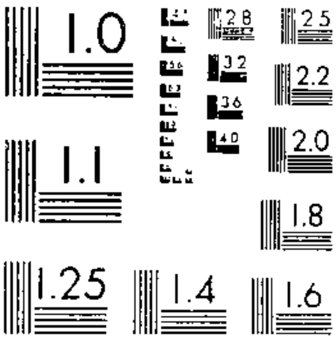
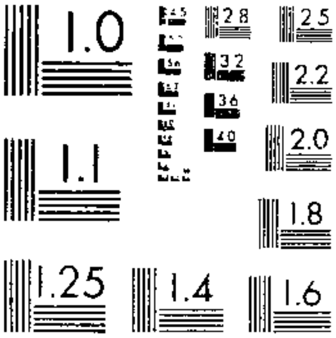
TB 174 (1930) USDA TECHNICAL BULLETINS UPDATA
THE AIR SEASONING OF WOOD
MATHEWSON, J. S. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

TECHNICAL BULLETIN No. 174 — APRIL, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE AIR SEASONING OF WOOD

By J. S. MATHEWSON[1]

Senior Engineer, Forest Products Laboratory,[2] Branch of Research, Forest Service

CONTENTS

INTRODUCTION

PURPOSE OF THE BULLETIN

The fullest utilization of our forest crop requires that the wood harvested from forests and wood lots be brought to a condition best suited to its ultimate use. One of the essential steps in securing maximum utilization is to season the stock to the proper moisture

[1] The author wishes to acknowledge his indebtedness to other members and former members of the Forest Service, particularly the authors of Department Bulletin No. 1425, The Air Seasoning of Western Softwood Lumber, S. V. Fullaway, jr., formerly in charge of the office of forest products, Missoula, Mont., Herman M. Johnson, assistant in forest products, Portland, Oreg., and C. L. Hill, forester, California Forest Experiment Station. Further, acknowledgement is also made to numerous lumber companies and associations, whose effective cooperation was essential to the conduct of the investigations upon which this bulletin is based.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

content, at the same time keeping waste and degrade to a minimum. Although the inherent properties of the wood of a tree are determined initially by the species and growth conditions of the tree itself, they can be modified by proper methods of seasoning. It is evident, therefore, that seasoning is one of the important factors in the conservation of our forest resources. Realizing this fact, the Forest Products Laboratory has been studying the entire problem of seasoning for a number of years. The results of the investigations concerned with air seasoning are embodied in this bulletin.

The purpose of this bulletin is threefold: To present the general principles involved in the drying of wood, to show their application to air seasoning, and to offer suggestions for better air-seasoning practice. Better practice will reduce seasoning losses, decrease the drain on our forests, and give to the consumer material that is better suited to his needs.

A large number of studies of seasoning have been made by the Forest Service in various parts of the United States.[3] These studies have shown that the fundamental principles of air seasoning and of kiln drying are the same. Consequently the results derived from kiln-drying investigations often help to solve problems that arise in air seasoning and conversely, although adequate recognition of any important differences in conditions is always necessary. This bulletin assembles the pertinent results of the Forest Service air-seasoning studies; it includes especially the quantitative results of the field studies of air seasoning made in the West on sugar pine, western yellow pine, redwood, western white pine, and Douglas fir.

Complete data pertaining to the volume of wood products air seasoned in the United States are not available; however, more than half of such products are air seasoned for a time, even though some of them may subsequently be kiln dried. Hence the importance of improvement in air-seasoning practice is obvious.

PURPOSE OF SEASONING

Broadly, the principal object in seasoning wood is to improve its suitability for the purpose for which it is to be employed, although in some instances the reduction in transportation costs may be of paramount importance.

AIR SEASONING

Among the results accomplished by employing proper methods of air seasoning of wood are the following:

A reduction in weight, with a resulting reduction in shipping costs.

A reduction in the shrinkage, checking, honeycombing, and warping occurring in service.

---

[3] The results of the general studies of kiln drying have been published in U. S. Dept. Agr. Bul. 1136 (*5*) (italic numbers in parentheses refer to Literature Cited, p. 56), and the results of some special kiln-drying studies in Technical Bul. 165, U. S. Dept. Agr. (*4*). Similarly the results of studies of air seasoning made in the principal lumbering regions of the West have been reported in U. S. Dept. Agr. Bul. 1425 (*1*). The national committee on wood utilization of the U. S. Department of Commerce has prepared four reports entitled "Seasoning, Handling, and Care of Lumber," which are designated, respectively, the consumers', the distributors', the fabricators', and the manufacturers' edition (*6, 7, 8, 9*).

A decrease in the tendency for blue stain and for other forms of mold to develop.

A reduction in liability to some forms of insect attack.

An increase in strength.

An improvement in the ability of the stock to be painted or to be impregnated with a preservative.

KILN DRYING[1]

Among the advantages over air seasoning that may result from kiln drying are the following:

A reduction in weight, and consequently in shipping charges, even greater than the reductions common for air-seasoned stock.

A reduction in moisture content to any desired value, which in many instances may be lower than that obtainable through air seasoning.

A reduction in drying time below that required in air seasoning.

The killing of any stain or decay fungi or insects that may be in the wood.

THE SOLUTION OF INDIVIDUAL AIR-SEASONING PROBLEMS

No single general rule is applicable to all seasoning problems; each individual problem requires its own special modifications of the general rules if satisfactory seasoning at minimum cost is to be attained. The following five distinct objectives must be borne constantly in mind in selecting the seasoning procedure to be followed in each instance: (1) Minimum depreciation of stock, (2) rapid rate of drying, (3) low and uniform moisture content, (4) economy in operating cost, and (5) low investment cost. Maximum attainment of any one of these objectives may often preclude full realization of the others.

Other complications of the seasoning problem should also be recognized. The various species of wood and the grades and sizes of stock require individual consideration. Because of climatic and other differences, the solution for one seasoning yard will not always hold for another. Seasonal weather variation must likewise be met individually by each yard.

It has therefore become obvious that the solution of the air-seasoning problem can not be found in any set of fixed rules. Consequently the chief aim of this bulletin is the presentation of rather general principles, based on the detailed knowledge available, which can be applied in a manner that will best meet specific conditions and problems.

To permit an orderly presentation of the information available, the major discussion is preceded by a brief review of the general principles of drying wood and by a statement of their application to the air-seasoning process.

MOISTURE IN WOOD

COMPOSITION OF SAP

The moisture in wood is commonly called "sap," although the use of this multipurposed term is often misleading. Sap in wood is chiefly water, but it also contains small percentages of soluble organic

[1] The Kiln Drying Handbook (5) presents a full discussion of the general subject of kiln drying and of matters related thereto.

and mineral matter. In the sapwood such materials are largely sugars, while in the heartwood a considerable proportion of them may be tannins and coloring matter. For all practical purposes in the drying of wood, however, sap may be considered as water alone.

OCCURRENCE OF MOISTURE

Moisture (sap) in green or wet wood is held in two ways. It is contained within the cell cavities, and it is absorbed in the cell walls. The bulk liquid is called "free" water, while the absorbed may be termed "imbibed" water.

VARIATION IN AMOUNT OF MOISTURE

Some free water is present in both the heartwood and the sapwood of most living trees, but the amounts in each differ greatly. Sapwood usually contains more moisture than heartwood does. Butt logs ordinarily have a higher moisture content than top logs. Contrary to common opinion, the variation during the year in the amount of moisture in green wood is slight. Species and place of growth, however, have an important bearing upon the amount of moisture in the living tree.

Marked variation in the moisture content of trees was indicated by the many moisture-content determinations on green wood made in connection with air-seasoning investigations in the western part of the United States. Differences among species were large. In all species, the select grades of green lumber contained more moisture than the common grades because of the greater proportion of sapwood in the clearer stock. Variation resulting from place of growth was well illustrated by the moisture-content values of western yellow pine stock in California and of that in the Inland Empire.[5] A usual range of moisture content for this species in the Inland Empire was from 80 per cent in the common grades to 115 per cent in the select grades, while in California the corresponding values were from 100 to 185 per cent. The following species showed moisture-content values, averaging about as indicated, for common and for select grades, respectively: Western white pine, 75 and 84 per cent; sugar pine, 75 and 190 per cent; white fir, 90 and 200 per cent; redwood, 70 and 200 per cent; coast Douglas fir, 32 and 53 per cent; and western hemlock, 28 and 120 per cent.

DETERMINATION OF MOISTURE CONTENT

The amount of moisture in wood, which is termed the moisture content, is ordinarily expressed as a percentage of the weight of oven-dry wood. Thus, if the moisture content of a green board is 71 per cent, there are by weight 71 parts of water to 100 parts of oven-dry wood. Again, should the moisture content of a board be exactly 100 per cent, the weight of the moisture and that of the oven-dry wood are equal; each is then half the total weight of the board. If the moisture content is 150 per cent, for example, the

[5] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

moisture is three-fifths and the oven-dry wood is two-fifths of the total weight of the board.

The average moisture content of any lot of lumber may be determined in the following manner:

(1) Select representative pieces, being careful to include typical amounts of both heartwood and sapwood, and taking about 1 out of every 100 pieces in the lot.

(2) Trim from one end of each piece a length of about 2 feet, making the cut at a place free from knots, rot, pitch streaks, and other defects. (The section must be far enough from the end to certainly avoid the effects of end drying; in addition, however, it is desirable to place the first cut so that the second one will leave the remaining piece of lumber sufficient for some standard length.)

(3) From the freshly exposed ends of each piece cut off a section three-fourths to 1 inch long in the direction of the grain.

(4) Trim all slivers off the sections.

(5) Weigh the individual sections immediately and carefully on a delicate balance. Each reading gives the original weight of a section.

(6) Place the sections in an oven heated to 212° F., or, if an oven is not available, on hot steam pipes, but do not scorch them; the maximum variation in the drying temperature should be not more than 5° between limits.

(7) When the sections have reached a constant weight, a condition that can be determined by repeated weighing, remove them from the oven. (After a little experience the time required to reach constant weight can be estimated with sufficient accuracy and some repeated weighings may thus be avoided. Twenty-four hours is about the maximum time necessary.) The final weight of a section is its oven-dry weight.

(8) Subtract each oven-dry weight from the corresponding original weight. Each difference, when the work has been properly done, is the loss in moisture of the section concerned.

(9) Divide the difference just obtained by the oven-dry weight and multiply the result by 100 for each section. Each final result is the percentage of moisture contained in the wood of a section, based on its oven-dry weight.

(10) Find the mean value of these individual percentages in order to obtain the average moisture content of all the sections. The result is considered the average moisture content of the lot of lumber that was sampled.

An example of the calculation for a typical moisture-determination section follows:

Original weight=284.7 grams.
Oven-dry weight=180.2 grams.
284.7 grams−180.2 grams=104.5 grams of moisture lost.
(104.5 grams ÷ 180.2 grams) ×100=58 per cent moisture originally in the wood.

For convenience and accuracy the gram is preferably used in moisture determination as the unit of weight, but other units, such as the ounce, may be employed. The scales customary in work on moisture-determination sections, however, are graduated in grams; a fraction of a gram is conveniently expressed as a decimal.

APPARATUS FOR MOISTURE DETERMINATION[6]

BALANCES

For weighing ordinary moisture-determination sections it is advantageous to use balances having a capacity of about 200 grams and sensitive to 0.1 gram. Several types are considered satisfactory: The ordinary analytical balance, the pans of which are suspended from a beam; the Harvard trip scale, which has the pans supported

[6] See footnote 4.

on top of its main beam and is provided with a scale beam and rider of 10 grams capacity; the torsion balance in which the beams are below the pans; and the triple-beam balance, in which the pan is suspended from one end of a multiple beam. Separate brass weights are used with the first three types, although the Harvard trip scale has also a small scale beam and rider. Balance is accomplished with the fourth type by means of a separate rider on each of the three units of the multiple beam.

For weighing larger samples or whole boards a platform scale having a capacity of 100 pounds or more and sensitive to 0.01 pound is quite satisfactory. Such a scale, although usual in type, is somewhat exceptional in quality, and only the better manufacturers make it.

OVENS

Both steam and electric ovens are in common use for drying moisture-determination sections. A suitable steam oven can be made of galvanized sheet iron, well insulated with mineral wool or equivalent material. It should be heated by means of a steam coil placed in the lower part, and ventilated by openings near the top and the bottom. Above the steam coil open shelves, usually of wire lattice or grating, should be provided for the sections. Steam ovens are generally home made. Electric ovens in which the heating element is thermostatically controlled may be purchased from various manufacturers.[7]

The moisture-determination sections, with either type of oven, should be open piled in order to permit good circulation of air around each piece and thus hasten drying. If some sections are dry and a large number of very wet sections are then placed in the oven, the dry sections may absorb moisture. Care should therefore be taken to avoid weighing supposedly dry sections under such a condition. It would be far better to weigh the previously dry sections either before the green sections are placed in the oven or after the green sections have become dry.

MOISTURE AND HUMIDITY

Wood possesses the property of giving off or taking on moisture from the surrounding atmosphere until the moisture in the wood has come to a balance with that in the atmosphere. This action is illustrated by Figure 1 which, for example, shows that wood, kept in an atmosphere constantly at 70° F. and 60 per cent relative humidity, will eventually come to a moisture content of about 11 per cent. The relative humidity of the surrounding air, therefore, is a very important factor in the seasoning of wood, and a general understanding of the relationship between humidity and drying is essential in any consideration of seasoning problems.

Absolute humidity is the weight of the water vapor contained in a unit volume of space; it is usually expressed as the number of grains of moisture per cubic foot (7,000 grains=1 pound avoirdupois). It does not indicate the drying capacity of the air, however, since the capacity of air to hold water, as illustrated by Table 1, varies greatly with temperature.

[7] A list of dealers handling apparatus for moisture content determination will be furnished by the Forest Products Laboratory, Madison, Wis., upon request.

TABLE 1.—*Moisture capacity of air at different temperatures at normal atmospheric pressure*

Temperature	Weight of moisture at saturation
° F.	*Grains per cubic foot*
20	1.2
40	2.9
60	5.8
80	11.1
100	20.0

RELATIVE HUMIDITY

Air containing the total number of grains of water vapor that it can hold at its temperature is saturated. The ability of air to dry

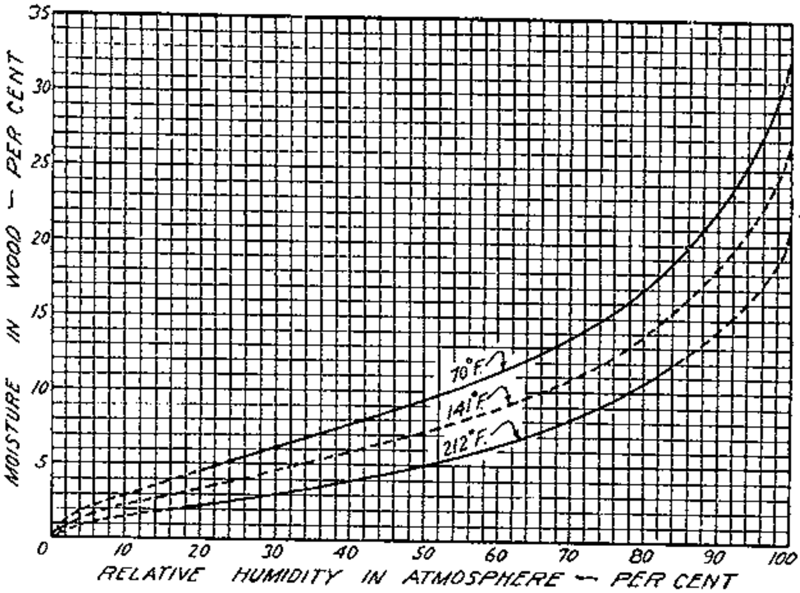


FIGURE 1.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere, at three temperatures

wood or any other substance varies with the amount of additional moisture it can hold before becoming saturated. The amount of vapor actually in the air, expressed as a percentage of the amount it would hold at saturation, is called its "relative humidity." The relative humidities of two equal amounts of air at the same temperature indicate their comparative drying abilities. Low humidities represent dry air and high ones moist air.

Referring to Table 1, 1.2 grains of moisture will saturate a cubic foot of air at 20° F.; the relative humidity of that air is then 100 per cent. If the air and its moisture are raised to a temperature of 80°, however, its relative humidity will decrease from 100 per cent to 11 per cent, thus:

$$\frac{1.2 \text{ grains}}{11.1 \text{ grains}} \times 100 = 11 \text{ per cent.}$$

At 100 per cent relative humidity air can not dry wood because it can hold no more moisture. At 11 per cent relative humidity, on the other hand, it may dry wood entirely too rapidly because of the great capacity for moisture it then has. At 60° the same air, with a relative humidity of about 21 per cent, perhaps would still dry wood more rapidly than is desirable. During the summer the relative humidities at representative points in the United States usually are between 40 and 80 per cent, although in very dry inland spots they may run as low as 20 per cent and on water fronts, especially on large bodies of water, they may go well above 90 per cent.

Assuming constant temperature and circulation, the drying of a given piece of wood depends entirely upon the humidity of the atmosphere surrounding it. On the other hand, when a given piece of wood is subjected to a given humidity the rate at which it loses moisture depends upon its moisture content; the higher its moisture content the faster it loses moisture.

Changes in atmospheric humidity range from the usual daily fluctuations to marked seasonal variations. Thus wood, when exposed to ordinary atmospheric conditions, is practically always undergoing at least slight changes in moisture content because of its tendency to come to definite balance with the surrounding air. This action accounts for the variation in final moisture content of thoroughly air-dry wood at different times of the year. The pick-up in moisture content of lumber left in a yard over the winter is likewise explained. Figure 1 shows the ultimate moisture content of wood when the wood is kept under constant temperature and relative humidity conditions for a sufficient length of time.

APPARATUS FOR RELATIVE-HUMIDITY DETERMINATION [5]

A very common method of determining relative humidity is by means of a wet-bulb and dry-bulb hygrometer. This instrument consists of two glass thermometers, the bulb of one of which is enveloped in a wick kept moist with distilled water, supplied from a small reservoir attached to the base of the instrument.

If the relative humidity is less than 100 per cent and a brisk air movement past the wick is taking place (it should be at least 15 feet per second), the reading of the wet-bulb thermometer will be less than that of the dry-bulb thermometer as a result of the cooling effect produced by the evaporation of moisture from the wick. The greater the difference between the two readings, the lower is the relative humidity, other conditions remaining constant. Table 2, which is based on experimental data, shows the relationship between dry-bulb temperature, the difference between wet-bulb and dry-bulb temperatures, and relative humidity.

[5] See footnote 4.

88499°—30——2

Table 2.—*Relative humidity table for use with wet-bulb and dry-bulb thermometers*

Temperature of dry bulb (° F.)	Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	---	---	---	---
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52	49	47	45	42	40	38	36	34	32
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	43	41	39	37	35	33
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56	53	51	49	46	44	42	40	38	36	34
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57	54	52	49	47	45	43	41	39	37	35
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58	55	53	51	49	47	44	42	40	38	36
114	97	94	91	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	49	47	45	43	41	39	37
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59	57	54	52	50	48	46	44	42	40	38
118	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59	57	55	53	51	49	47	45	43	41	39
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40
122	97	94	91	88	85	83	80	77	75	72	70	67	65	63	60	58	56	54	52	50	48	46	44	42	40
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61	59	57	54	52	50	48	47	45	43	41
126	97	94	91	88	86	83	80	78	75	73	70	68	66	64	61	59	57	55	53	51	49	47	45	44	42
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60	58	56	54	52	50	48	46	44	42
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	58	56	55	53	51	49	47	45	44
134	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63	61	59	57	55	53	51	49	48	46	44
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63	61	59	57	55	54	52	50	48	46	45
138	97	94	92	89	87	84	82	79	77	75	72	70	68	66	64	62	60	58	56	54	52	50	49	47	45
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46
142	97	95	92	89	87	84	82	80	77	75	73	70	68	66	64	62	60	58	57	55	53	51	49	48	46
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63	61	59	57	56	54	52	50	49	47
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	60	58	56	54	53	51	49	48
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48

Temperature of dry bulb (° F.)	Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit																								
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
60	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
70	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
80	12	10	7	5	3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
90	22	19	17	15	13	11	9	7	5	3	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---
100	28	26	24	22	21	19	17	15	13	12	10	8	7	5	4	2	1	---	---	---	---	---	---	---	---
102	30	28	26	24	22	20	18	16	15	13	11	10	8	7	5	4	2	1	---	---	---	---	---	---	---
104	31	29	27	25	23	21	20	18	16	14	13	11	10	8	7	5	4	2	1	---	---	---	---	---	---
106	32	30	28	26	24	23	21	19	17	16	14	13	11	10	8	7	5	4	3	1	---	---	---	---	---
108	33	31	29	27	25	24	22	20	19	17	16	14	12	11	10	8	7	5	4	3	2	---	---	---	---
110	34	32	30	28	26	25	23	21	20	18	17	15	14	12	11	10	8	7	6	4	3	2	1	---	---
112	35	33	31	29	27	26	24	23	21	19	18	16	15	14	12	11	9	8	7	6	4	3	2	1	---
114	35	34	32	30	28	27	25	24	22	20	19	18	16	15	13	12	11	9	8	7	6	5	3	2	1
116	36	34	33	31	29	28	26	25	23	22	20	19	17	16	14	13	12	11	9	8	7	6	5	4	2
118	37	35	34	32	30	29	27	25	24	23	21	20	18	17	16	14	13	12	11	9	8	7	6	5	4
120	38	36	34	33	31	29	28	26	25	23	22	21	19	18	17	15	14	13	12	10	9	8	7	6	5
122	39	37	35	34	32	30	29	27	26	24	23	22	20	19	18	16	15	14	13	11	10	9	8	7	6
124	39	38	36	34	33	31	30	28	27	25	24	22	21	20	18	17	16	15	14	12	11	10	9	8	7
126	40	38	37	35	33	32	30	29	27	26	25	23	22	21	19	18	17	16	15	13	12	11	10	9	8
128	41	39	37	36	34	33	31	30	28	27	25	24	23	22	20	19	18	17	16	14	13	12	11	10	9
130	41	40	38	37	35	33	32	30	29	28	26	25	24	22	21	20	19	18	16	15	14	13	12	11	10
132	42	40	39	37	36	34	33	31	30	28	27	26	24	23	22	21	20	18	17	16	15	14	13	12	11
134	43	41	39	38	36	35	33	32	30	29	28	26	25	24	23	21	20	19	18	17	16	15	14	13	12
136	43	41	40	38	37	35	34	33	31	30	28	27	26	25	23	22	21	20	19	18	17	16	15	14	13
138	44	42	40	39	37	36	35	33	32	30	29	28	27	25	24	23	22	21	20	19	17	16	15	14	14
140	44	43	41	40	38	37	35	34	32	31	30	29	27	26	25	24	23	21	20	19	18	17	16	15	14
142	44	43	42	40	39	37	36	34	33	32	30	29	28	27	26	24	23	22	21	20	19	18	17	16	15
144	45	44	42	41	39	38	36	35	34	32	31	30	29	27	26	25	24	23	22	21	20	19	18	17	16
146	45	44	43	41	40	38	37	36	35	33	32	30	29	28	27	26	25	24	22	21	20	19	18	17	17
148	46	45	43	42	40	39	38	36	35	34	32	31	30	29	28	26	25	24	23	22	21	20	19	18	17
150	46	45	43	42	41	39	38	37	36	34	33	31	30	29	28	27	26	25	24	23	22	21	20	19	18

TABLE 2.—*Relative humidity table for use with wet-bulb and dry-bulb thermometers*—Continued

Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit

Temperature of dry bulb (° F.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	56	54	52	50	49
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68	66	64	62	60	59	57	55	54	52	51
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	54	53	51
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	59	57	56	54	53
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	60	58	56	55	54
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	60	59	57	56	54
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	61	59	57	56	55
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	62	59	58	57	55
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59
220	[1]98	[1]96	[1]94	[1]92	[1]91	[1]89	[1]87	[2]85	83	82	80	78	77	75	74	72	71	69	68	66	65	64	62	61	60

Temperature of dry bulb (° F.)	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
152	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29	28	26	25	24	23	22	21	20	19	19
154	47	46	44	43	42	40	39	38	37	35	34	33	32	30	29	28	27	26	25	24	23	22	21	20	19
156	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30	29	28	27	25	24	23	23	22	21	20
158	48	47	45	44	43	41	40	39	38	36	35	34	33	31	30	29	28	27	26	25	24	23	22	21	20
160	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31	30	29	28	27	25	24	24	23	22	21
162	49	47	46	45	44	42	41	40	39	37	36	35	34	32	31	30	29	28	27	26	25	24	23	22	22
164	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32	31	30	29	28	26	25	25	24	23	22
166	50	48	47	45	44	43	42	41	39	38	37	36	35	33	32	31	30	29	28	27	26	25	24	23	23
168	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23
170	51	49	48	47	45	44	43	41	40	39	38	37	35	34	33	32	31	30	29	28	27	26	25	24	24
172	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34	33	32	31	30	28	27	26	26	25	24
174	51	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24
176	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	29	28	27	27	26	25
178	52	51	49	48	47	46	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
180	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35	35	34	33	31	30	29	28	27	27	26
182	53	51	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26
184	53	52	50	49	48	47	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	27
186	53	52	51	49	48	47	46	44	43	42	41	40	39	38	37	36	35	34	33	32	30	30	29	28	27
188	54	52	51	50	49	47	46	45	44	43	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
190	54	53	51	50	49	48	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	30	29	28
200	55	54	53	52	51	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34	33	32	32	31	30
210	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	32
220	58	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	41	39	39	38	37	36	35	34	33

[1] Possible only at pressures higher than normal atmosphere.
[2] Superheated steam, at normal atmospheric pressure, no air present. At lower humidities air is mixed with the water vapor.

MOISTURE AND SHRINKAGE

Shrinkage of wood takes place only in conjunction with a loss of moisture,[9] and, conversely, swelling of wood is a result of the absorption of moisture. Some loss of moisture, however, is not accompanied by shrinkage. As wood dries it first gives up only its free water, leaving the moisture in the saturated cell walls undisturbed until the cell cavities have become empty, and wood does not start to shrink until the cell walls themselves begin to lose moisture.

FIBER-SATURATION POINT

The condition in which the cell cavities are entirely empty, with the cell walls still saturated throughout, is thus an important point in drying. It is known as the "fiber-saturation point." The moisture content at which this condition occurs varies from 20 to 35 per cent, but for most species it is between 25 and 30 per cent. In actual practice, of course, the cells near the surface of a piece of wood dry below the fiber-saturation point before those in the interior reach it. Then, even though the average moisture content of the whole piece may be above the fiber-saturation point, the outer portion tends to shrink, while the interior does not; in fact, the interior resists the shrinkage pressure of the outer portion. Such a state is often the cause of serious drying troubles.

CHARACTERISTIC SHRINKAGE VALUES

The recently revised figures in Table 3[10] indicate the volumetric, radial, and tangential shrinkages of a number of species of commercial importance. Volumetric shrinkage, as the name shows, is the reduction in the volume of a piece as it dries below the fiber-saturation point. Radial shrinkage, for example, is the reduction in width of a quarter-sawed board as it dries. (Fig. 2.) Tangential shrinkage similarly is the reduction in width of a flat-sawed board. The shrinkage values in the table, which are based on the green dimensions, are expressed as percentages. They represent the averages of measurements of 1 by 4 by 1 inch specimens in drying from the green condition to the oven-dried condition. To approximate the shrinkage from the green to an air-dry condition of 12 to 15 per cent moisture content, the tabular percentages should be multiplied by one-half. Likewise, the shrinkage from the green condition to a kiln-dried condition of 5 per cent moisture content may be estimated as about four-fifths of the tabular percentages. For example, the average tangential shrinkage of red gum is 9.9 per cent when it is dried from the green to the oven-dry condition. Thus an average 10-inch plain-sawed green board would shrink about 1 inch if oven dried, about one-half inch if dried to 12 or 15 per cent moisture content, and about three-quarters of an inch if dried to approximately 5 per cent moisture content.

In using figures like those of Table 3, it should be borne in mind that shrinkage is an extremely variable property, one that is in-

---

[9] In common usage "moisture" means water, often water having small amounts of minerals or of acids in solution; this meaning is sufficient for the present purpose.

[10] The names of species of wood in the tables following are the standard common names given in the Check List of the Forest Trees of the United States (2).

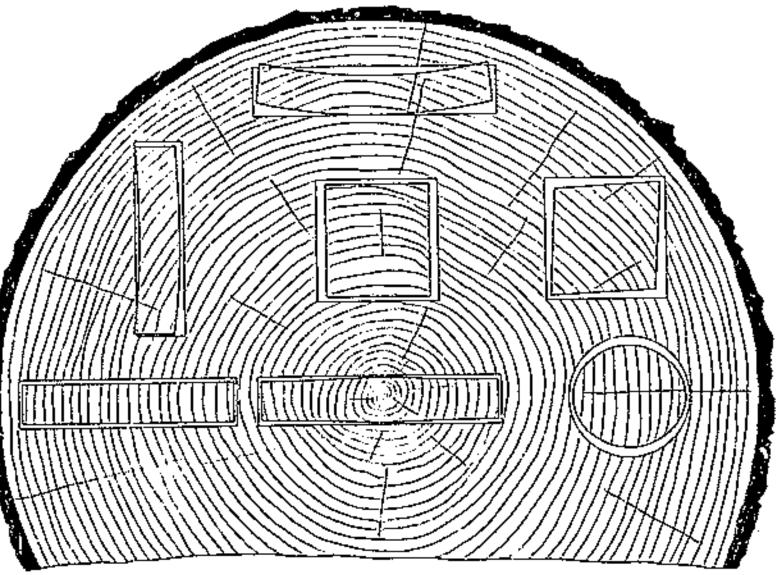


FIGURE 2.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial

fluenced by the density, the size, and the shape of the specimen and also by the drying conditions to which the specimen is exposed.

MOISTURE CONTENT AND FINAL USE

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, during drying from the green to the oven-dry condition, expressed in percentage of the green dimensions,*[1] *and average specific-gravity and weight values*

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Alder, red (Alnus rubra)	12.6	4.4	7.3	1.66	0.37	46	28
Apple (Malus pumila var.)	17.6	5.6	10.1	1.80	.61	55	47
Ash, Biltmore white (Fraxinus biltmoreana)	12.6	4.2	6.9	1.64	.51	45	38
Ash, black (Fraxinus nigra)	15.2	5.0	7.8	1.56	.46	53	34
Ash, blue (Fraxinus quadrangulata)	11.7	3.9	6.5	1.67	.53	46	40
Ash, green (Fraxinus pennsylvanica lanceolata)	12.5	4.6	7.1	1.54	.53	49	40
Ash, Oregon (Fraxinus oregona)	13.2	4.1	8.1	1.98	.50	46	38
Ash, pumpkin (Fraxinus profunda)	12.0	3.7	6.3	1.70	.48	46	36
Ash, white (Fraxinus americana)	13.3	4.9	7.9	1.61	.55	48	42
Ashes, commercial white (average of four species[2])	12.8	4.6	7.5	1.63	.54	48	41
Aspen (Populus tremuloides)	11.5	3.5	6.7	1.91	.35	43	27

[1] Radial and tangential shrinkage values are based on width measurements of small clear pieces 1 inch thick, 4 inches wide, and 1 inch along the grain; volumetric values are based on pieces 2 by 2 inches in cross section and 6 inches long.

[2] Fraxinus biltmoreana, F. quadrangulata, F. pennsylvanica lanceolata, and F. americana.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values): Volumetric	Shrinkage (measured values): Radial	Shrinkage (measured values): Tangential	Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—When green	Weight per cubic foot—At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Aspen, largetooth (Populus grandidentata)	11.8	3.3	7.9	2.30	0.35	43	27
Basswood (Tilia glabra)	15.8	6.6	9.3	1.41	.32	41	26
Beech (Fagus grandifolia)	16.3	5.1	11.0	2.16	.56	54	45
Beech, blue (Carpinus caroliniana)	19.1	5.7	11.4	2.00	.58	53	48
Birch, Alaska white (Betula neoalaskana)	16.7	6.5	9.9	1.52	.49	48	38
Birch, gray (Betula populifolia)	14.7	5.2			.45	46	35
Birch, paper (Betula papyrifera)	16.2	6.3	8.6	1.37	.48	50	39
Birch, sweet (Betula lenta)	15.6	6.5	8.5	1.31	.60	57	46
Birch, yellow (Betula lutea)	16.7	7.2	9.2	1.28	.55	57	43
Blackwood (Avicennia nitida)	15.6	6.2	9.7	1.56	.83	74	58
Buckeye, yellow (Aesculus octandra)	12.0	3.5	7.8	2.23	.33	40	25
Butternut (Juglans cinerea)	10.2	3.3	6.1	1.85	.36	46	27
Buttonwood (Conocarpus erecta)	14.6	5.4	8.5	1.57	.69	64	50
Cascara (Rhamnus purshiana)	7.6	3.2	4.6	1.44	.50	50	36
Catalpa, hardy (Catalpa speciosa)	7.3	2.5	4.9	1.96	.38	41	29
Cherry, black (Prunus serotina)	11.5	3.7	7.1	1.92	.47	46	35
Cherry, pin (Prunus pennsylvanica)	12.8	2.8	10.3	3.68	.36	33	28
Chestnut (Castanea dentata)	11.6	3.4	6.7	1.97	.40	55	30
Chinquapin, golden (Castanopsis chrysophylla)	13.2	4.6	7.4	1.61	.42	61	32
Cottonwood, black (Populus trichocarpa)	12.4	3.6	8.6	2.39	.32	46	24
Cottonwood, eastern (Populus deltoides)	14.1	3.9	9.2	2.36	.37	49	28
Dogwood (Cornus florida)	19.9	7.1	11.3	1.59	.64	64	51
Dogwood, Pacific (Cornus nuttalli)	17.2	6.4	9.6	1.50	.58	55	45
Elder, blueberry (Sambucus coerulea)	15.6	4.4	9.0	2.05	.46	65	36
Elm, American (Ulmus americana)	14.6	4.2	9.5	2.26	.46	54	36
Elm, rock (Ulmus racemosa)	14.1	4.8	8.1	1.69	.57	54	44
Elm, slippery (Ulmus fulva)	13.8	4.9	8.9	1.82	.48	56	37
Gum, black (Nyssa sylvatica)	13.9	4.4	7.7	1.75	.46	45	35
Gum, blue (Eucalyptus globulus)	22.5	7.6	15.3	2.01	.62	70	52
Gum, red (Liquidambar styraciflua)	15.0	5.2	9.9	1.90	.44	50	34
Gum, tupelo (Nyssa aquatica)	12.5	4.2	7.6	1.81	.46	56	35
Gumbo-limbo (Bursera simaruba)	8.6	2.3	3.6	1.57	.30	38	22
Hackberry (Celtis occidentalis)	13.8	4.8	8.9	1.85	.49	50	37
Hickory, bigleaf shagbark (Hicoria laciniosa)	19.2	7.6	12.6	1.66	.62	62	48
Hickory, mockernut (Hicoria alba)	17.9	7.8	11.0	1.41	.64	64	51
Hickory, pignut (Hicoria glabra)	17.9	7.2	11.5	1.60	.66	64	53
Hickory, shagbark (Hicoria ovata)	16.7	7.0	10.5	1.50	.64	64	51
Hickories, pecan (average of four species [3])	13.6	4.9	8.9	1.82	.59	62	45
Hickories, true (average of four species [4])	17.9	7.3	11.4	1.56	.65	63	51
Hickories, pecan and true (average of eight species[5])	17.7	7.2	11.3	1.57	.64	63	50
Holly (Ilex opaca)	16.2	4.5	9.5	2.11	.50	57	40
Hop-hornbeam (Ostrya virginiana)	18.6	8.2	9.6	1.17	.63	60	50
Inkwood (Exothea paniculata)	18.8	6.6	10.9	1.65	.73	71	56
Ironwood, black (Krugiodendron ferreum)	11.0	6.2	8.0	1.29	1.04	96	80
Laurel, mountain (Kalmia latifolia)	14.4	5.6	8.8	1.57	.62	62	48
Locust, black (Robinia pseudoacacia)	9.8	4.4	6.9	1.57	.66	58	48
Locust, honey (Gleditsia triacanthos)	10.8	4.2	6.6	1.57	.60	61	44
Madroño (Arbutus menziesii)	17.4	5.4	11.9	2.20	.58	60	46
Magnolia, cucumber (Magnolia acuminata)	13.6	5.2	8.8	1.69	.44	49	34
Magnolia, evergreen (Magnolia grandiflora)	12.3	5.4	6.6	1.22	.46	62	35
Magnolia, mountain (Magnolia fraseri)	13.0	4.4	7.5	1.70	.40	47	31
Mangrove (Rhizophora mangle)	15.8	5.4			.89	77	67
Maple, bigleaf (Acer macrophyllum)	11.6	3.7	7.1	1.92	.44	47	34
Maple, black (Acer nigrum)	14.0	4.8	9.3	1.94	.52	54	40
Maple, red (Acer rubrum)	13.1	4.0	8.2	2.05	.49	50	38
Maple, silver (Acer saccharinum)	12.0	3.0	7.2	2.40	.44	45	33
Maple, striped (Acer pennsylvanicum)	12.3	3.2	8.6	2.69	.44	37	32
Maple, sugar (Acer saccharum)	14.9	4.9	9.5	1.94	.57	56	44

[3] Hicoria cordiformis, H. myristicaeformis, H. aquatica, and H. pecan.
[4] Hicoria laciniosa, H. alba, H. glabra, and H. ovata.
[5] Species under footnotes 3 and 4 combined.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Mastic (Sideroxylon foetidissimum)	11.7	6.1	7.5	1.23	0.80	77	65
Myrtle, Oregon (Umbellularia californica)	11.9	2.8	8.1	2.80	.51	54	39
Oak, black (Quercus velutina)	14.2	4.5	9.7	2.16	.56	63	43
Oak, bur (Quercus macrocarpa)	12.7	4.4	8.8	2.00	.58	62	45
Oak, California black (Quercus kelloggii)	12.1	3.6	6.6	1.83	.51	66	40
Oak, canyon live (Quercus chrysolepis)	16.2	5.4	9.5	1.76	.70	71	54
Oak, chestnut (Quercus montana)	16.7	5.5	9.7	1.76	.57	61	46
Oak, laurel (Quercus laurifolia)	19.0	4.0	9.9	2.48	.56	65	44
Oak, live (Quercus virginiana)	14.7	6.6	9.5	1.44	.81	76	62
Oak, Oregon white (Quercus garryana)	13.4	4.2	9.0	2.14	.64	69	51
Oak, pin (Quercus palustris)	14.5	4.3	9.5	2.21	.58	63	44
Oak, post (Quercus stellata)	16.2	5.4	9.8	1.81	.60	63	47
Oak, red (Quercus borealis)	13.5	4.0	8.2	2.05	.56	63	44
Oak, Rocky Mountain white (Quercus utahensis)	12.5	4.1	7.2	1.76	.62	62	51
Oak, scarlet (Quercus coccinea)	13.8	4.6	9.7	2.11	.60	62	47
Oak, southern red (Quercus rubra)	16.3	4.5	8.7	1.93	.52	62	41
Oak, swamp red (Quercus rubra pagodaefolia)	16.4	5.2	10.8	2.08	.61	68	48
Oak, swamp chestnut (Quercus prinus)	16.4	5.9	9.2	1.56	.60	65	47
Oak, swamp white (Quercus bicolor)	17.7	5.5	10.6	1.93	.64	69	50
Oak, water (Quercus nigra)	16.4	4.2	9.3	2.21	.56	63	44
Oak, white (Quercus alba)	15.8	5.3	9.0	1.70	.60	62	48
Oak, willow (Quercus phellos)	18.9	5.0	9.6	1.92	.56	67	49
Oaks, commercial red (average of 9 species [6])	14.8	4.2	9.0	2.14	.56	64	44
Oaks, commercial white (average of 6 species [7])	16.0	5.3	9.3	1.75	.59	63	47
Oaks, commercial red and white (average of 15 species [8])	15.3	4.7	9.1	1.94	.57	63	45
Osage-orange (Toxylon pomiferum)	8.9	----	----	----	.76	62	----
Palmetto, cabbage (Sabal palmetto)	25.0	----	----	----	.37	54	27
Paradise-tree (Simarouba glauca)	8.6	2.2	5.2	2.36	.33	37	24
Pecan (Hicoria pecan)	13.6	4.9	8.9	1.82	.60	61	47
Persimmon (Diospyros virginiana)	18.3	7.5	10.8	1.44	.64	63	52
Pigeon-plum (Coccolobis laurifolia)	15.7	4.4	7.8	1.77	.77	73	55
Poisonwood (Metopium toxiferum)	11.6	4.2	7.2	1.71	.51	54	37
Poplar, balsam (Populus balsamifera)	10.5	3.0	7.1	2.37	.30	40	23
Poplar, yellow (Liriodendron tulipifera)	12.3	4.0	7.1	1.78	.38	38	28
Rhododendron, great (Rhododendron maximum)	16.2	6.3	8.7	1.38	.50	62	40
Sassafras (Sassafras varifolium)	10.3	4.0	6.2	1.55	.42	44	32
Serviceberry (Amelanchier canadensis)	18.7	6.7	10.8	1.61	.66	61	52
Silverbell (Halesia carolina)	12.0	3.8	7.6	2.00	.42	44	32
Sourwood (Oxydendrum arboreum)	15.2	6.3	8.9	1.41	.50	53	38
Stopper, red (Eugenia confusa)	13.3	6.2	9.1	1.47	.83	73	61
Sugarberry (Celtis laevigata)	12.7	5.0	7.3	1.46	.47	48	36
Sycamore (Platanus occidentalis)	14.2	5.1	7.6	1.49	.46	52	35
Walnut, black (Juglans nigra)	11.3	5.2	7.1	1.37	.51	58	39
Walnut, little (Juglans rupestris)	10.7	4.4	4.6	1.05	.53	55	40
Willow, black (Salix nigra)	13.8	2.5	7.8	3.12	.34	50	26
Willow, western black (Salix lasiandra)	13.8	2.9	9.0	3.10	.39	50	31
Witch-hazel (Hamamelis virginiana)	18.8	----	----	----	.56	59	43

SOFTWOODS (CONIFERS)

Cedar, Alaska (Chamaecyparis nootkatensis)	9.2	2.8	6.0	2.14	0.42	36	31
Cedar, incense (Libocedrus decurrens)	7.6	3.3	5.7	1.73	.35	45	26
Cedar, Port Orford (Chamaecyparis lawsoniana)	10.1	4.6	6.9	1.50	.40	36	29

[6] Quercus velutina, Q. laurifolia, Q. palustris, Q. borealis, Q. coccinea, Q. rubra, Q. rubra pagodaefolia, Q. nigra, and Q. phellos.
[7] Quercus macrocarpa, Q. montana, Q. stellata, Q. prinus, Q. bicolor, and Q. alba.
[8] Species under footnotes 6 and 7 combined.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

SOFTWOODS (CONIFERS)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Cedar, eastern red (Juniperus virginiana)	7.8	3.1	4.7	1.52	0.44	37	33
Cedar, western red (Thuja plicata)	7.7	2.4	5.0	2.08	.31	27	23
Cedar, northern white (Thuja occidentalis)	7.0	2.1	4.7	2.24	.29	28	22
Cedar, southern white (Chamaecyparis thyoides)	8.4	2.8	5.2	1.86	.31	26	23
Cypress, southern (Taxodium distichum)	10.5	3.8	6.2	1.63	.42	50	32
Douglas fir (Pseudotsuga taxifolia) (coast type)	11.8	5.0	7.8	1.56	.45	38	34
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	10.9	3.6	6.2	1.72	.40	35	30
Fir, alpine (Abies lasiocarpa)	9.0	2.5	7.1	2.84	.31	28	23
Fir, balsam (Abies balsamea)	10.8	2.8	6.6	2.36	.34	45	26
Fir, corkbark (Abies arizonica)	9.0	2.8	7.4	2.64	.28	29	21
Fir, lowland white (Abies grandis)	10.6	3.2	7.2	2.25	.37	44	28
Fir, noble (Abies nobilis)	12.5	4.5	8.3	1.84	.35	30	26
Fir, California red (Abies magnifica)	11.8	3.8	6.9	1.82	.37	48	27
Fir, silver (Abies amabilis)	14.1	4.5	10.0	2.22	.35	36	27
Fir, white (Abies concolor)	9.4	3.2	7.0	2.19	.35	47	26
Firs, white (average of four species [9])	10.9	3.8	7.9	2.08	.35	41	26
Hemlock, eastern (Tsuga canadensis)	9.7	3.0	6.8	2.27	.38	50	28
Hemlock, mountain (Tsuga mertensiana)	11.4	4.4	7.4	1.68	.43	44	33
Hemlock, western (Tsuga heterophylla)	11.0	4.3	7.9	1.84	.38	41	29
Juniper, alligator (Juniperus pachyphloea)	7.8	2.7	3.6	1.33	.48	42	36
Larch, western (Larix occidentalis)	13.2	4.2	8.1	1.93	.48	48	36
Pine, jack (Pinus banksiana)	10.4	3.4	6.5	1.91	.39	50	30
Pine, Jeffrey (Pinus jeffreyi)	9.0	4.4	6.7	1.52	.37	47	28
Pine, limber (Pinus flexilis)	8.2	2.4	5.1	2.13	.37	39	28
Pine, loblolly (Pinus taeda)	12.0	5.5	7.5	1.36	.50	54	36
Pine, lodgepole (Pinus contorta)	11.5	4.5	6.7	1.49	.38	39	29
Pine, longleaf (Pinus palustris)	12.3	5.3	7.5	1.42	.55	50	41
Pine, mountain (Pinus pungens)	10.9	3.4	6.8	2.00	.49	54	37
Pine, northern white (Pinus strobus)	8.2	2.3	6.0	2.61	.34	36	25
Pine, Norway (Pinus resinosa)	11.5	4.6	7.2	1.57	.44	42	34
Pine, pitch (Pinus rigida)	10.9	4.0	7.1	1.78	.45	50	34
Pine, pond (Pinus rigida serotina)	11.3	5.1	7.1	1.39	.50	49	38
Pine, sand (Pinus clausa)	10.0	3.9	7.3	1.87	.45	38	34
Pine, shortleaf (Pinus echinata)	12.0	5.1	8.2	1.61	.49	51	38
Pine, slash (Pinus caribaea)	12.7	5.8	8.2	1.41	.64	56	48
Pine, sugar (Pinus lambertiana)	7.9	2.0	5.6	1.93	.35	51	25
Pine, western white (Pinus monticola)	11.8	4.1	7.4	1.81	.36	35	27
Pine, western yellow (Pinus ponderosa)	9.6	3.9	6.3	1.62	.38	45	28
Piñon (Pinus edulis)	9.9	4.6	5.2	1.13	.50	51	37
Redwood [10] (Sequoia sempervirens)	6.8	2.7	4.2	1.56	.41	55	30
Spruce, black (Picea mariana)	11.3	4.1	6.8	1.66	.38	32	28
Spruce, Engelmann (Picea engelmannii)	10.4	3.4	6.6	1.94	.31	39	23
Spruce, red (Picea rubra)	11.8	3.8	7.8	2.05	.38	34	28
Spruce, Sitka (Picea sitchensis)	11.5	4.3	7.5	1.74	.37	33	28
Spruce, white (Picea glauca)	13.7	4.7	8.2	1.74	.37	35	28
Spruces (average of red, white, and Sitka [11])	12.1	4.3	7.7	1.79	.37	34	28
Tamarack (Larix laricina)	13.6	3.7	7.4	2.00	.49	47	37
Yew, Pacific (Taxus brevifolia)	9.7	4.0	5.4	1.35	.60	54	44

[9] Abies grandis, A. nobilis, A. amabilis, and A. concolor.

[10] The trees on which these values are based were somewhat higher in density than the general average for the species. Hence it is very probable that further tests, which are now under way, will slightly lower the present figures.

[11] Picea rubra, P. sitchensis, and P. glauca.

As previously mentioned, green wood is seasoned to remove a part of the moisture that it contains. It thus becomes better fitted for commercial use; the tendency to shrink, warp, and check after being placed in service is reduced, it is less subject to stain, mold, and insect attack, and the loss in weight results in lower freight charges and reduces other handling costs.

The fact that wood below the fiber-saturation point shrinks and swells with changes in moisture content makes it highly desirable, in the seasoning process, to obtain for the wood a final moisture content that will be suitable for the condition of ultimate use. In the past this matter has been given too little consideration, but the necessity for attention to this phase of drying is becoming more and more apparent.

The moisture content of lumber dried even according to the best air-seasoning practice varies somewhat. Neglecting this condition, which can be corrected by heated storage or similar means, absolute attainment of a proper final moisture content for all uses is not feasible in commercial work, both on account of the diverse purposes for which wood is employed and the wide range of atmospheric conditions to which it is subjected. Wood thoroughly air-dry at Galveston, Tex., for example, is likely to have a moisture content somewhat greater than that of air-dry wood in the general Middle West States and considerably greater than that customary for interior woodwork in heated buildings. Such conditions indicate clearly that the final moisture-content problem is a difficult one and also emphasize its importance. To solve the problem it is often necessary to kiln-dry the wood instead of air-drying it, or in addition to air-drying it.

GENERAL PRINCIPLES OF DRYING WOOD

MOVEMENT OF MOISTURE IN WOOD

PRESENT KNOWLEDGE

Although the actual phenomena of drying wood are not yet understood in all their details, there is considerable knowledge that bears on the practical seasoning problem. As stated before, wood upon drying first loses its free water and then that which is contained in the cell walls. The moisture in the interior of a piece of wood can come to the surface only as a vapor moving along the capillary channels in the wood, after evaporating inside of the piece, or as a liquid moving either through the same channels or through the cell walls. Regardless of whether such moisture moves outward as a vapor, or as a liquid, or as both, on account of the nature of wood structure the end grain of wood loses moisture more rapidly than the side grain does.

In a consideration of the air-seasoning process, a general understanding of the movement of moisture in wood is sufficient. It can be assumed that the moisture tends to distribute itself evenly through the wood, moving from the moist regions to the drier ones. The really important fact, however, is that the temperature and the humidity of the atmosphere at the surface of the wood are controlling factors, while circulation of the air is of extreme importance in maintaining and in modifying them.

EFFECT OF TEMPERATURE

The temperature of the air surrounding wood affects seasoning in a number of ways. Heat is consumed when evaporation takes place, and the ease of transfer of the heat from the air to its point of consumption increases with increase in temperature of the air entering the pile. The heat required for evaporation must be supplied by the air, adequate circulation of the air is required for such supply, and largely because of increased cooling effects local circulation in the pile is likely to be better at high temperatures than at low. As already pointed out, an increase in the temperature of the air increases its capacity to hold moisture and thus hastens evaporation. Below the fiber-saturation point a certain amount of heat is required to separate water from wood, the amount increasing as the wood becomes drier; air at a high temperature holds more heat, which it can give up for this purpose, than the same air at a low temperature.

The effects of the temperature of the surrounding air upon the drying process explain certain conditions encountered in air seasoning. For example, even during the coolest months of the year a comparatively rapid loss of moisture from bare wood occurs until a moisture content of about 30 per cent is reached. Then a rather abrupt decrease in the drying rate usually takes place.

EFFECT OF RELATIVE HUMIDITY

The relation of the relative humidity of the surrounding air to the moisture in wood has been discussed previously (p. 6). It was pointed out that this relationship determines the extent to which wood dries. At a given temperature, the relative humidity determines also the rate of drying. In general, other factors remaining constant, the lower the relative humidity the faster will drying take place, and, conversely, the higher the relative humidity the slower will be the drying. This is true because lowering the humidity reduces the moisture content of the wood at the surface, thus increasing the rate of movement of moisture toward the surface and consequently hastening the drying.

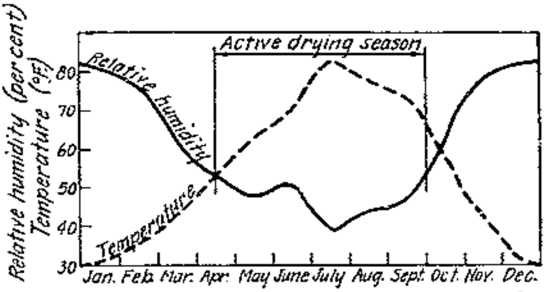
EFFECT OF CIRCULATION

Circulation also plays a large part in the seasoning process. As wood dries, the evaporation both uses up heat and increases the amount of moisture in the surrounding air. Hence circulation is required to supply the heat necessary for evaporation and also to remove the evaporated moisture. Circulation is thus a prime factor in the drying of wood by any method and is particularly important in air seasoning, because there it is the only essential factor that can be controlled to an appreciable extent. Further, when the circulation is sluggish, the air in direct contact with a green board is likely to be at a high relative humidity, perhaps even as high as 100 per cent. Obviously the relative humidity of the film of air immediately at the surface of the board has a major effect on the drying rate of the wood and, since this relative humidity is influenced directly by the rate of circulation, the importance of circulation is again evident.

APPLICATION TO AIR SEASONING OF THE GENERAL PRINCIPLES OF DRYING WOOD

GENERAL CONDITIONS AT THE LUMBER PILE

The air seasoning of lumber, like any process for drying wood, is dependent upon the temperature, humidity, and circulation of the surrounding air. Consequently the regional climatic conditions,



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF THE VALUES READ DAILY AT 4 P.M.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
150	120	100	100	90	75	50	75	225	225	225	200

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20	20	18	15	14	14	12½	13	14	15	20	20

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

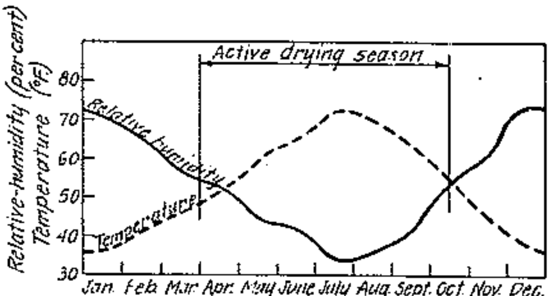
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	–	–	–	–	–	–	–	1	2	2	2

D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 3.—Graphic chart of major air-seasoning factors in the Inland Empire. The chart is based on average figures covering a period of two years and representing five yards drying 4/4-inch western white pine and western yellow pine stock. It indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

affected as they are by local factors such as elevation, topography, drainage, and water bodies, constitute the primary influences in air seasoning. Although efficient air-seasoning practice is designed to exert some control upon the drying conditions within the lumber pile, there is some relationship between these conditions and those outside. No matter what the yard methods, a warm, dry, and windy climate will cause faster drying and lower final moisture content than will cool, damp, and calm climatic conditions.

There is considerable variation in geographic and climatic factors among the various lumber-producing regions and also among yards in the same region. The influence of such natural conditions upon the air-seasoning process is illustrated in a broad way by the data presented in Figures 3 to 6, inclusive, which show the effect of different weather conditions upon actual seasoning in the western softwood regions. The moisture content for thoroughly air-dry



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
120	90	70	70	60	55	50	45	160	160	140	140

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR 6/4-INCH STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20	18	16	14	12	10	9	9	10	12	16	18

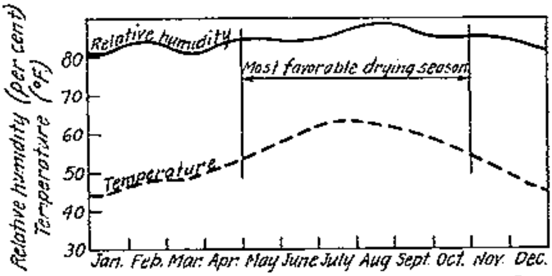
C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	—	—	—	—	—	—	—	—	1	1½	2

D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 4.—Graphic chart of major air-seasoning factors in the California pine region. The chart, which is based on the average of representative figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

stock (C of figs. 3–6) indicated for each month is not to be considered as the equilibrium moisture content for the temperature and the relative humidity shown in the curves of the same chart (A of figs. 3–6), because the temperature and the relative humidity readings for each day represent only two observations, which are not sufficient in number to give true averages. The curves adapted from Department Bulletin No. 1425, however, do show the general trend in temperature and relative humidity from month to month. Even though these natural conditions must be largely accepted, a knowledge of them and recognition of their consequence in seasoning are essential in the intelligent selection of a yard site, in the proper laying out of the seasoning yard, and in the development of effective piling methods.



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
180	150	150	120	100	80	70	100	250	220	200	180

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR 4/4-INCH STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
24	25	22	20	18	16	15	15	16	17	19	21

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	1	—	—	—	—	—	—	—	1	2	3

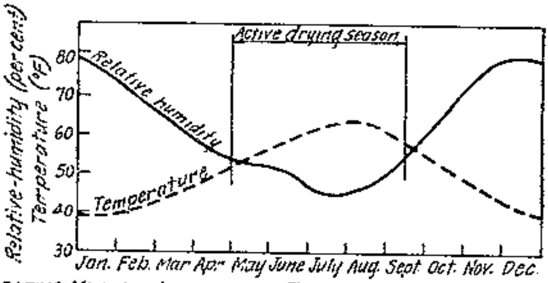
D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 5.—Graphic chart of major air-seasoning factors in the redwood region. The chart, which is based on the averages of representative figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

The aim of air-seasoning practice must be limited to employing the favorable natural elements to the greatest possible advantage and to minimizing the unfavorable factors as far as is practicable. The means for accomplishing this aim are brought out in the later and more detailed discussion of air-seasoning practice.

TEMPERATURE IN THE LUMBER PILE

Within the limits of existing climatic conditions, some indirect control of temperature in the lumber pile is possible. Through the provision of adequate means for circulation both in the yard and in the pile, the air cooled by evaporation is replaced by warmer air from the outside, thus increasing the temperature. Further, some heat is transmitted to the lumber from the direct rays of the sun, which reach at least a part of the pile during some portion of the



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

	Th'kness	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct.	Nov.	Dec
To Reach 20 Per Cent Moisture Content	4/4	100	80	55	35	25	20	20	15	220	190	160	130
	8/4	110	90	65	45	35	30	30	25	230	200	170	140
To Reach 15 Per Cent Moisture Content	4/4	145	120	100	70	45	40	40	45	270	240	210	180
	8/4	165	140	115	90	60	55	55	320	290	260	230	200

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR STOCK, PILED IN THE MONTHS INDICATED, TO REACH THE MOISTURE CONTENT SHOWN; LOCAL VARIATION IN CONDITIONS MAY CAUSE A DIFFERENCE OF 10 TO 20 DAYS FROM THE AVERAGE PERIOD

Jan	Feb.	Mar	Apr	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
26	24	22	18	16	15	12	13	15	16	22	26

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY 4/4-INCH STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct.	Nov.	Dec
—	—	—	—	—	—	—	—	2	2	2	2

D.—AVERAGE PICK-UP OF MOISTURE BY 4/4-INCH YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 6. Graphic chart of major air-seasoning factors in the Douglas fir region. The chart, which is based on the averages of representatives figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant.

day. The extent of the pile surface that receives direct sunlight, as well as the length of the daily period during which it is received, can be controlled to some extent by varying the spacings around the pile and changing the direction of the openings between piles.

HUMIDITY IN THE LUMBER PILE

Control of humidity conditions within the pile, as far as it is possible, also can be accomplished only by indirect means. Circulation, if it occurs, carries away the moist air resulting from seasoning and replaces it with air from the outside that contains less moisture. The regulation of temperature mentioned in the preceding paragraph also affects the relative humidity, since an increase of temperature means that the drying capacity of the air is increased.

CIRCULATION IN THE LUMBER PILE

The functions and the importance of circulation in air seasoning have been indicated in the discussions of temperature and humidity control. Circulation is the only drying factor that is subject to direct methods of control.

The movement of air in a lumber pile is the resultant of two general types of circulation. Horizontal circulation is caused primarily by the local wind currents. Vertical circulation, on the other hand, is an internal movement produced by evaporation and the resulting differences in temperature throughout the pile.

Horizontal circulation can be regulated to some extent by variations in yard layout, in foundation construction, and in piling methods. The arrangement and spacing of main alleys and rear alleys and the intervals between piles on the same alley affect the movement of the local air currents to a large extent. Likewise the clearance under the pile foundations exerts an appreciable influence. The actual inlet and outlet of the wind currents to and from the pile are greatly affected by the method of pile construction. For example, an increase in the thickness of the stickers materially assists in building up positive horizontal circulation.

Vertical circulation in a lumber pile is a seasoning factor of the utmost importance and hence should be thoroughly understood. As the green stock in a pile dries, the evaporation uses up heat, which is taken from the air in contact with the stock. This air, thus becoming cooler and consequently heavier, tends to drop [11] gradually toward the bottom of the pile. Methods of pile construction should therefore be designed to aid this natural movement, permitting as far as possible an unobstructed and continuous vertical flow of air. To secure the maximum benefits from vertical circulation, it must be adequate, not only at a single point but also entirely across the pile from one side to the other. This means that vertical air channels, well distributed, are essential.

The natural downward movement of cool, moist air in a lumber pile results in partial stagnation and slow drying in the lower section unless proper means are provided to insure the removal of such air. Thus horizontal circulation, particularly in the lower portion of the pile and beneath it, is a necessary adjunct to the vertical circulation. Such movement toward the outside of the pile results from external

[11] Such movement is in the general direction that normally obtains during the greater part of the time in which actual drying is taking place. During cool days, and especially during cool nights when the lumber is dry or practically so, the cooler outside air entering a warmer space within the pile may cause a temporary reversal of this downward movement.

wind currents and to a less degree from a natural outward flow in the lower portions of the pile, caused by the pressure of the downward movement. The outward flow can be aided materially by the control methods already discussed in connection with horizontal circulation.

There is much misconception as to the movement of air in a lumber pile. If the natural tendency of the air to drop toward the bottom of the pile is not fully appreciated and adequately recognized in the development of the entire air-seasoning practice, serious drying troubles are almost certain to develop. The drying in the lower

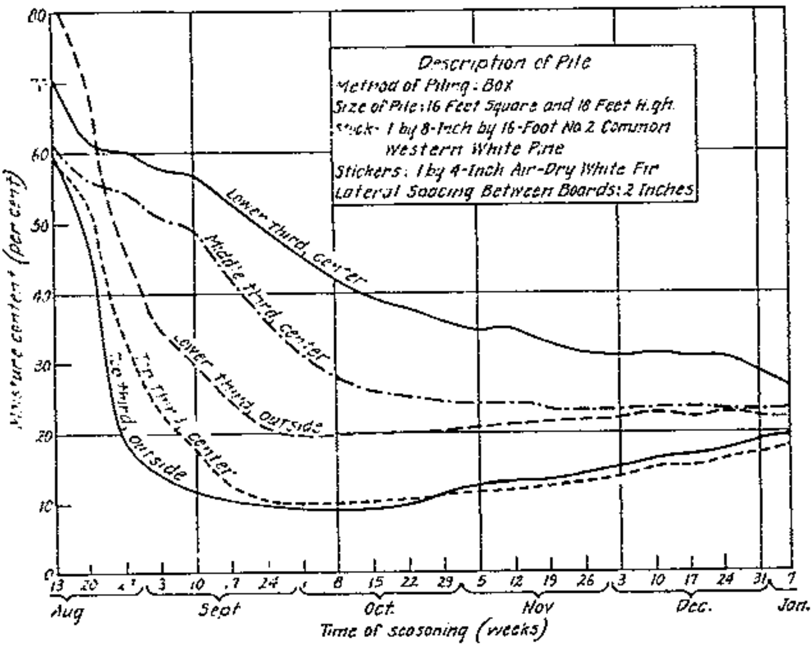


FIGURE 7. Representative changes in moisture-content values in different parts of a typical pile of softwood yard lumber

part of the pile will then lag behind that in the other parts. As a result, the average drying time will be lengthened, a portion of the stock may never reach a thoroughly air-dry condition, and the liability of the development of stain and decay will be increased. Such a lag in drying is illustrated by Figure 7, taken from Department Bulletin No. 1425, which represents actual drying conditions in different parts of a common type of lumber pile.

SMOKE MACHINE

In studying the effect of wind, temperature, and method of piling on the direction and the rate of air movement in a lumber pile, it may be helpful to use a smoke machine. This apparatus may consist of two glass containers, each about 1¼ inches in diameter and 5 inches long, one of which is filled halfway with ammonium hydroxide (ammonia water: specific gravity 0.9) and the other with hydrochloric acid (specific gravity 1.19). The containers are provided with 2-hole rubber stoppers and are connected by a glass tube about one-fourth inch in outside diameter. By means of a rubber bulb air is blown into the upper part of one container, forcing the vapor there over to the similar space in the second container, where it unites with the vapor above the other liquid, thus forming ammonium chloride. This salt emerges as a white smoke. When the smoke is released in a current of air it is carried along with the current, thus making the air movement evident. For the sake of convenience the containers may be supported in a small wood block drilled with holes of the proper size and provided with a short handle. In some cases it is advantageous to connect several feet of ⅜-inch rubber hose to the discharge opening in the second rubber stopper, so that the smoke can be directed to any desired point. If the tubing becomes clogged, the ammonium chloride may be readily dissolved in water.

The Kiln Drying Handbook[12] illustrates a smoke machine of similar construction.

SEASONING DEFECTS AND THEIR CAUSES

The defects responsible for the depreciation incident to air seasoning are definitely related to the drying process itself or to the time element of that process. An explanation of their causes will permit a better appreciation of the possibility and the means of preventing them. These defects may be grouped as those resulting from shrinkage and those caused by the action of minute organisms that belong to a low form of plant life known as fungi.

In the first group are check, honeycomb, cup, bow, crook, twist, loosening of knots, and collapse. The second group includes stains and decay. Blue stain is the principal stain of economic importance in the air seasoning of many species, both hardwoods and softwoods, although brown stain (p. 29) is of some importance in certain softwoods. On account of the general climatic conditions in the West and the drying periods usually required there, decay need not be considered an air-seasoning defect in lumber in that region. In the South, on the other hand, both climatic and logging conditions are very conducive to the development of decay. All of the measures taken to reduce blue-stain development are also helpful in decay prevention.

DEFECTS RESULTING FROM SHRINKAGE

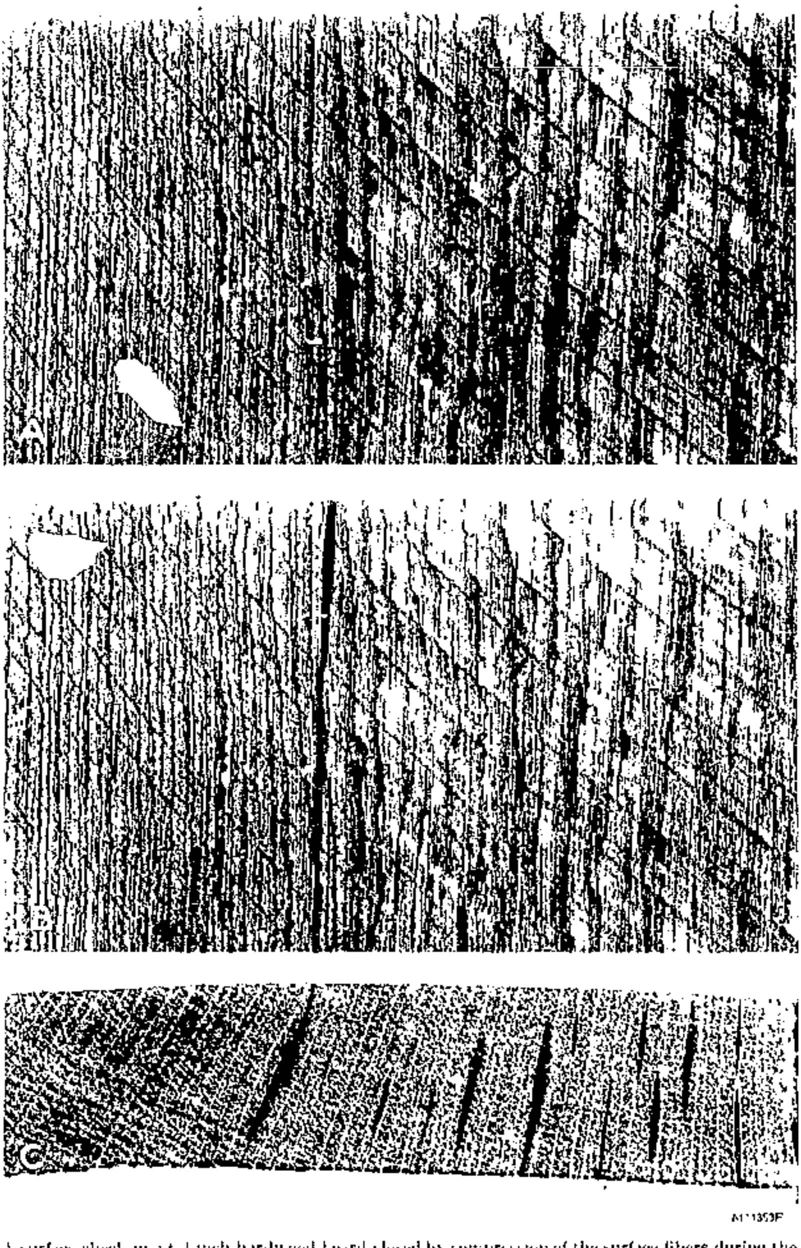
END AND SURFACE CHECKS

Lumber checks as a result of uneven shrinkage. Such shrinkage may be due to one or both of two causes, uneven drying and the inherent difference in the amounts of radial and tangential shrinkage of wood.

There are three common causes of uneven drying: (1) The end grain of wood gives off moisture more rapidly than the side grain; (2) surface layers dry faster than those in the interior, especially during the early stages of drying; (3) a portion of a board fully

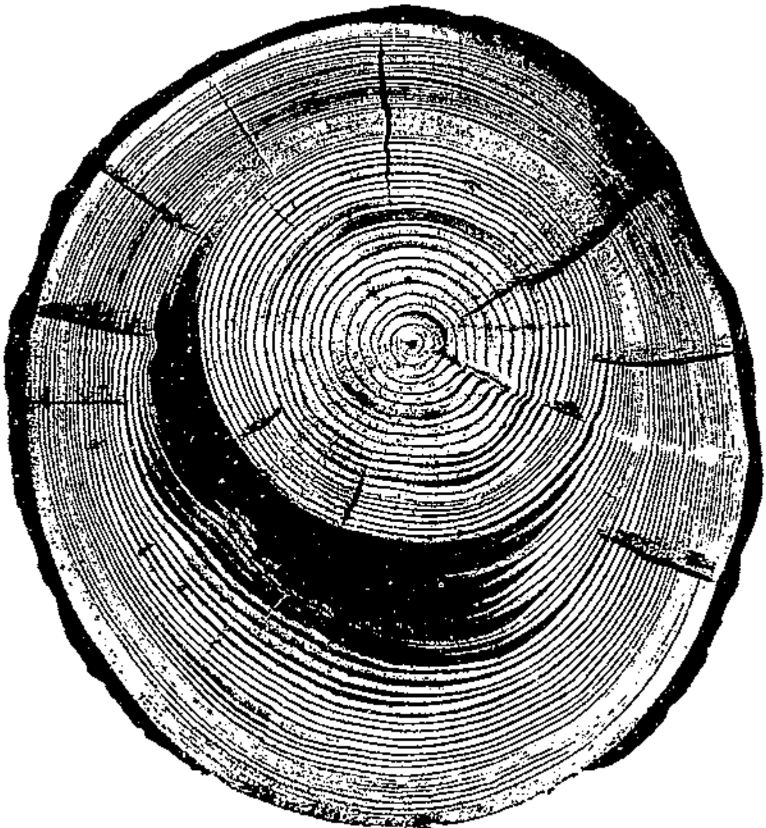
---

[12] See footnote 4.



M11350F

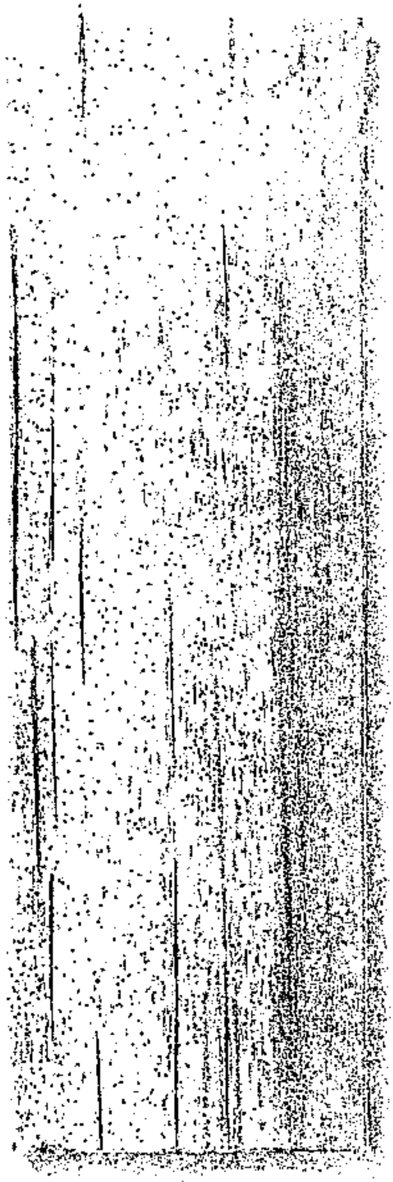
A surface check in a 6/4-inch hardwood board closed by compression of the surface fibers during the latter part of the seasoning period. A, Normal appearance of the surface; B, the sides of the check forced apart at one surface; C, cross section of the board at the check.



A

M11569F

Compression wood. A, The dark, wide rings in the lower part of the cross section are compression wood; B, crook caused by the extreme longitudinal shrinkage of compression wood on the upper edge of a 2 by 4 inch stud. The 12-inch ruler indicates the length of the 8-foot stud



Blue stain in a conifer. The dark-blue specks are the ends of the wood rays. The pale orange-colored wood at the right is unstained heartwood

A section of damaged heartwood of a conifer. The typical decay illustrated is caused by the ring-scale fungus. The light-colored wood at the right is sound sapwood exposed to the drying effect of the air loses its moisture before an adjacent section not so exposed dries to the same extent.

Tangential shrinkage, the shrinkage across the width of plain-sawed stock, is on an average about twice as great as radial shrinkage, which is the shrinkage across the width of quarter-sawed stock. Table 3 gives the ratios of tangential to radial shrinkage for various commercial species.

The end checking of lumber during air seasoning is largely due to the uneven shrinkage caused by the exposed ends of the boards drying more rapidly than the adjoining portions. Not only does end grain give off its moisture more rapidly than side grain, but in addition portions of both the major side-grain surfaces, near or next to the ends, are kept from direct contact with the drying effect of the air by the stickers that cover them. It follows that two actions are necessary to minimize end checking: Ends of the stock should be shaded to decrease the rate of end drying, and the area of the board faces not exposed to the air should be reduced as far as practicable. As explained on page 40, end coating may be used instead of shading in order to reduce end checking.

Season checks that appear on the faces of the stock result both from uneven drying and from the difference between tangential and radial shrinkage. Checks caused by uneven drying may be due to one of two conditions. With excessively rapid surface drying, the outer layers become much drier than those in the interior and tend to shrink before the inside portion is dry enough to do so. The stresses thus set up in the piece may cause checking, which may become apparent either immediately or when the stock is run through the planer. The other condition causing checks obtains when a portion of the piece is shut off from the air. The exposed portion begins to shrink before the protected one is dry enough to do so, and checking occurs in the shrinking portion because of the restraint of the unchanged one. Stickers are often responsible for such checks in the stock. The checking in plain-sawed pieces for which the difference between radial and tangential shrinkage is responsible occurs because the face of the piece that is closer to the heart is more nearly a radial face than the other. Such a piece also tends to cup, but because it may be restrained by the stickers the stresses set up may result in checking. The avoidance of excessively rapid drying tends to reduce all forms of checking, while a decrease in the area covered by the sticker will materially lower the amount of checking resulting from differences in exposure to the air.

Very wide flat-sawed boards and planks are liable to check. For this reason it is advisable to season lumber, particularly aircraft stock, in the narrowest usable widths, unless warping interferes.

HONEYCOMB

The surface of a piece of green wood dries before the interior, and in consequence its shrinkage is opposed by the interior, which during the early stages of drying remains above the fiber-saturation point. During these stages the difference in tendency to shrink sets up a tension in the surface, which may result in checking, and a compression in the interior; the tension and the compression are across the grain. As the drying process continues shrinkage of the interior begins, and in turn is opposed by the surface, which has become set in an expanded condition: that is, the surface has been partially restrained in shrinking and consequently is wider across the grain than it would be at the same moisture content if it had been free to shrink. The difference in shrinkage now results in a compression of the surface and a tension in the interior. The compression may be sufficient to close the surface checks so that they become invisible. (Pl. 1.) Although the checks possibly are invisible and can not be detected by a grader, they may again become visible if the piece is exposed alternately to high and to low humidities either in a dry kiln or elsewhere.[13]

The interior tension just described may exceed the strength of the wood, and consequently may tear the interior fibers apart. If it does so, the resulting defect is called honeycomb. The minimization of honeycomb involves methods of piling that will retard the drying rate.

CASEHARDENING

When the surface of a piece of wood is set in an expanded condition, and consequently is in compression, while the interior is in tension, the piece is said to be casehardened. When such a piece is resawed the new surfaces tend to become concave. If casehardening is objectionable, it can be relieved by proper steaming methods in a dry kiln. For most purposes for which stock in the air-seasoned condition is to be used, however, such a procedure is not required.

CUP, BOW, CROOK, AND TWIST

Cupping, the transverse (crosswise) concaving of a piece of lumber, is caused in a number of ways. The difference in shrinkage resulting from uneven drying is often responsible. When stock is piled with two layers to the course, one face of each piece dries more rapidly and reaches a lower final moisture content than does the other. This condition may result in cupping. Further, a plain-sawed board, although uniformly dried, may tend to cup because, as previously mentioned, the face that grew nearer the center of the tree may be more nearly a radial face than the opposite face. Such a condition produces cupping away from the heart. In general cupping may be held to a minimum by allowing both faces of the stock to dry evenly and by proper stickering.

Bow may be defined as a longitudinal distortion of a board, of such a kind that its face has become convex or concave. Crook is the corresponding edgewise distortion. Twist, on the other hand, makes one or both edges of a board take the form of a helix or of a spiral. Warp involves any kind of distortion: it is the general term that includes cup, bow, crook, and twist. Such types of defect are usually the result of uneven shrinkage caused by a lack of uniformity in the structure of a piece of wood. Spiral, interlocked, or diagonal grain is commonly responsible, although the large longitudinal shrinkage of compression wood is the most frequent cause of crook.

---

[13] See footnote 4.

(Pl. 2.) Minor distortional defects may result from uneven drying, and those defects caused primarily by the wood structure can be aggravated in this manner. Preventive measures consist chiefly in the use of piling methods that will hold the stock firmly in proper alignment.

LOOSENING OF KNOTS

Knots are loosened during seasoning because of the drying of the cementing resins and gums and because of differences in the shrinkage of the knot and of the surrounding wood. Since the axis of a knot-forming branch is approximately at right angles to that of the tree, a knot in a plain-sawed board shrinks away from the wood lengthwise of the board and also shrinks away, though to a less extent, crosswise of the board. Further, since the shrinkage in the thickness of the board (across its grain) is greater than that of the knot in the same direction (along its own grain), knots are often loosened also when the stock is machined, probably as much because the knot frequently projects beyond the surface of the board as because it is harder than the wood around it. The loosening of knots can not be entirely avoided by any method of seasoning, since a certain type of knot is not directly connected with the wood surrounding it: such knots, which are called "encased," are usually surrounded with bark. Depreciation from knot loosening, however, can be reduced somewhat in air seasoning by measures that prevent excessively rapid drying and extremely low final moisture content. When the knot is firmly intergrown with the surrounding wood it is likely to check rather than to come loose as a unit.

COLLAPSE

During air seasoning a form of defect called collapse sometimes occurs in the heartwood of a few species, such as red gum and swamp oak. Rows of cells collapse like a punctured rubber tire; and if the collapse has been at or near the surface, the surface of the wood then has a washboard appearance; this appearance occurs in boards rather than in planks. Collapse is relatively uncommon in air seasoning.

OTHER IMPORTANT DEFECTS [11]

BLUE STAIN

In the air seasoning of such species as southern and western yellow pine, northern and western white pine, red gum, sugar pine, basswood, and maple, the prevention of blue stain is often the major drying problem. This defect is a discoloration of the sapwood that is due directly to the growth within the wood of threads of the blue-stain fungi. These fungi are minute plants that absorb their nourishment from the wood they inhabit, feeding principally upon the cell contents. As the fungous threads grow, they pass from one cell to another, usually through openings in the cell wall, but occasionally boring through the wood itself. (Figs. 8 and 9.)

---

[11] The author wishes to make special acknowledgment to the Office of Forest Pathology, which is maintained by the Bureau of Plant Industry of the U. S. Department of Agriculture in cooperation with the Forest Products Laboratory. The Office of Forest Pathology has contributed very materially to the present knowledge of blue stain and other fungous defects in wood.

Blue stain, in its development, appears first in spots or streaks on the surface of the wood. Later, as the fungus penetrates deeply, the entire sapwood may be discolored. The blue-gray color of the stain appears in the wood only after numeous very small threads of the fungus have reached a certain development within the wood cells. (Pls. 3 and 4.) When these threads, feeding on the contents of the cell and to a slight extent on the cell walls, reach a certain stage of their growth, fruiting bodies—comparable in some ways to the seed pods of a flowering plant—are produced upon the surface of the wood. These fruiting bodies, which appear as tiny black specks upon the blued wood, resemble small black hairs or bristles swollen at the base. (Fig. 10, A.) Minute spores, which are comparable to seeds, are ejected from them. (Fig 10, B.)

These spores, when carried about by the wind or other means, cause new infections by germinating on bright lumber green from the saw or on other favorable places. Although a blue-stain organism may be present in certain logs before the logs are sawed into lumber, the chief source of infection is that just mentioned. Accordingly, yard sanitation and discrimination in the repeated use of stickers are highly important measures in blue-stain prevention.

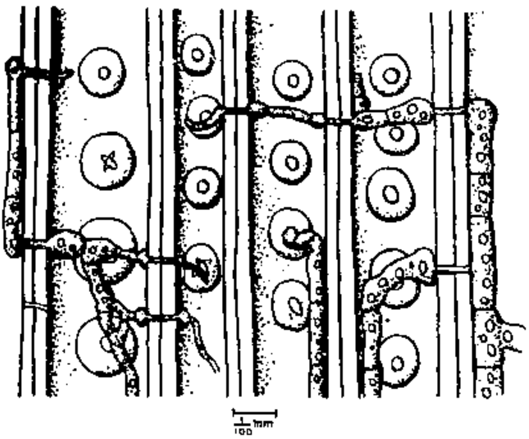


FIGURE 8.—A diagram of young threads (hyphae) of a blue-stain fungus in the cells of a softwood, showing direct penetration of the cell walls. The threads are constricted where they pass through the walls. In the lower center one thread is passing through a bordered pit. Enlarged about 500 times

Blue stain does not materially affect the strength properties of wood; it is not an early stage of decay. The stain, however, often lowers the value of the product for uses, such as natural-finish surfaces, where the discolorations are objectionable.

Blue-stain fungi require an abundant food supply in the wood, a comparatively high moisture content of the wood, and warm weather. Blue stain is likely to occur, especially during rainy periods, in the warmer seasons of the year when the air is humid and seasoning is correspondingly slow, particularly if proper piling and storage methods are not employed.

It has been observed that blue-stain fungi grow best on substances that contain some acid: the acid of sour sap is very favorable for the development of the blue-stain and decay organisms. This fact indicates why souring or fermenting of the sapwood is often advanced as the origin of the blue-stain blemish and decay instead of the true cause, fungous development.

The blue-stain organisms ordinarily do not attack the normal living tree. In wood products the blued areas are usually confined to the sapwood, ending where the heartwood begins. The fact that some species of wood blue more readily than others has not been explained. Possibly the food or moisture conditions in the sap vary sufficiently among species to account for this selective action. From the investigative work conducted so far on the moisture requirements of the blue-stain organisms it seems safe to assume that there is little danger of sap-stain development in wood that has a moisture content not exceeding 20 per cent.

The relation between the seasoning process and blue-stain fungi is obvious. The occurrence of this defect is primarily the result of insanitary yard conditions and of practices conducive to slow seasoning. Measures for minimizing it include steaming, chemical dips, yard sanitation, and yard practices that will permit rapid seasoning, especially in the initial stages of seasoning and in the lower third of the lumber pile. Preliminary steaming and chemical dips are discussed on pages 52 and 53.

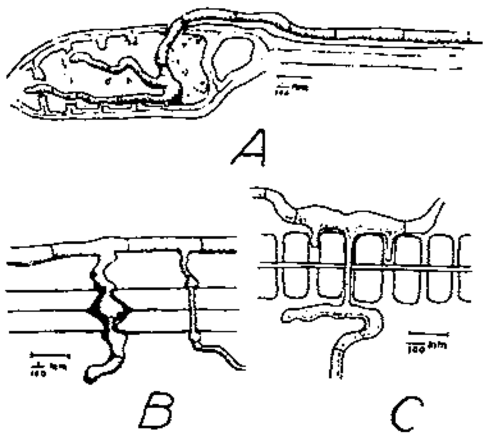


FIGURE 9.—A diagram of a blue-stain fungus in a softwood decomposing the wood ray at A and penetrating the cell walls at B and C. Enlarged about 500 times

BROWN STAIN

Brown stains occur during both air seasoning and kiln drying; consequently they are sometimes called yard brown stain and kiln brown stain. Yard brown stain appears as a yellow to a dark-brown discoloration, chiefly in air-seasoned sapwood and heartwood stock of sugar pine, western yellow pine, and northern white pine. Kiln brown stain is also yellow to dark brown in color; it develops during kiln drying of the heartwood and sapwood stock in the species just mentioned, and also, for example, in hickory sapwood.

The brown stain that occurs during air seasoning, while definitely known in some cases to be due to chemical action, in other cases may be due to fungous action. Kiln brown stain is of a chemical nature. The cause of chemical brown stain is not definitely known, but it is thought to be due to the deposition and subsequent oxidation of water-soluble materials as the wood dries. Sometimes the chemical stain appears on the surface of a rough board. Frequently, however, the water-soluble substances appear to be concentrated just beneath the surface, and the stain does not become evident until the board is planed.

No positive remedy for brown staining is yet known.

DECAY

What has been said with reference to the cause of blue stain and the conditions conducive to its growth is applicable likewise to wood-destroying fungi, with one important exception, namely, blue-stain fungi affect the strength to only a minor degree if at all, whereas the wood-destroying organisms use certain constituents of the cell walls of the wood for food, with the result that the cells may be broken down and the strength of the wood may be greatly reduced.

INSECT ATTACK[15]

Certain woods are subject to insect attack in the green lumber, some in insufficiently seasoned lumber, and others in dry lumber. Some of the wood-destroying insects bore into sapwood and heartwood without discrimination, whereas others confine their eating to sapwood or even to bark. The sapwood of a few fully seasoned hardwoods is attacked by an insect known as the powder-post beetle. This beetle lays its eggs in the pores of the wood, and the eggs are big enough to require large pores. Hence hickory, ash, and oak are most liable to its injury, but other species are also attacked to some extent by this same beetle. The actual destruction of the wood comes from the larvæ of this borer, as is usual with such insects. With some wood destroyers, however, either the adults alone or both the adults and the young do the damage.

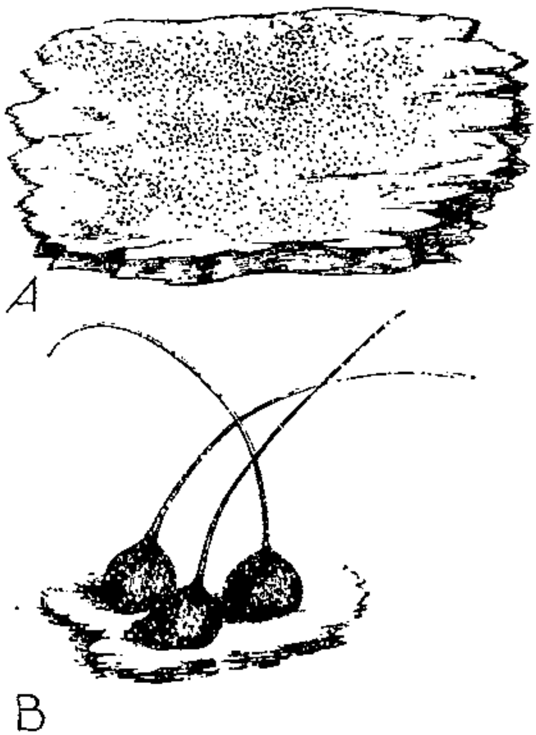


FIGURE 10.—A, Fruiting bodies of blue stain (*Ceratostomella* sp.) appearing as black, powdery masses on a portion of a board; B, fruiting bodies, enlarged about 70 times

On account of borer attack, seasoned hickory, ash, and oak in storage should be moved in rotation, old stock being used before new, so that none of it will remain in storage an excessively long time. In addition all stored stock should be examined regularly and with care. Any stock showing the slightest indication of attack should be reexamined, often by cutting into it, and borer-infested stock should either be heat sterilized or destroyed. The powder-post beetle lays its eggs below the surface of the wood, usually entering the piece from the end, and the larvæ ordinarily work in-

[15] The author is pleased to acknowledge the assistance of the Bureau of Entomology, U. S. Department of Agriculture, in the preparation of this section.

ward, so that a piece of wood may be eaten to a shell before any external indications of the destruction appear. Further, the adult beetles fly, which makes infestation of adjacent stock merely a matter of time if proper preventive measures are not taken.

Without much question, economic considerations justify both constant inspection of stores of the woods most subject to borer attack and also suitable heat sterilization of such stock immediately before its remanufacture. Similar treatment is desirable for all seasoned wood subject to the attack of any insect.

Seasoned stock that is entirely free from the eggs and larvæ of powder-post beetles may be protected from attack through filling the pores of the wood with varnish or gloss oil, which will prevent the adult beetle from laying its eggs in the wood.

KILN DRYING TO KILL WOOD BORERS

About 180° F. is required to kill many of the borers that infest wood, although considerably lower temperatures will suffice for some. When wood infested by heat-endurant borers, such as the Lyctus powder-post beetle, has not been subjected to a temperature of 180° or higher during the drying process, the kiln temperature should be raised to 180° at the end of the run and so held for a half hour or longer, the exact time depending upon the thickness of the stock. If the moisture content of the wood does not exceed 12 per cent, and if the relative humidity during the heating period is controlled so as to prevent any visible damage, it is improbable that subjecting the stock to 180° for two or three hours will injure the strength of the wood.

KILN DRYING PRELIMINARY TO AIR SEASONING

Subjecting green lumber to relatively high temperatures accomplishes more than merely killing the fungi and insects present. When such temperatures are employed in conjunction with proper relative humidities, as in kiln drying, the process offers also a means of minimizing checking in refractory hardwood boards during subsequent air drying. The principle involved may be understood by referring to the discussion of honeycomb on page 25 and by the following considerations: During the early stages of kiln drying, the rate of drying, under proper conditions, can be controlled so as to prevent checking. At some point in the drying process the stress in the surface of the board changes from tension to compression. At this point, which in northern red or white oak, for instance, may be at a moisture content of about 30 per cent, the danger of checking is practically gone, as long as the surface does not subsequently absorb moisture and then again lose it. Consequently the problem of minimizing checking in refractory hardwoods may be simplified by preliminary kiln drying for several days before the stock is piled in the yard. To make it possible for such drying to remain effective, however, care must be taken to protect the stock from rain.

COMMERCIAL METHODS OF PILING BOARDS, PLANKS, AND OTHER SHAPES OF WOOD FOR AIR SEASONING

BOARDS AND PLANKS

FLAT PILING

Yard Site

While in some cases the location of the seasoning yard is limited by such factors as availability of the timber supply and means of transportation, when possible the site selected should be well drained, and for species that withstand rapid drying should be on high ground well exposed to the wind. Freedom from débris, weeds, and other vegetation is essential if the development of blue stain and decay is to be kept at a minmum.

Obviously the opportunity for movement of air around the piles shown in Plate 5, A, is much greater than for those in Plate 5, B.

Yard Layout

MAIN ALLEYS

To facilitate the transportation and piling of lumber the main alleys should be 16 to 20 feet wide. (Pl. 5, A.) In some yards the alleys have no surfacing, in others planking is used, and occasionally alleys are surfaced with concrete.

REAR ALLEYS

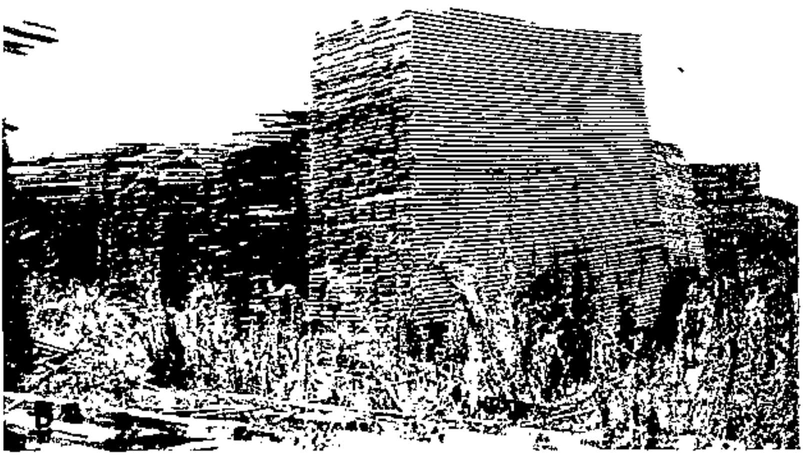
In some instances the rear alleys are used for unpiling the lumber. Even though they may not be used for this purpose, they should be at least 8 feet wide if rapid air movement is needed. The advantage of the alleys shown in Plate 6, B and C, as compared with that in Plate 6, A, is evident.

CROSS ALLEYS

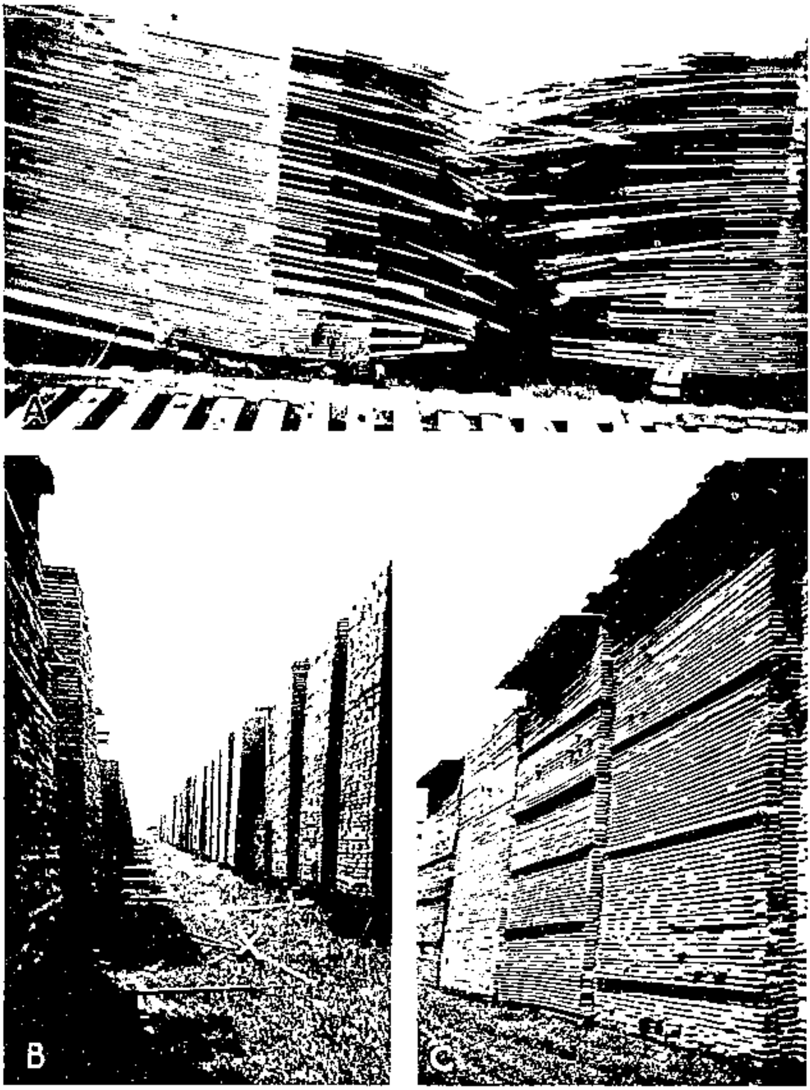
The alleys at right angles to the main alleys should be spaced 200 or 300 feet apart to facilitate the movement of lumber. If they are made wide enough, say 60 feet or more, they will tend to limit the extent of a fire. These alleys, like the others, of course influence the movement of air through the yard.

TRAMWAYS

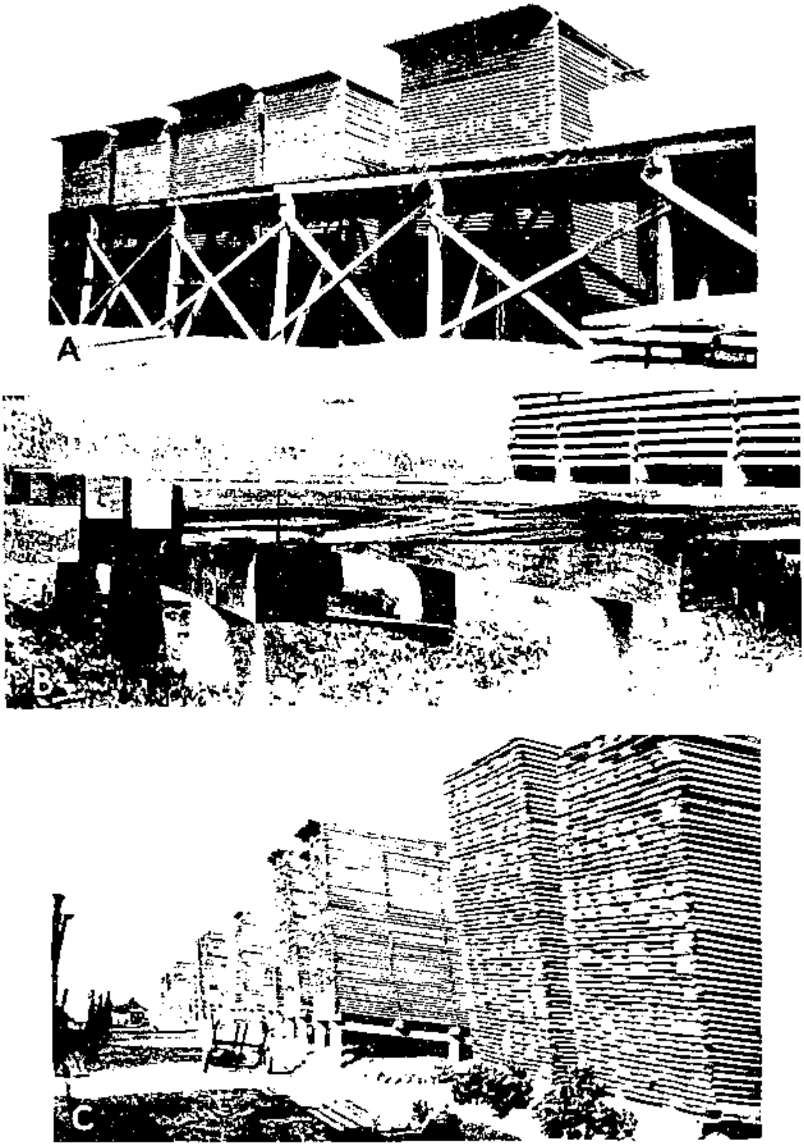
Because of variations in the level of a yard and also in order to permit higher piling without mechanical equipment, elevated wood runways, called tramways, are sometimes built in the main alleys. (Pl. 7, A.) It has been found, however, that a tramway in front of a pile materially retards the drying rate in the lower part of the pile and increases the danger of depreciation from blue stain and decay to such an extent that the apparent advantages ordinarily are outweighed by the disadvantages.



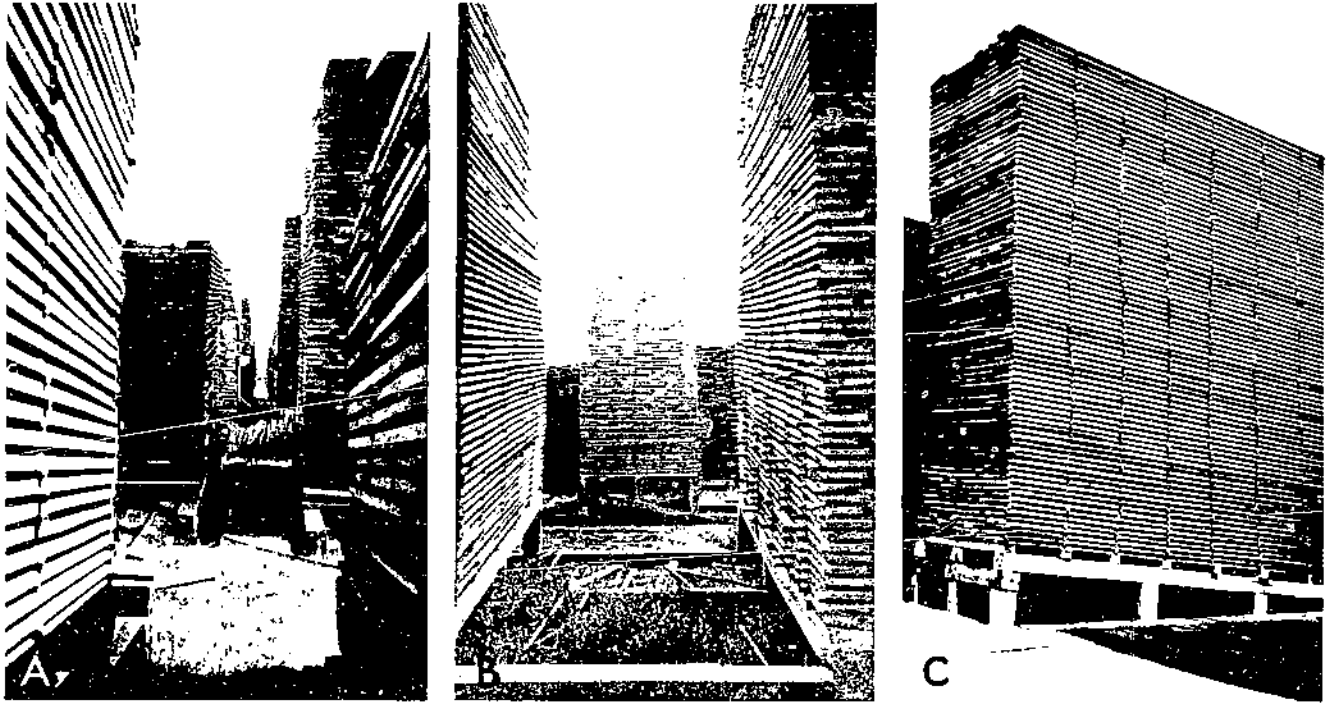
Sanitation in air-seasoning yards: A, Excellent sanitation in an air-seasoning yard; the layout, the foundations, and in the main the piling also are good. All these features are conducive to the necessary good ventilation in the piles; B, poor sanitation in an air-seasoning yard. The loss resulting from stain and decay that are directly chargeable to the choking of circulation caused by the weeds alone would more than pay the cost of putting the yard into good condition and maintaining it properly.



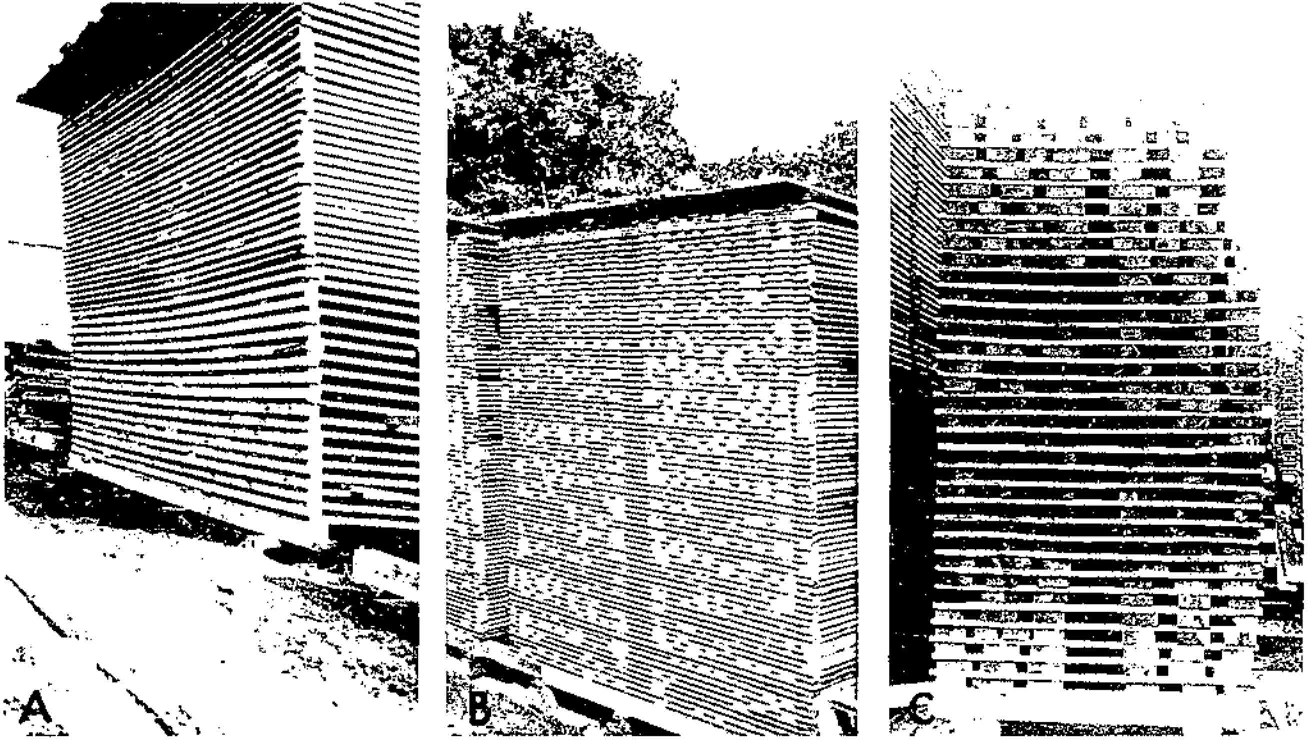
Rear alleys, bad and good practice: A, Poor piling of yard lumber. Overhanging ends, inadequate stickering, insufficient and improper foundations, weeds, and a narrow and obstructed alley all cause degrade, with its resulting loss; B, an adequate rear alley, wide and well-kept except for the few scattered stickers. All the piles are set up properly (box piled), and the sanitation is good; C, one side of a well-appearing rear alley. The stock is piled without overhanging ends (box piling), a desirable feature. Three or four rear pile ends, in addition, have drip boards. On the other hand, higher foundations are desirable.



A, An elevated tramway in a main alley. The usual purpose of a tramway in a lumber yard, particularly where hand piling is practiced, is to facilitate running the piles higher than would otherwise be economically feasible, but sometimes the tramway merely bridges low spots in an uneven ground surface. Although its construction is open, a tramway retards the drying in the lower part of the adjacent piles, thus increasing the loss from stain and decay enough to make its advantage questionable. B, concrete piers, set at a depth sufficient to insure stability, supporting the stringers and beams of a pile foundation; C, concrete piers adequate in height and well-kept surroundings, as shown in the center of the illustration, make for excellent ventilation and tend to prevent loss from stain and decay. The low and solid foundations, at the right, are in marked contrast

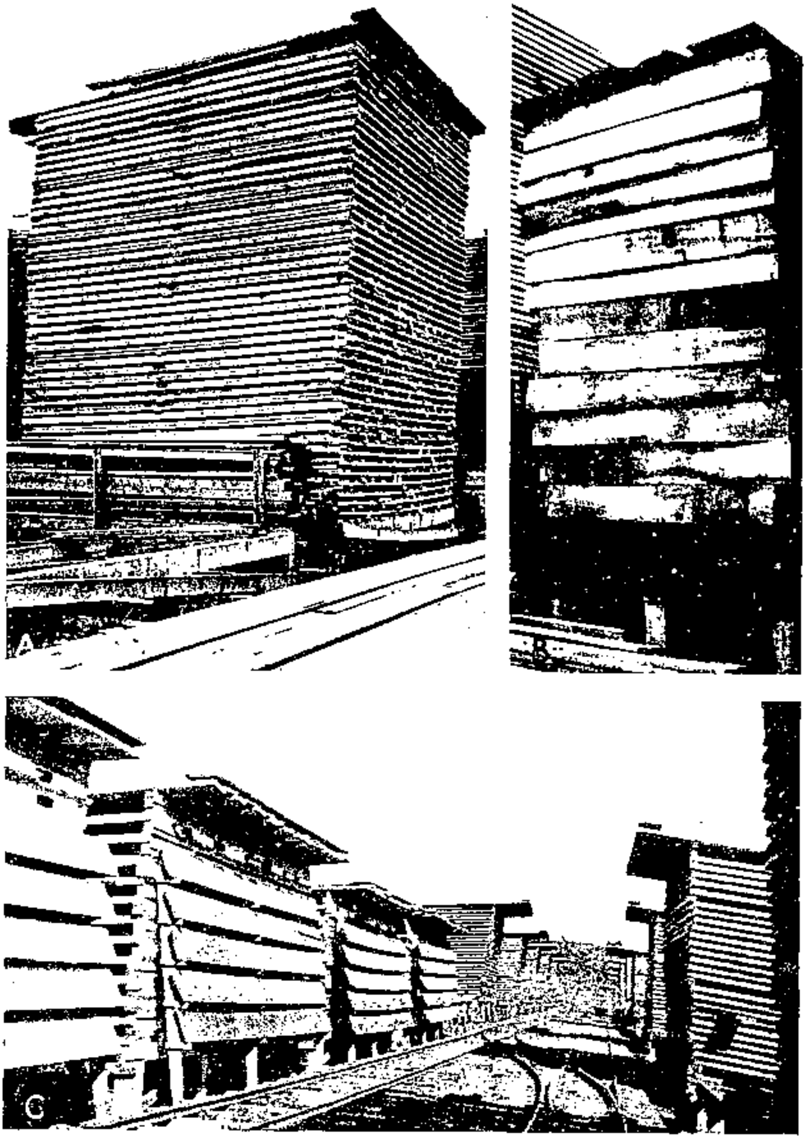


Yard piling practice: A, The alley between lumber piles that are in excellent lateral alignment; B, a section of the alley formed by staggered lumber piles; C, each tier of stickers in the pile is firmly supported by a beam, which in turn rests solidly on a stringer



M11574F

Methods of piling to increase circulation: A, A lumber pile with its lower third opened up by means of stickers thicker than those in the rest of the pile; B, a central chimney of uniform width in a yard pile of random-width lumber; C, a tapered central chimney in a yard pile



M11575F

A, A roof of standard-length lumber made in two sections, one overlapping the other, to permit adequate extension of the roof at both the front and the rear of the yard pile. The practice of double decking: that is, piling two layers of boards between two consecutive rows of stickers as also shown in the illustration, is liable to cause an excessive amount of checking and warping; B, a yard pile boarded up to shield the lumber from the direct rays of the sun, thus reducing the excessive end checking that is caused by too rapid drying; C, a simple and effective type of portable sun shield for protecting the ends of the lumber from the direct rays of the sun

FOUNDATIONS

REQUIREMENTS

The principal requirements of satisfactory supports for a lumber pile are firmness, durability, and a height sufficient to allow the air that has circulated through the lumber to escape readily, especially by allowing wind from any direction to blow beneath the pile. The minimum distance between the ground and the first layer of lumber should be 18 inches. Firmness and durability are required to prevent sagging and consequent warping of the stock.

UNIT FOUNDATIONS

Foundations may consist of heavy planks resting directly on the ground and supporting piers and stringers. The unit type, as this construction is called, is built the same width as the pile and separate from the adjoining foundations. Such a foundation permits definite alignment of the piles (p. 36), is readily adjusted for different lengths of stock, and is easily repaired. A disadvantage is the tendency of the wood in contact with the ground to decay.

CONTINUOUS FOUNDATIONS

The stringers of the continuous type of foundation are supported in a manner similar to that of the unit type, but they extend from one cross alley to the next.

PIERS

Concrete piers, which are sometimes built as shown in Plate 7, B, are very satisfactory. The low, solid foundations shown at the right in Plate 7, C, are in marked contrast with those near the middle of the illustration; the solid ones should not be used because they prevent proper circulation under the piles.

SLOPE

Regardless of the type of foundation, the slope from front to rear should be approximately 1 inch to the foot of length of pile.

PRESERVATIVE TREATMENT

Timbers used in the construction of foundations for lumber piles should be impregnated with creosote, especially if they are of a nondurable species of wood or the sapwood of any species. If the cost of the impregnation process is not justified, the timbers should at least be given two coats of hot creosote, or an equivalent treatment, on the surfaces that are to be in contact with other surfaces or with the ground. I-beams and inverted railroad rails also make satisfactory stringers for such service.

SEPARATION OF STOCK

Because of the marked difference in the drying rates and in the seasoning degrades of stock of various species, grades, and thicknesses, the separation of stock should in some cases be made at least on the basis of these three factors. For instance, 4/4-inch sap gum requires rapid drying conditions to prevent blue stain, while 4/4-inch southern lowland red or white oak should be subjected to more moderate drying conditions, since it is very liable to check and to honeycomb.

Upper-grade stock of coniferous species is clear, while the lower-grade stock has knots, which are liable to check and become loosened if subjected to the extreme drying conditions that the upper grades can withstand. Likewise the conditions to which the heartwood of red gum should be subjected are more mild than those proper for its sapwood. Thus in any species in which the drying rates of heartwood and of sapwood differ materially, separation on this basis should be given careful consideration.

Thick stock of a given species requires a longer drying period than thin stock does and is also more liable to check. Further difficulty is encountered when pieces of more than one thickness are piled in the same layer, since the stickers then fail to hold the thinner pieces in position effectively and therefore permit warping. In addition, such thin pieces in a layer fail to support the stickers above them, a condition that always causes at least deformation of the unsupported stickers, with resultant injury to the stock above them, and may cause breakage of the stickers, with still greater injury to the stock.

Not only is it advisable to separate the stock with respect to species, grades (at least by groups), and thicknesses, but proper piling will be facilitated and seasoning degrade will be reduced if the separation is made also with respect to width and length. With uniform-width stock, straight flues of any desired width from bottom to top can be provided so that air movement will be reasonably uniform throughout the pile. When the lumber is separated as to length, piling so as to avoid overhanging ends, which are liable to check and warp, is simplified.

For hardwoods, the distance between flues should ordinarily be about 12 or 14 inches; too great a distance causes too slow drying. Boards, including those of random width, may be grouped to obtain the proper distance; for example, three 4-inch boards, two 6-inch, or one 4-inch and one 8-inch are all equivalent to one 12-inch board.

For much softwood lumber the distance between flues should be approximately the same as for hardwoods. Local conditions, however, always determine the exact spacing that is proper; the species of lumber is merely one of these conditions. Extremely high humidity and light winds, for instance, might make correct a spacing between flues of only 8 inches, and on the other hand when the boards are 30 inches wide the flue spacing obviously can not be less than 30 inches.

TYPES OF PILES

RANDOM-LENGTH PILES

Sometimes the separation of stock with respect to length is not feasible. Too often the result of piling random-length stock without sorting is as shown in Plate 6, A. Except for very low-grade material, such a method of piling should never be used, since the consequent depreciation in the value of the stock because of warping and checking is unnecessarily high; the loss in such depreciation will more than equal the additional cost of proper piling.

BOX PILES

If stock is piled without overhanging ends, as the lumber in Plate 6, B and C, is, the method is called box piling. In piling random-length stock for air seasoning, the longest boards or planks should be placed in the two outer tiers; and if there is a sufficient number of these boards for additional tiers, such tiers should be uniformly distributed across the width of the pile. As far as possible the boards throughout any tier should be of the same length, whatever that length may be. Whether the short boards should all be placed with their ends flush with the front face of the pile or whether adjacent short-board tiers should be flush with the front and the rear faces, respectively, depends on the stickering. Let us suppose, for example, that 12-foot and 16-foot boards are being piled and that three tiers of stickers are adequate for the 16-foot stock. If the short-length tiers of boards are all flush with the front face of the pile, one less tier of stickers to support the ends of the 12-foot stock will be required than if the alternate method is used. On the other hand, if the number of interior 16-foot tiers is limited, saving one tier of stickers by such piling may result in too much sag in the rear tier of stickers, which is almost certain to deform the boards resting on them. If five or more sticker tiers are required to keep the 16-foot stock from warping, adjacent short-length tiers of boards should be placed flush with the front and the rear faces of the pile, respectively. Such staggering of the short-length tiers is well adapted to a pile in which there are no interior long-length tiers of boards.

Minor modifications of the method of piling just described are also called box piling. For example, in proper kiln drying, with flat piling, the tiers of long boards are grouped in the sides of the pile instead of being distributed over it, and the tiers of short boards are always staggered from end to end instead of sometimes being concentrated at one end. This distribution of the vertical air channels at the ends of the short tiers is required for proper circulation in the limited space within a dry kiln. Again, in air-seasoning practice the term "box piling" is sometimes applied to properly piled boards of the same length, either nominal or actual. The essential features of the box pile are accurate separation of the boards by length, the use of long boards for the outer tiers, and proper support under each end of every board, so that no ends overhang.

SPECIAL PILES

One intentional divergence from an essential feature of the box pile is sometimes found in the piling of certain self-stickered softwoods, especially with wide boards. The rear stickers are set back 18 to 24 inches from the ends of the stock, perhaps with the idea that, when the boards are not trimmed accurately to length, it is impossible to have the stickers flush with their ends. When it is possible, however, placing the rear stickers so that they overhang the ends at least 1 inch is desirable, because then less end checking is likely to occur.

Another divergence is the staggering of the middle and the rear tiers of stickers. This practice appears advantageous for the middle tier; it should decrease both the moisture content and the checking of the portions of the boards and stickers that are in direct contact. At the same time, if the staggering is not properly done, there is danger of warping. In such staggering one edge of each sticker is directly over the center line of the sticker below it, and successive stickers are offset in opposite directions.

Direction of Piling

Almost invariably boards and planks are piled perpendicular to the main alley, as in the piles previously illustrated. This method is endwise piling. Occasionally, however, the lumber is piled parallel to the alley; this practice is sidewise piling. The sidewise method might be expected to afford more rapid drying than the endwise because the face of the sidewise pile, next to the alley, is more open than that of the endwise pile. The conclusion from examination of actual air-seasoning test piles in the southern yellow pine region, however, was that the difference in drying rate between endwise and sidewise piling was negligible. It appeared also that the difference in the amount of blue stain resulting from the two methods was negligible, although the data on this point were not sufficient to be conclusive. Sidewise piling is more inconvenient than endwise piling and is probably more costly.

Pile Spacings

In the various lumber regions the lateral spacing between yard piles varies from a few inches to 6 feet. This spacing is one of the most important factors affecting the air movement around and through the piles. It is hardly possible to recommend the proper lateral spacing in all cases. Broadly, and by way of example, it may be stated that 4 feet for species such as the pines and that 6 feet for the sapwood of red gum and for basswood are considered satisfactory. A definite answer in a given case depends upon how rapidly the lumber dries, the width of the pile, the lateral and also the vertical spacing between adjoining boards, whether checking or stain is likely to be the principal cause of degrade, and climate.

Irrespective of the lateral spacing it is advantageous from the standpoint of the effect on general air movement through the yard to have the piles aligned as shown in Plate 8, A. An alternative arrangement sometimes used is a "checkerboard" layout as illustrated in Plate 8, B. In this plan the piles on one side of an alley are directly opposite spaces of the same width on the other side. In other words, only half the usual number of piles is placed on each side of the alley. Although the checkerboard arrangement undoubtedly has advantages, the superiority of the checkerboard over the more usual layout, when the usual layout is given the same proportion of free space, has not yet been proved.

Occasionally the piles are so disposed in a yard that there is some opportunity for selecting the foundations on which fresh stock is to be put. If a species like sap gum is to be seasoned, the piles should be placed as far from other piles as possible in order to hasten the drying rate. On the other hand, if oak is to be seasoned, the stock should, if possible, be placed between two piles of some other green stock to retard the drying rate and thus reduce checking and honeycombing.

Pile Widths

The width of a pile affects the rate of drying, and should therefore be given careful consideration before any particular dimension is adopted as permanent.

In the softwood regions the width of a pile is usually made equal to its length. In the South the width of hardwood piles is generally 6 feet, while in the North it is 12 to 16 feet. For sapwood boards of a species like red gum a very narrow pile is desirable, in order to hasten drying and to decrease blue stain. With oak, on the other hand, the danger of checking and honeycombing is very great, and from this standpoint extremely narrow piles are objectionable. At the same time wide piles do not fit in well with a southern hardwood operation because of the large number of items and the relatively small amount of each item cut daily at the average southern mill. Consequently the wider the pile the more the stock is exposed to sun and rain before the roof is provided, because the pile then is built up more slowly. Possibly it would be worth while for hardwood operators, especially in the South, to consider devising a form of roof built in sections of convenient size and weight that could be placed over incompleted piles until additional stock is available.

The marked effect of the width of the pile on the drying rate was indicated by two piles of redwood, 8 and 16 feet wide, respectively, that were of the same class of stock and erected at the same time. In 136 days the narrow pile reached a moisture content of 19 per cent, while the other pile dried only to 36 per cent. Although redwood, the species selected for this drying test, is not subject to blue stain, it is reasonable to expect that the faster drying rate obtained with the narrow pile would reduce blue-stain loss in species that are subject to such attack. Narrowing the pile unquestionably has somewhat the same result as opening up the pile, a matter that is discussed a little later under the headings "Stickers" and "Board spacings."

Pile Height, Pitch, and Slope

In the western softwood regions the height of piles averages probably 14 to 18 feet and in the southern softwood regions about 12 to 16 feet, except in yards with tramways or with mechanical piling equipment, where the height may be 20 feet or more. In the southern hardwood region the height averages about 12 feet and in the northern hardwood region about 15 to 18 feet, although in northern yards having tramways the height is sometimes 30 feet. Since the general trend of the air movement in a pile is downward, it is obvious that the higher the pile the greater will be the difference in drying rate between the top and the bottom of the pile. No significant difference has been found in a pile 10 feet high, but in a 20-foot pile the difference is considerable. Thus the advantage of saving yard space by the use of high piles may be offset by retardation in the drying rate and resultant degrade in the lower part of such a pile.

The usual pitch of the front face of a pile toward the alley is about 1 inch to the foot of height. Such inclination permits the rain to drip from the front face, so that the water is less likely to trickle through the pile. The slope of the pile from front to rear is usually about 1 inch to the foot of length, an amount that permits water entering the pile from the top or the sides to drain off.

Stickers

The strips or boards used for separating the layers in a pile are generally referred to as stickers, and sometimes as crossers. They are of two kinds: Stock stickers and special stickers. As the name indicates, stock stickers are boards of the same kind as those being piled. Special stickers, on the other hand, may be of the same or of a different species. The usual special sticker for softwoods is nominally 1 inch thick by 4 inches wide, and for hardwoods is nominally 1 inch thick by 1¼ inches wide. All stickers in the same layer should be of uniform thickness to minimize warping.

Where the prevention of checking or staining is important, special stickers should unquestionably be used. With low-grade stock, however, the use of stock stickers is justified, not only because the loss from depreciation is small but also because they permit more stock to be piled both in a given space and in less time than when special stickers are used.

Special stickers should at least be thoroughly air-dry if not kiln-dry in order to minimize blue stain, decay, and checking in the lumber they support. If green stickers are used the portions of the boards in contact with them dry out more slowly than do the remaining portions, thus increasing the danger of fungus development and at the same time setting up shrinkage stresses that may result in checking. Heartwood is preferable to sapwood for stickers because it does not blue stain and is more resistant to decay.

The number and the position of stickers may have an important bearing on degrade, and these factors, therefore, may vary with the species of the wood to be air-dried. For instance, a sufficient number of stickers is necessary to prevent warping, but too many sticker tiers may result in blue stain and consequently an unnecessary depreciation. Usually three tiers of stickers are considered sufficient for 16-foot western yellow pine boards, while nine tiers are required for red gum boards of the same length. It has been found that if special stickers are placed so that their outer sides project beyond the ends of a pile of boards the drying rate of the wood covered by the stickers is retarded sufficiently to effect a material reduction in end checking; such stickers may be 2 inches wide instead of the customary 1¼ inches. As a rule the stickers should be aligned so that the tiers are parallel to the front face of the pile, in order to minimize warping. Each tier of stickers should be supported directly by a foundation beam. (Pl. 8, C.)

Because of the common tendency of the lower part of a pile to dry more slowly and to stain more than the upper part and because this tendency is directly related to the air movement within the pile, studies have been made of the effect on drying conditions of using thicker stickers in the lower third or half of the pile. (Pl. 9, A.) The results obtained show a very definite advantage for opening up part of the pile by this means. On the other hand, if the thicker stickers were used in the upper part of the pile also, the more rapid drying resulting in that portion would in some instances be objectionable because of increased shrinkage defects.

Where the operator does not wish to carry two sizes of stickers, the desired opening of the pile may be attained simply by doubling the stickers, that is, by using two 1-inch stickers, one on top of the other, instead of one 2-inch sticker. Further increase in the area of horizontal openings to aid circulation within the pile may be provided, of course, by using still thicker stickers, either solid or built up.

Board Spacings—Flues and Chimneys

Mention has been made of the fact that in the main the air movement in a pile of seasoning lumber is downward. Consequently if the stock is separated as to width (p. 34), it can be piled with straight flues, which will aid circulation. The width of flue, which is the horizontal spacing between boards, can be varied to suit the conditions; that is, if the principal cause of degrade is stain, the spacing between boards should be increased. On the other hand, if checking is the principal defect, the spacing between boards should be decreased. The disadvantage of this method is that it can be applied practically only to the entire pile.

More or less arbitrarily, the space between two tiers of boards may be called a flue when it is less than 6 inches in width. If the space is 6 inches or more in width, it may be called a chimney or a vent; it then may be either straight or tapered. (Pl. 9, B and C.)

If ordinary random-width stock is to be piled, it is good practice to provide three or more straight chimneys about 6 inches wide and to place the boards in any layer between two chimneys so that adjacent edges are in contact or nearly so. In this way the edges of the boards on each side of a chimney can be placed in approximately vertical alignment.

If very wide random-width stock is to be piled, it may be more practicable to provide one wide, tapered, central chimney than several narrow chimneys.

Where desirable, it is possible, of course, to supplement the effect of the chimneys by providing increased horizontal openings in the lower part of the pile, as previously described.

Roofs, Drip Boards, and Sheds

Except for very low-grade stock, some form of pile covering is advantageous in decreasing depreciation from alternate exposure to sun and rain, which causes checking and warping. Roofs should always be made of low-grade material, in order to minimize costs. The boards in the first layer of the roof may be spaced about one-half inch apart, and those in the top layer should then be placed directly over the spaces between the boards in the lower layer. The roof, if it is tight, should slope about 1 inch to the foot; if it is not tight the slope must be somewhat greater, perhaps 25 per cent greater, in order to provide for satisfactory run-off. The roof should project about 1 foot at the front and 2½ feet at the rear to aid in keeping snow and rain from the ends of the pile. To afford additional protection, drip boards are sometimes used, as shown in Plate 6, C. Where it is desired to have the roof project in the manner described without using extra-length stock, the sectional construction shown in Plate 10, A, can be provided. However, more space than that shown between the roof and the top layer at the rear would be advisable. In any event this space should be ample to allow plenty of air to enter the top of the pile. An average of 5 inches is considered sufficient for this purpose.

In a windy location the roof should be fastened to the pile by wiring or equivalent means.

End Protection

PROJECTING STICKERS AND SUN SHIELDS

Reference has been made to the fact that if special stickers are placed so that they project beyond the ends of the boards in the layer below them, they will retard the drying rate in those ends and thus decrease end-checking. In thick stock the protection afforded by projecting stickers may be very inadequate, and in this event sun shields may be useful. Plate 10, B, illustrates the use of boards for sun protection, and a convenient type of portable sun shield is shown at the left in Plate 10, C.

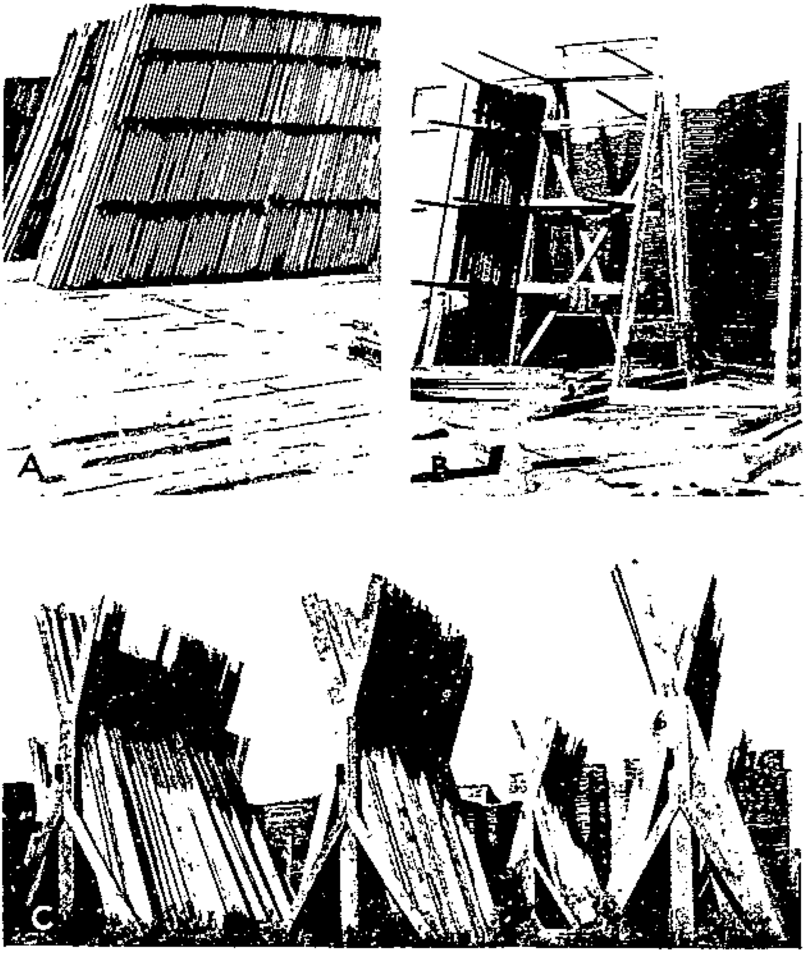
COATINGS

Coatings for reducing changes in the moisture content of wood are another means of protection against end checking. Such coatings should be applied before checking begins. Paraffine is one material that may be used for this purpose. It should be melted so that the stock can be end-dipped in it and thus given a coating about one thirty-second of an inch thick. Another coating material, which may be applied with a brush and which is more convenient to use, since it need not be heated, is filled hardened gloss oil. It is made up by paint manufacturers. Various kinds of hardened gloss oil are on the market, some of which are not suitable for end coatings. Hardened gloss oil having a high degree of resistance to the passage of moisture consists of 100 parts, by weight, of rosin, 8 parts of quicklime, and 57.5 parts of a thinner, such as mineral spirits. Filled hardened gloss oil[16] is made by mixing 25 parts, by weight, of fibrous talc, 25 parts of barytes, and 100 parts of hardened gloss oil; the purpose of the inert pigment is to increase the moisture resistance.

END PILING

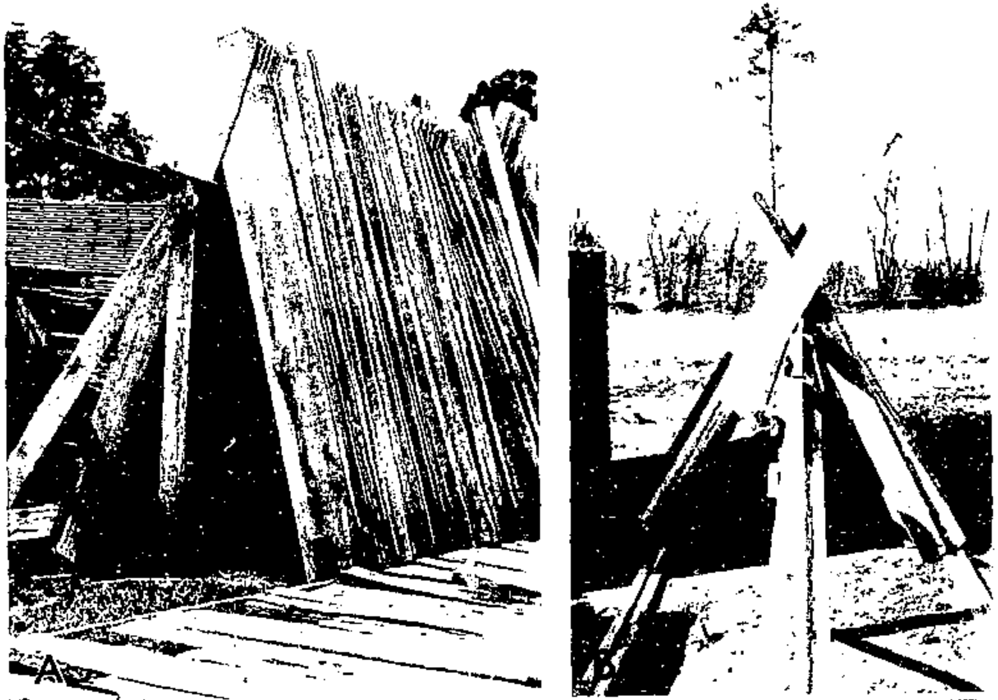
End piling for seasoning, which is illustrated in Plate 11, is used to a limited extent in piling sap gum in the drier sections of the southern hardwood region. Thick, clear lumber in the sugar-pine

[16] A list of the dealers from whom the component materials may be purchased can be obtained, upon application, from the Forest Products Laboratory.

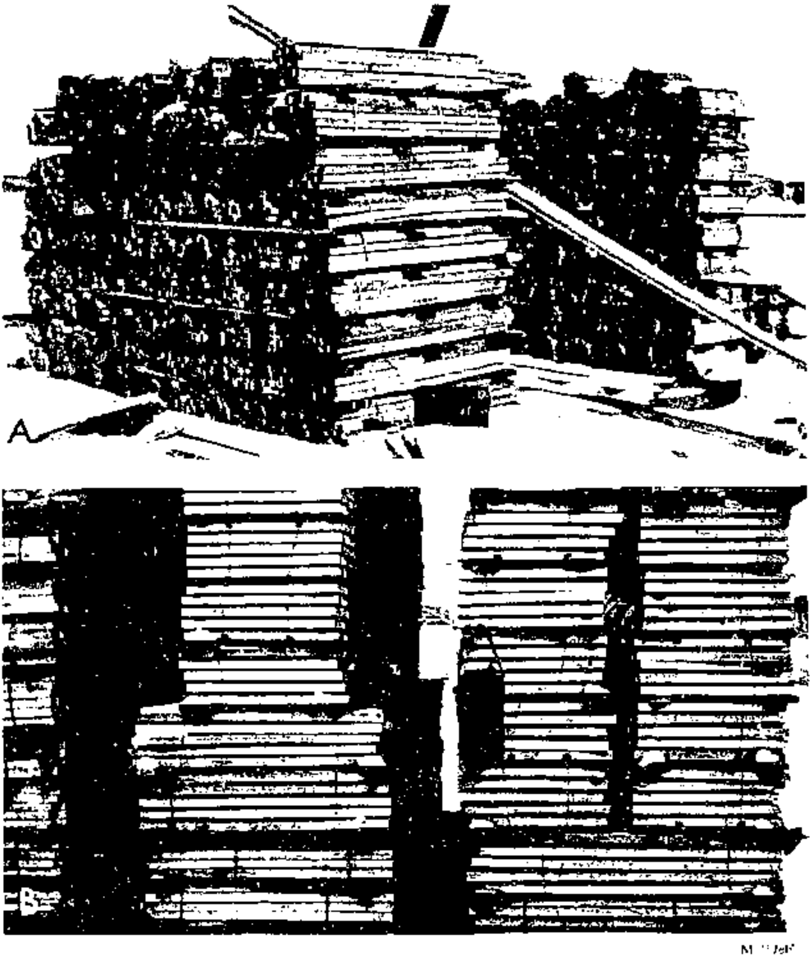


M 157-F

Some methods of piling other than flat: A, Lumber end piled on a solid wooden platform. An open framed floor for each pile, raised a foot or more above the ground, would afford better air movement around the bottom of the pile; B, a rack for the end piling of lumber; C, yard lumber end racked in the form of an X

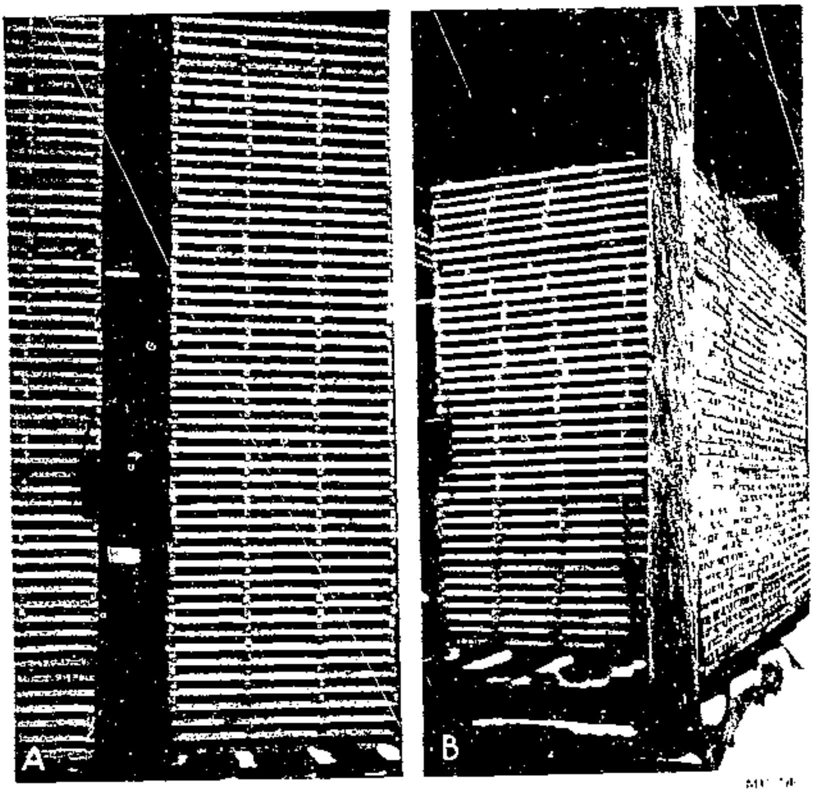


Reasonably good end-racking practice. A, Yard lumber end racked in the form of an inverted V; B, supports for end racking lumber

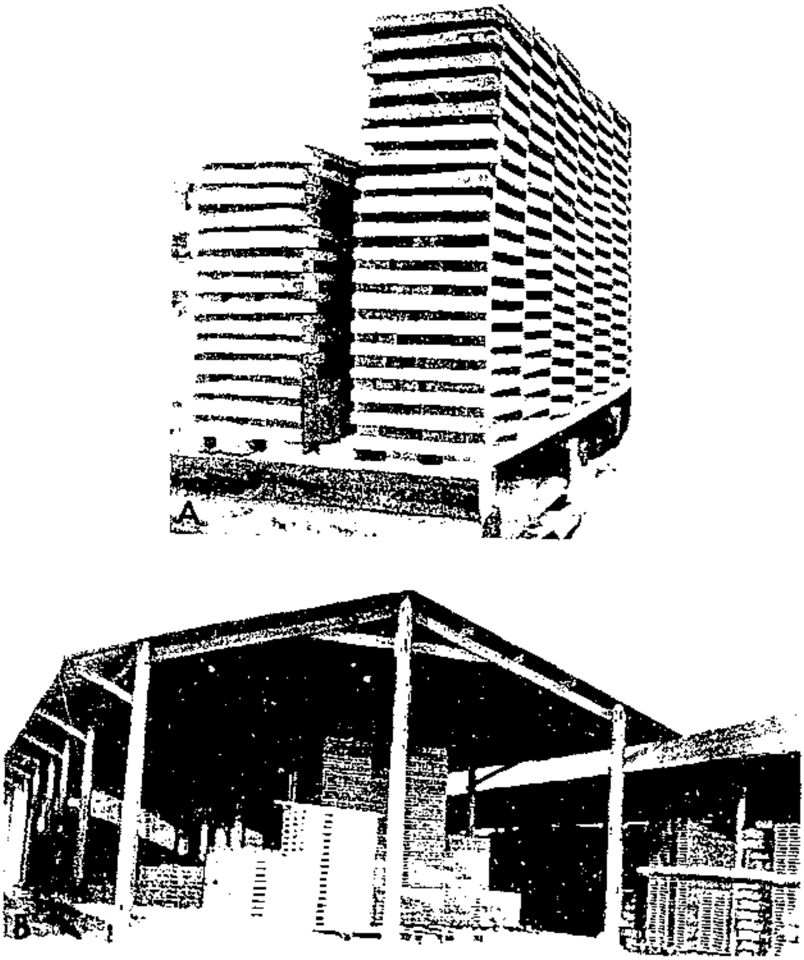


M [illegible]

Piling of bundled dimension stock: A, Twine-bound bundles of dimension stock piled in the open; B, wire-bound and twine-bound bundles of dimension stock having stickers between courses, and also twine-bound solid bundles, all with stickers separating layers of bundles

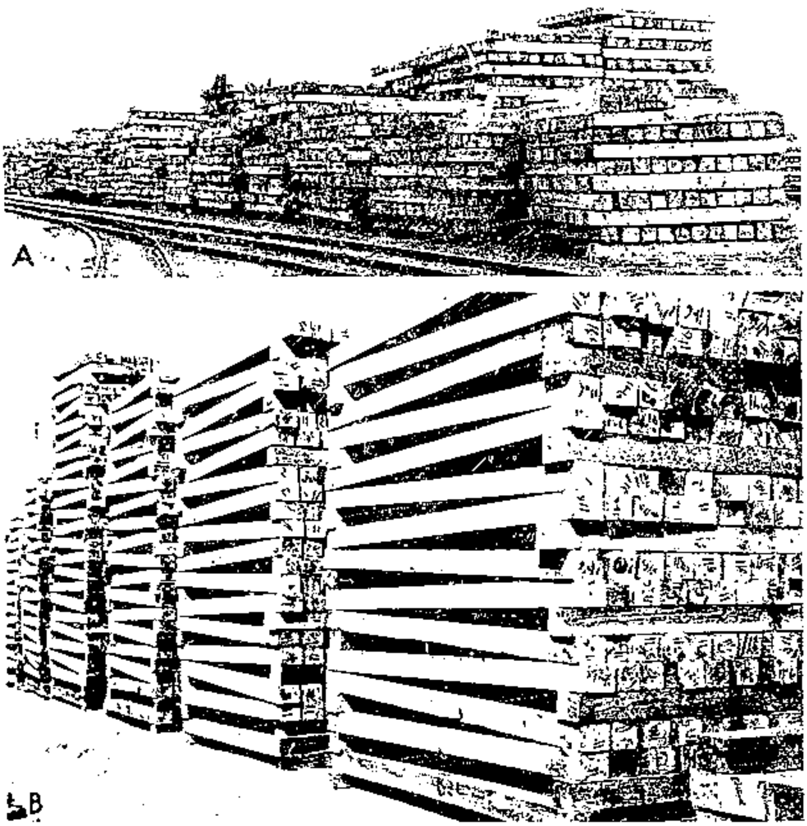


Self-stickered [illegible] stack piled under cover: A, A well-stickered pile; B, a well-built foundation, with careless stickering



M11560F

Dimension stock piled for immediate and for ultimate economy: A, Lap-piled flat dimension stock. B, a general view of an open shed sheltering dimension stock during seasoning



M1158F

Railway crossties piled for air seasoning: A, Solid piling with 11 by 11 layers; B, a common form of open piling; the illustration shows 10 by 1 layers region of California is also occasionally end piled under shelter. End-piled lumber in a seasoning yard is virtually the same thing as lumber flat piled in the ordinary manner and then tipped up on end. Although the term "end piling" is also used in kiln drying, the piling method is different [17] and, further, end piling in finish sheds is customarily done without the stickers that are essential for green lumber. Just as in flat piling, care should be taken in placing the stickers for end piling so as to avoid warping and end checking, and in providing proper flues or chimneys in the pile.

Some operators in the lower Mississippi Valley maintain that end piling permits the lumber to dry faster than flat piling does. In a certain yard the lumber is end piled for about 15 days, until the surface is dry enough to prevent the development of blue stain, and is then flat piled. In other Mississippi Valley yards the lumber is left end piled until dry. On the other hand, in a yard in which the drying conditions are typical of those in the Appalachian region, end piling was found so unsatisfactory that it has been discarded in spite of the loss involved in tearing down the expensive supports it requires.

END RACKING

There are two common methods of end racking yard lumber. One may be designated as the X form and the other as the inverted-V form. (Pls. 11, C, and 12, A.) Less warping and end checking are likely to occur in the inverted-V form than in the other form and the inverted V is therefore preferred. Another advantage of this method is that stain, if it occurs, is most likely to be at the intersection of the boards, and a smaller loss from trimming results if this defect is near the end than if it is near the middle.

The upper support shown in Plate 12, B, rests on posts braced longitiudinally and laterally, and the lower ends of the boards rest on planks on the ground. Better drying would probably be secured in the lower portions of the boards if they were supported a foot or more above the ground.

The statements previously made (p. 33) concerning the firmness, durability, species, and preservative treatment of wood foundations for flat-piled lumber apply likewise to the supports for the end racking or the end piling of lumber.

It is obvious that the air can circulate much more freely around end-racked than around flat-piled lumber, especially in the vertical direction, and this fact accounts for the more rapid drying that occurs with end racking. After being end racked for from two days to two weeks, stock is usually dry enough to prevent blue stain unless it again becomes wet. When the work is done properly end racking is desirable where stock is especially subject to blue stain. The total length of time that stock is end racked depends on the weather; 3 to 10 days is a usual range. It should be long enough to permit the drying necessary to prevent blue stain and the stock should then be flat piled immediately to keep warping and checking to a minimum.

The species of wood most commonly end racked are sap gum, yellow poplar, and magnolia.

---

[17] See footnote 4.

CRIB PILING

Occasionally lumber is crib piled. Such a pile, which is in the form of a hollow triangle, permits rapid drying, but it has the disadvantage of requiring excessive space and the method is liable to result in considerable degrade because of checking, staining, and the warping that comes from lack of support.

DIMENSION STOCK

DEFINITION OF DIMENSION STOCK

Dimension stock is the wood stock of the different sizes and shapes required by wood-using industries in the manufacture of fabricated articles, such as furniture and turnings. It varies in thickness from one-half to 6 inches, in width from one-half to 8 inches, and involves lengths up to 8 feet. Most of the stock, however, consists of sizes less than 3 inches square, or the equivalent in cross-sectional area, and less than 4 feet in length.

To facilitate handling, it is more or less common practice to bundle the smaller sizes.

SOLID BUNDLES

A pile of solid bundles is shown in Plate 13, A. Although the sticks within each bundle are in close contact, the bundles are separated by stickers. This method of bundling is rapid, and it probably holds small squares straighter than when stickers are used within the bundles. If the stock is susceptible to stain, however, this defect is almost certain to develop.

STICKERED BUNDLES

Stickered bundles are shown in the upper part of Plate 13, B. In this type of bundle the air may circulate more freely over each stick so that the rate and uniformity of drying will be better than in a solid bundle. In some species and sizes, however, the tendency to warp is so marked that the resulting degrade is excessive; the amount of the loss involved seems to indicate that in such cases the stock might better be dried in the board or plank form; the lumber could then be recut to any desired size.

COB PILES

In a cob pile the stock is not bundled but is stickered with itself in about the same manner as that of the piles shown in Plate 14, except that the number of pieces in a layer is the same for all layers. Cob piling permits a larger amount of stock to be stored in a given space, but it is conducive to slow drying.

STOCK STICKERS OR SPECIAL STICKERS

The choice of the kind of sticker involves a compromise among economy of space, drying time, and degrade. Obviously, the thinner the sticker the more the stock that can be piled in a given space, and within limits, the thicker the sticker the faster will be the drying rate. The most desirable drying rate will vary with the species of wood and the size of stock; it depends upon whether the dominant defect is likely to be checking or staining. The use of special stickers offers a flexibility in piling, not only in different piles but also within the same pile, that may prove advantageous at times. Further, special stickers can be previously dried, so that the sapwood in contact with the stickers will be less liable to blue stain.

Plate 14, A, is an example of good piling practice where self-stickering is required. The placing of stickers at the ends of the stock and the vertical alignment of stickers are points to be particularly noted because of their tendency to reduce end checking and warping. With squares that are likely to surface check it may be advantageous to minimize this defect by placing each piece so that the quarter-sawed surfaces are horizontal: that is, in direct contact with the stickers. The plain-sawed surfaces, of course, are then vertical, and the adjacent surfaces of all squares in the same layer are close together. By this means the drying of the plain-sawed surfaces may be retarded sufficiently to reduce checking. Ordinarily the danger of checking of quarter-sawed surfaces is negligible.

LAP PILING

Plate 15, A, illustrates a piling method sometimes used for flat stock. Each successive piece overlaps the one below it, so that only two tiers of stickers, one at each end of the pile, are required.

SEASONING SHEDS

Even though stock of a given species may not be subject to blue stain, it may, if exposed to the sun and the rain, become so badly weather stained that the discoloration will not be taken off in machining. With high-grade stock, therefore, seasoning in a shed such as that illustrated in Plate 15, B, may be profitable. As with unsheltered lumber, the foundations should be firm, durable, and high enough to afford adequate circulation of air under the piles.

LATH

Apparently one of the most satisfactory methods of piling lath for air seasoning consists in placing the bundles about 8 inches apart on 2 by 4 inch stickers. The lowest layer of bundles is supported about a foot above the ground, and a tight roof is provided. Such a method is not entirely satisfactory, however, for in damp weather the laths near the middle of a bundle, which usually consists of 50, dry so slowly that they blue stain. In one instance, after air seasoning for 32 days in early fall, the average moisture-content values of a lath from the outside and of one from the center of a bundle were 17 and 182 per cent, respectively. The lath of high moisture content was heavily blue stained throughout its length; the other one was bright. The difficulty in preventing blue stain in lath is probably greater than with a timber of the same size as a bundle of lath, because, if the surface of the timber is dried quickly enough to prevent the stain from getting a foothold, the inside is likely to be free from attack. On the other hand, fungous spores can easily enter the interior of a bundle of lath.

Blue stain in the air seasoning of lath may perhaps be reduced, possibly through a modification of the method of bundling or through chemical dips, but at present the only positive means known for preventing the development of blue stain in lath, as in lumber, is artificial drying.

RAILWAY CROSSTIES

METHODS OF PILING

The general principles involved in preventing decay and checking of lumber are applicable likewise to railway crossties and other timbers. The tie problem, however, is somewhat more complicated than the lumber problem because of the larger size of the individual piece. Thus, the naturally slower drying rate of the interior of crossties, as compared with that of boards and planks, is conducive to the development of decay in untreated ties. Further, the greater difference in drying rate between the inside and the outside of a crosstie tends to cause a larger amount of checking. On the other hand, more checking is permissible in crossties than in lumber of the upper grades, and uniform drying throughout is not required, since in general only the outer part of the tie is treated with preservative, and the primary purpose in seasoning such timbers is to make them take a satisfactory preservative treatment.

Plate 16, A, illustrates the 11 by 11 method of solid-piling; the ties in each successive layer are at right angles to those in the layer beneath. With this method, surface checking is not so likely to occur, because of the relatively slow drying resulting from very slow circulation of air through the pile. The method may be used safely only where there is practically no danger of decay, and in practice is used chiefly for treated ties.

Another type of pile, known as the 10 by 1 form, is shown in Plate 16, B. Because of the more open character of this pile, more rapid drying may occur, with an increased amount of checking and a decreased amount of decay resulting. Somewhat more rapid drying may be expected from still more open piling like the 7 by 2, and similar kinds.

Special stickers to separate the layers of crossties have been used in exceptional cases.

The particular method of piling best adapted to any given seasoning yard depends upon such factors as species of wood, yard site, and weather conditions, and on whether the dominant defect is decay or checking. In one yard where drying conditions are especially favorable and the species of wood involved, lodgepole pine, is not very refractory, surprisingly good results are said to be obtained by piling the ties in rows like cordwood, all pieces being parallel. At each end of each row a crib or a solid pile is erected.

The lowest layer of ties sometimes rests directly on the ground. This practice generally is objectionable because it is liable to result in slow drying and decay. To avoid this difficulty, it is advisable to pile the lowest layer on treated stringers a foot or more above the ground.

Crosstie piles may be 10 to 16 feet high, the spacing between adjacent ties varying from less than 1 inch up to 4 inches. A few companies are erecting piles 30 feet high or more. Often the piles are erected in rows 30 or 40 feet long, with practically no space between piles. The rows, however, are spaced 3 to 5 feet apart.

END COATINGS

Although the use of coatings to prevent the end checking of crossties has not been investigated extensively, it seems quite possible that a moisture-retardant coating, such as roofing pitch or as the filled hardened gloss oil referred to on page 40, may prove advantageous in the seasoning of crossties as well as in that of lumber. To secure the maximum benefit, the coating should be applied before the tie has begun to check. The foregoing relates to the problem from the standpoint of checking only. One operator reports satisfactory results from brush treating the ends of crossties with hot creosote in order to prevent decay; the spots where other ties cross a tie should also be brush treated.

ANTICHECKING IRONS

Two forms of irons designed to hold the ends of crossties intact against checking are in more or less common use; they are known respectively as crinkle irons and **S**-irons. Which of the two to use appears to be more or less a matter of individual preference.

SEASONING PERIODS

The seasoning time allowed for crossties by different operators varies considerably with the species of wood, as shown in Table 4. The methods of piling, ranging in some instances from 10 by 1 to 10 by 10 for the same species in the same region, appear to vary with the personal preference of the individual operator. The seasoning periods for the same species also show considerable variation, even after allowing for the natural difference between summer and winter rates of seasoning. Of course differences in local conditions, such as wind and humidity, often require great differences in seasoning periods, yet even these factors fail to account for all the variations.

TABLE 4.—*Summary of seasoning periods employed by different treating plants for railway crossties of various species*

Species of wood	Region	Method of piling	Time of seasoning [1]
Beech	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	10 by 4	8 to 12 months.
Birch, yellow	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	8 by 4	6 months.
	do	10 by 4	8 to 12 months.
Douglas fir, coast	Rocky Mountains	do 10 by 1	10 to 12 months.
	do	do	6 to 7 months.
	do	10 by 10	6 months.
	Pacific coast	do	3 months.
	do	do	6 months.
	do	do	10 to 12 months.
Douglas fir, mountain	Rocky Mountains	10 by 1	9 to 12 months.
	do	do	About 6 months.
	do	10 by 10	1 to 1½ months.

[1] When periods of different length are given for the same species the shorter ones include the summer months.

TABLE 4.—*Summary of seasoning periods employed by different treating plants for railway crossties of various species*—Continued

Species of wood	Region	Method of piling	Time of seasoning
Hemlock, eastern	Lake States	10 by 4	8 to 12 months.
Hemlock, western	Rocky Mountains	8 by 4	12 months.
Larch, western	do	10 by 1 10 by 4	9 to 12 months.
Maple	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	10 by 4	6 months.
	do	do	8 to 12 months.
Oak, red	do	do	12 months.
	do	10 by 10	8 months.
Oak, white	Middle West	do	14 to 18 months.
Pine, lodgepole	Rocky Mountains	do	6 to 8 months.
	do	10 by 1	12 months.
Pine, southern yellow	Atlantic coast	8 by 1	3 to 4 months.
Pine, western yellow	Rocky Mountains	10 by 1	6 months.
	do	9 by 1	8 to 12 months.
	do	8 by 4	3 to 4 months.
Spruce, Engelmann	do	10 by 10	6 months.
	do	do	8 to 10 months.

POLES

METHODS OF PILING

In some cases green poles are piled so high and so close together that seasoning is greatly retarded, especially when the lowest layer rests directly on the ground. In order to hasten the drying rate one large producer of poles has developed the method of piling shown in Plate 17. The piers and beams, which are creosoted, support the lowest layer of poles about 2 feet above the ground. Successive layers of poles are separated by treated stickers about 4 inches thick. A chimney 2 feet wide is left in the middle of the pile from bottom to top. The poles, in this case southern yellow pine, are seasoned about two months during the summer or four months during the winter, prior to preservative treatment; in some parts of the United States a seasoning period of four to six months or even more is considered desirable. The time permissible is determined largely by decay conditions.

SEASONING PERIODS

Table 5 gives the reported seasoning periods allowed for air seasoning of poles of several species from the green condition to the average moisture-content values indicated.

TABLE 5.—*Time allowed for air-seasoning poles of western red and northern white cedar and the final moisture-content values*

Species	Locality	Top diameter	Time of seasoning	Final moisture content
		Inches	*Years*	*Per cent*
Western red cedar	Idaho	7	3	15
Do	do	7½	1	21
Northern white cedar	Wisconsin	7½	2	27

Figure 11 shows air-seasoning curves for chestnut poles in a Maryland yard. In this case the final moisture content, although satisfactory, was so high that only a negligible amount of shrinkage had occurred.

TIMBERS

METHODS OF PILING

It has been common practice to bulk pile timbers unprotected, as shown in Plate 18, A. This practice has resulted in heavy losses on account of stain and decay, especially if the timbers were exposed to rain for some time just before being loaded into vessels for long ocean shipment. Some operators, however, are now finding that the cost of properly storing timbers on stickers and under an open shed is well repaid; the timbers are so stored that they have opportunity to dry considerably, at least on the surface. (Pl. 18, B.)

END COATINGS

As with lumber and crossties, the use of moisture-retardant coatings to prevent checks in timbers may be advantageous (p. 40).

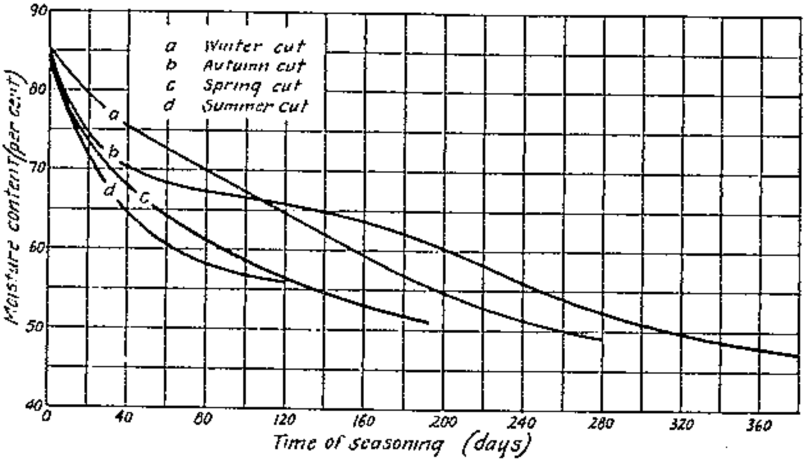


FIGURE 11.—Air-seasoning curves for chestnut poles cut at different times of the year

DRYING DATA

The drying curves for 12 by 12 inch by 24 foot southern yellow pine and Douglas fir timbers, air seasoned in an open shed for two years at Madison, Wis., appear in Figures 12 and 13; these are species commonly used for structural timbers. The timbers were piled on 2 by 4 inch stickers and were spaced 2 to 3 inches apart. The retarding effect of winter weather conditions on the drying rate is very evident.

During July, 1922, the precipitation was 53 per cent above normal, and the sunshine was 18 per cent below normal. On the contrary, in October, 1922, the precipitation was 73 per cent below normal and the sunshine was 33 per cent above. These conditions appear to be reflected in the curves (fig. 12), which show more nearly uniform seasoning during the period July to October than would ordinarily be expected. Likewise, the relatively slow seasoning rate of the Douglas fir timbers during March, 1923 (fig. 12, B), is probably attributable to the fact that during that month the temperature was 19 per cent below normal and the precipitation was 87 per cent above.

POSTS AND CORDWOOD

Posts and cordwood are often piled solidly, all pieces being parallel. This method of course is most liable to produce decay and least liable to produce checking. More rapid drying is likely to result if the pieces are piled in the form of a hollow square, the so-called log-cabin style. This method is liable to bring about an increase in the amount of checking, but with cordwood checking is not objectionable; the chief disadvantage of the method is that it requires a great deal of space. A modified log-cabin piling gives almost as good results and occupies much less space. In the modified method the pile is self-stickered, each layer resting on single pieces at opposite ends of the pile. (Pl. 19, A.)

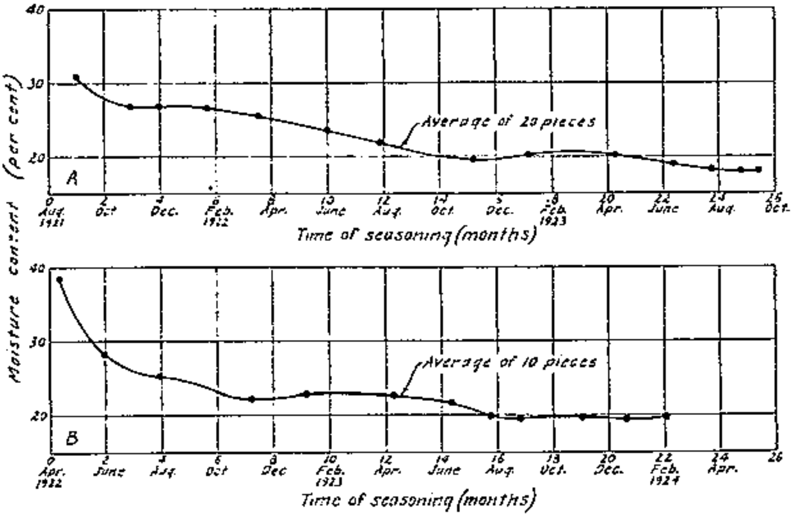


FIGURE 12.—Air-seasoning curves for southern yellow pine heartwood timbers 12 inches square by 24 feet long, seasoned in an open shed. The stickers were 2 by 4 inch and the timbers in each layer were spaced 2 to 3 inches apart

COOPERAGE

STAVES

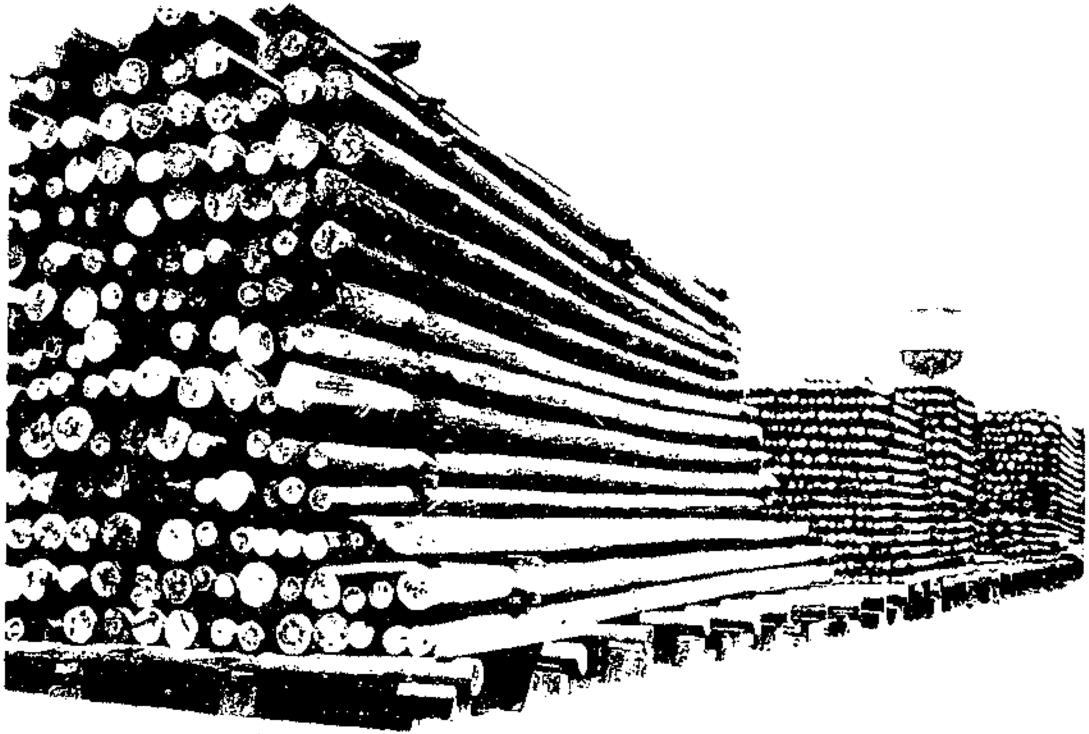
The piling of staves in the form of a hollow square to secure rapid drying is shown in Plate 19, B. With this method of piling, 90 days is ordinarily required to air season 2-inch staves satisfactorily. The staves are half-lapped, so that the weight of the upper ones does not tend to change the desired curvature of those supporting weight.

HEADING

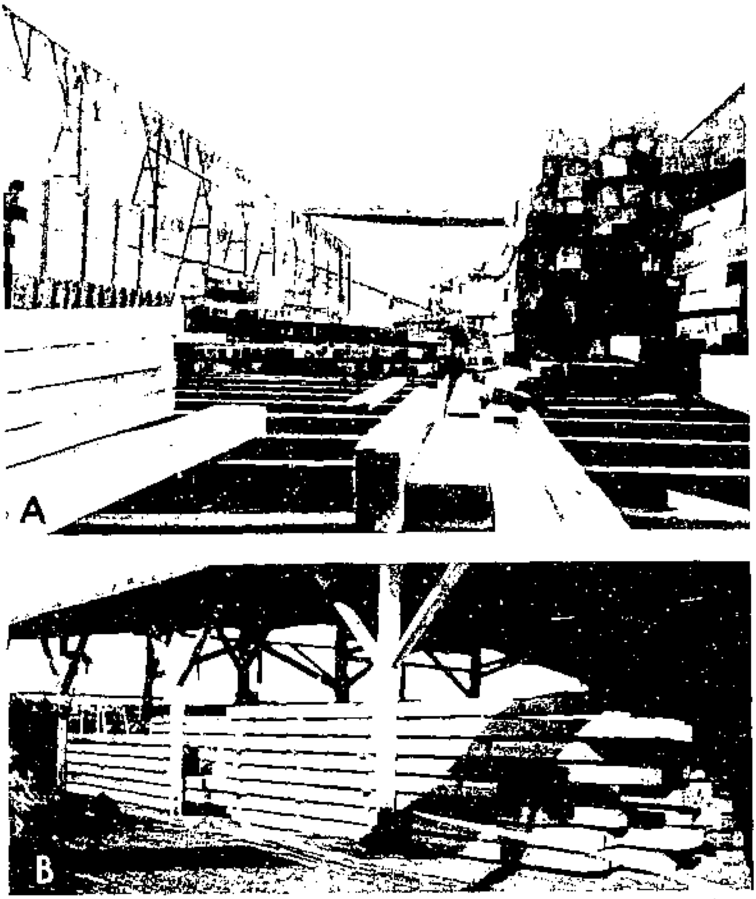
A method of open piling, which is particularly adapted to heading, is shown in Plate 20, A. Here the pieces are piled approximately in the form of a hollow cylinder. In some instances the top of the pile is built up in the form of a cone for the purpose of providing some protection against rain.

VENEER

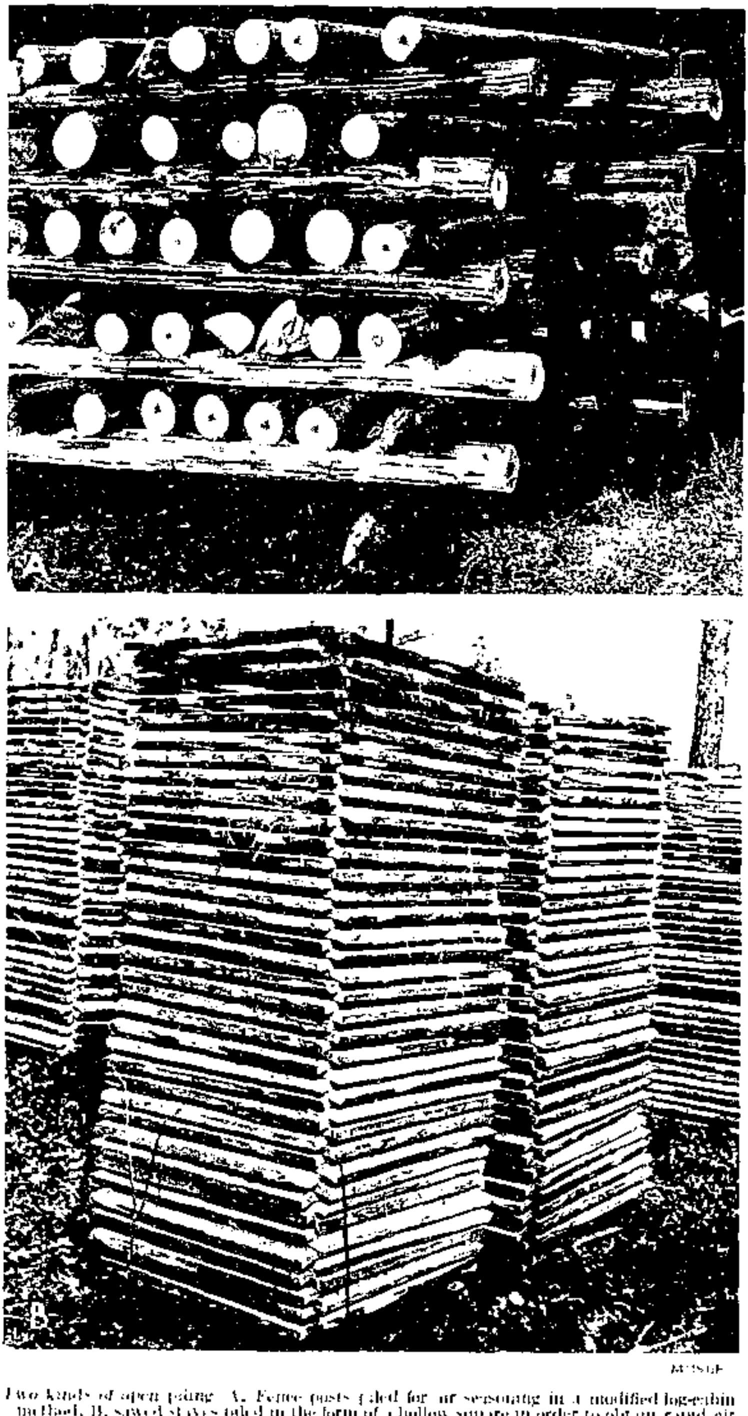
Only a relatively small amount of veneer is air seasoned. Most of it is dried either in standard dry kilns or in special mechanical driers.



Well-piled poles in an air-seasoning yard. Each pile is high above the ground on treated piers and stringers. Heavy stickers, also treated with preservative, separate successive layers. The sanitation is excellent

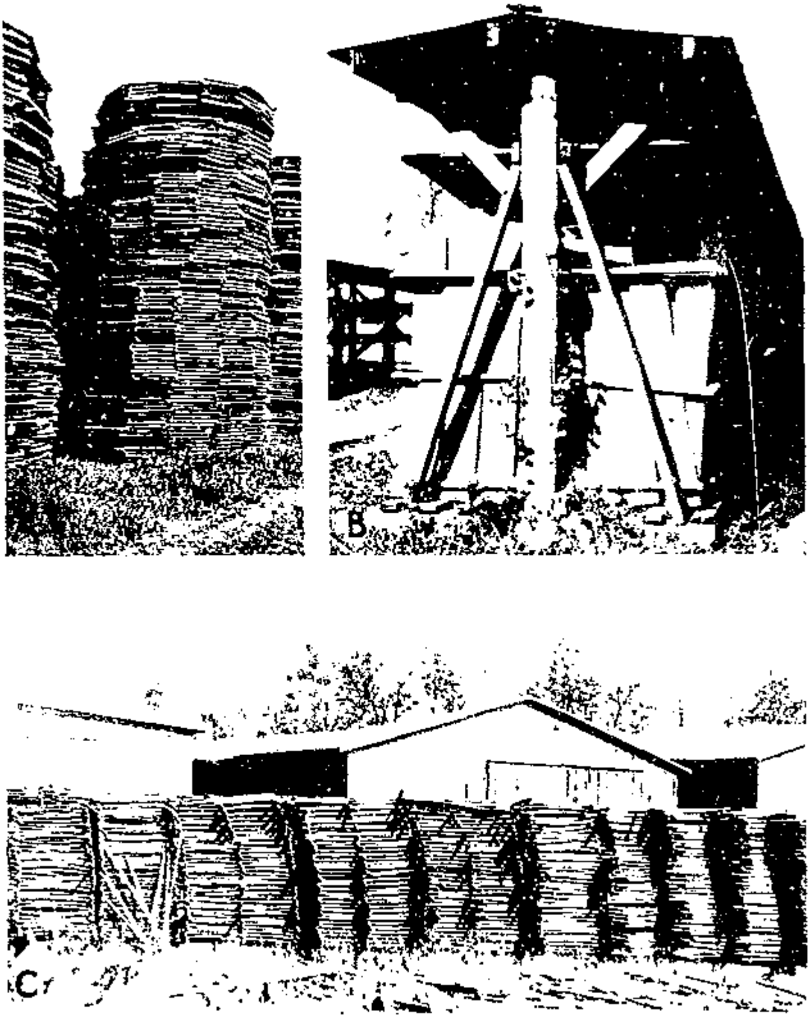


Common practice and good practice in temporary storage: A, Lumber and timbers, in temporary storage, bulk piled unprotected in a loading yard; B, timbers stored temporarily on stickers and under protection from rain and snow, in order to obtain rapid seasoning for the purpose of reducing the likelihood of stain and decay developing during long water shipment.



M13SGF

Two kinds of open piling: A, Fence posts piled for air seasoning in a modified log-cabin method; B, sawed staves piled in the form of a hollow square in order to obtain rapid air seasoning.



A, Oak barrel-heading stock piled for air seasoning in the form of a hollow cylinder; B, thick veneer stock end piled for air seasoning under a double roof; C, Veneer stock flat piled for air seasoning.

Two methods of piling thick veneer for air seasoning are shown in Plate 20, B and C. In the first method the courses of veneer are stacked on end, separated by stickers, and are given some protection from sun and rain by a roof. One modification of this method was observed in which the stickers were vertical and the pieces of veneer were racked on edge. In the second method the veneer is flat piled on stickers in a manner similar to that in which boards are commonly piled. A third method is to suspend the sheets.

DRYING RATES AND FINAL MOISTURE CONTENT

EFFECT OF CLIMATE

As already explained (p. 17), temperature and humidity affect both the drying rate and the equilibrium moisture content of wood. From this it follows that a hot, dry climate, such for example as

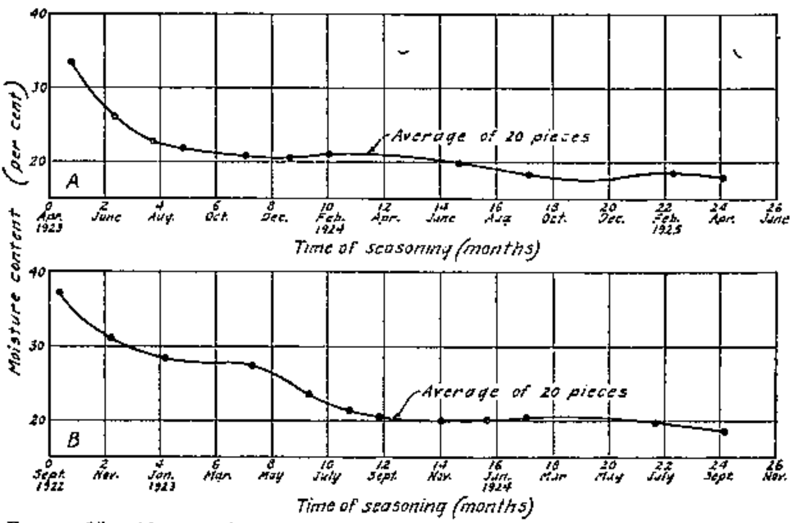


FIGURE 13.—Air-seasoning curves for Douglas fir heartwood timbers 12 inches square by 24 feet long, seasoned in an open shed. The stickers were 2 by 4 inch and the timbers in each layer were spaced 2 to 3 inches apart

that which prevails in the Southwest, is much more conducive to a rapid drying rate and lower final moisture content than, for instance, is the damp climate of the redwood region of California.

EFFECT OF SEASON OF YEAR

The influence of summer and of winter conditions on the drying rate and the final moisture content of wood is clearly shown in Figures 12 and 13, which have been discussed previously. In another instance some 1-inch birch boards were air seasoned from the green condition to a moisture content of 15 per cent in about six weeks during the summer, but during the fall they absorbed moisture, and by December 1 the moisture content had increased to 20 per cent.

EFFECT OF SPECIES OF WOOD

Some species of wood differ markedly in their rates of drying. In northern Wisconsin, for example, 1-inch basswood is reported to dry in about one month less time than 1-inch maple does. The maximum difference in the final moisture-content values of 1-inch boards of the various common species, however, is probably not more than 2 per cent when the boards are subjected to the same air-seasoning conditions for a time sufficient to bring them to equilibrium conditions.

EFFECT OF THICKNESS

Some 2-inch southern swamp white oak planking required 270 days to air season from 70 to 23 per cent moisture content at Madison, Wis. Under similar conditions the corresponding drying time for 4½-inch oak wagon bolsters was 464 days. After 379 days of seasoning the final average moisture content of the 2-inch plank was 16 per cent and after 710 days the corresponding moisture content of the 4½-inch bolsters was 19 per cent. Records for certain western softwoods indicate that 1-inch stock may air season in half the time required by 2-inch stock of the same species. An approximate rule appears to be that the rate of air seasoning for different thicknesses of stock of a given species ranges from the proportion

$$\frac{R_1}{R_2}=\frac{T_1}{T_2}$$

to the proportion

$$\frac{R_3}{R_4}=\sqrt{\frac{T_3}{T_4}}$$

in which the T's represent respective thicknesses and the R's represent respectively the corresponding drying rates. The rule applies to thicknesses not less than 1 inch and not exceeding 4½ inches.

Data sufficient to show the effect of air seasoning on the equilibrium moisture content of stock of different thicknesses are not available. In a series of experiments on partially air-dry white ash, however, the pieces were exposed in a room at approximately 80° F. and 90 per cent relative humidity. The 1-inch stock then absorbed moisture up to an average value of 23.8 per cent, while the 3½-inch stock reached a moisture content of 23.3 per cent under the same conditions. When the stock was dried in a chamber at 120° and 28 per cent relative humidity, the corresponding moisture-content values of the 1-inch and the 3½-inch pieces were 5.8 and 6.5 per cent, respectively. So far as white ash is concerned, therefore, it appears from the foregoing that thickness has a negligible effect on equilibrium moisture content under the constant conditions noted. On the other hand, if the stock were exposed where the temperature and the humidity fluctuated through a considerable range and remained uniform only for brief periods, the effect on the moisture content of the interior of a thick piece might be reduced. Consequently, the average equilibrium moisture content of a thick piece might remain higher (or lower) than that of a thin piece of the same wood in localities where the weather changes frequently.

EFFECT OF SAPWOOD AND OF HEARTWOOD

The curves in Figure 14 indicate the change in moisture content of loblolly pine cross arms, both sapwood and heartwood. Initially the sapwood cross arms had about twice as much moisture as the heartwood, but at the end of five weeks both had reached the same moisture content. At the end of six months the moisture content of the sapwood was 23 per cent, while that of the heartwood was 31 per cent. If the experiment had been continued for another six months, it is probable that the difference in moisture content would have been much smaller. With some species the upper grades contain more sapwood than heartwood, and in order to secure the most rapid drying rate for such grades it may be advantageous to segregate them from the lower grades.

EFFECT OF LOCALITY OF GROWTH

Data covering the comparative air-seasoning rates of drying and the final moisture-content values of boards cut from trees of a given species, grown in different localities, are not available. In kiln

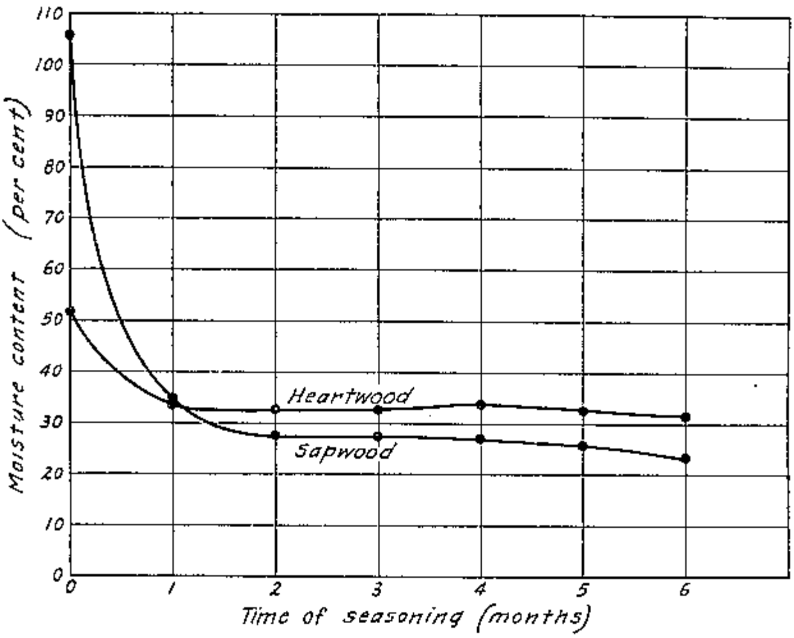


FIGURE 14.—Air-seasoning curves for loblolly pine cross arms of heartwood and of sapwood, 3¼ by 4¼ inches by 10 feet

drying, however, it has been found that southern swamp white oak dries much more slowly than northern highland white oak does. It seems probable that a similar difference would exist if the two kinds of stock were air dried, and also that the difference in equilibrium moisture content would be of no practical importance.

EFFECT OF YARD LOCATION AND ARRANGEMENT

In Louisiana are two hardwood yards owned by the same company and located about 10 miles apart. One is at a slightly lower elevation than the other and is surrounded with trees, which tend to reduce the air movement through it. This yard is approximately square, while the other one is relatively long and narrow, with its long dimension across the direction of the prevailing wind. As would be expected, the conditions in the square yard result in a slower drying rate than do those in the narrow one.

In another Louisiana hardwood yard piles of various lengths were located side by side under conditions the same except for pile length and relative position. It was noticed that where a 10-foot pile was to leeward of a 16-foot pile, the circulation through the short pile was retarded sufficiently by the obstructing pile to cause more blue stain in it than in the obstructing one. In addition to the retarded circulation, the slower drying of the 10-foot pile may in some measure have been caused by a higher humidity resulting from the moisture carried over from the windward pile. Although actual data in this instance are not available, it is probable that the final moisture content of the 10-foot pile was appreciably higher than that of the 16-foot pile.

Although the two cases just cited were in a particular locality, the factors mentioned are likely to have an important effect on the air seasoning of lumber in other regions.

SELECTION OF THE PILING METHOD

The effect of piling methods in reducing check, blue stain, and decay has been discussed in a previous section. Further, the point has been made that a piling method that permits rapid drying is liable to cause checking, and also that too slow drying is conducive to the development of blue stain and decay. The various factors that bear on the choice of a piling method are summarized in Table 6.

TABLE 6.—*Piling methods that minimize the occurrence of the more common air-seasoning defects*

Location of defect	Procedure for reducing the occurrence of—		
	Blue stain and decay	Checking	Warping
Throughout the pile	Raise the foundations. Increase the spacing between boards and between piles. Provide one central flared chimney or a series of narrow chimneys. Use thicker, narrower stickers. Narrow the piles.	Lower the foundations. Decrease the spacing between boards and between piles. Use thinner, narrower stickers. Place the end stickers so that they project beyond the ends of the pile. Use end coatings and antichecking irons.	Use stickers of uniform thickness, properly aligned and supported, and sufficient in number.
The lower part of the pile only.	Provide short chimneys (one-third or one-half height of pile). Use thicker stickers in the lower part of the pile.		

SPECIAL TREATMENTS

PRELIMINARY STEAMING

The usual object of steaming lumber before it is piled in the yard is to heat the stock so that when it is piled outdoors the surface will dry rapidly to the point at which blue-stain fungi can not develop. This point, according to present information, is approximately 20 per cent moisture content. If the lumber is exposed to damp weather immediately after the steaming process, however, the desired drying can not occur, and consequently stain is likely to result. Similarly, the desired drying does not occur if the stock is handled improperly immediately after the period of steaming; the stock must be open piled just as soon as it is cool enough. Preliminary steaming at 180° F. and 100 per cent relative humidity for four hours per inch of thickness is effective also in killing any fungi already present in the green stock.[18]

Preliminary steaming for the foregoing purposes is advantageous with the sapwoods of red gum, poplar, and magnolia. On the other hand, such steaming is very detrimental with such woods as cypress and oak, because of their marked tendency to check.

It is common practice to steam the sapwood of black walnut so that its color will be darkened and will more nearly resemble that of the heartwood.

DIPPING

Many southern yellow pine mills have equipment for dipping green lumber in a solution of a chemical, such as sodium carbonate or sodium bicarbonate, or a mixture of such chemicals. This treatment appears to reduce the danger of blue stain during subsequent air seasoning. The exact nature of the action of the alkaline chemical is not definitely understood, but the alkali is supposed to counteract the wood acids that are favorable to the development of blue stain. In dry weather a 4 per cent water solution and in damp weather an 8 per cent water solution of sodium carbonate is considered satisfactory; the corresponding figures for sodium bicarbonate are 5.5 and 11 per cent, respectively. With either alkali the solution should be kept at 140° F. The concentration and the temperature of the solution appear to be important factors in securing the best results; these factors may change materially during use of the dip, and hence should be observed frequently. When necessary they should be returned to their proper values.

At some mills the green chains carry the boards to and from the dipping tank, while at others the boards are conveyed on dollies from the green chain to the dipping tank.

Both spraying and dipping are used also for southern yellow pine timber. Dipping only is occasional in several lumber regions.

STORAGE OF DRY LUMBER

GENERAL

Previous discussion in this bulletin has emphasized the importance of having the moisture content of lumber suitable for the use requirements of the stock. Obviously the moisture content of stock as it is placed in service is affected by the practice of the manufacturer, the wholesaler, the retailer, the fabricator, and the contractor. Any one of these five can undo to some extent the good work of the others. It will avail little, for example, to have the first four follow correct practice if the last one then nullifies their results by

---

[18] Further details are given in Department Circular 421 (3).

subjecting such items as flooring, doors, window frames, and sash to weather conditions. Ordinary atmospheric conditions cause an increase in the moisture content of lumber properly dried for interior use, and then shrinkage occurs when the heating system of the completed building is put into operation. Cracks in floors and around windows and doors certainly are not an asset in maintaining satisfaction in the use of lumber, and neither are warped doors.

On the other hand, if the manufacturer dries the lumber improperly any or all of the others who handle it can improve the moisture condition of the stock considerably by means of heated storage. The retailer or the fabricator, for instance, can largely and sometimes completely correct through heated storage any improper moisture treatment by the manufacturer or the wholesaler. Purchase specifications, which should be employed, will place definitely the responsibility for final results that is now divided at random among all those who contribute to the finished product.

OPEN YARDS

Since in most regions there is considerable difference between summer and winter values of equilibrium moisture content, it may be advantageous in some cases to bulk pile in the yard stock that has become thoroughly air-dry during the summer, in order to prevent or to reduce the absorption of moisture during the winter. If, however, the locality under consideration is subject to heavy snows or driving rains, a better practice is to allow the stock to remain on stickers. In either case a tight roof should be provided.

SHEDS

Piling stock within a shelter obviously affords it protection better than the best possible in an open yard. In Plate 21, A and B, are shown the exterior and interior of a shed adapted to flat bulk piling.

Some of the studies previously referred to in this bulletin have indicated the reasons for variation in the moisture content of lumber when it is taken from the yard. Other studies have indicated the range in moisture content of air-dried and of kiln-dried softwoods; when the average moisture content is the same, the range is greater for the kiln dried than for the air dried.

Additional data pertaining to certain softwood sawmills are available to show that, if the stock is bulk piled in a closed storage shed, the range in moisture content can be materially reduced. For instance, numerous moisture-content values determined for certain grades of kiln-dried softwood flooring ranged from about 2 to 30 per cent, with an average of 7.1 per cent. After being bulk piled for 30 days in partly open sheds the range was from about 2.5 to 16.5 per cent, with an average of 8.5 per cent. Further, the increase in moisture content of lumber in sheds may be less than if the stock is stored in yards. Incidentally, an added advantage of bulk piling in a closed shed is that the lumber is kept cleaner than when it is exposed to rain and dust.

HEATED STORAGE

If, after air seasoning or kiln drying, it is necessary to prevent an increase in moisture content, the desired result can be accomplished by bulk piling or by open piling the stock in a heated building. The same means may be employed also to reduce moisture content. When this result is desired the stock should be piled on stickers rather than bulk piled, if the duration of the storage period is to be minimized. Such a method of drying is particularly suitable where dry kilns or skilled operators are not available. It is also advantageous where a high degree of refinement in the quality of the finished product is necessary. Such excellence is essential, for instance, in fine handwork and in instruments of precision. With articles like jewel boxes, level rods, and slide rules, for example, in which nicety of construction, appearance, and service are prime requisites, the cost of drying the material properly is negligible in comparison with the value of the finished product.

As an offset to the saving in time that would be obtained by kiln drying, the simplicity of equipment and operation of heated storage may in some cases prove an important consideration. Probably it is feasible to maintain or even to attain a considerable range of desired moisture-content values, corresponding to certain relative humidities, simply by controlling the temperature, which in most cases would probably be from 50° to 100° F.; the relative humidity of the air, and in consequence the moisture content of the stock, would decrease as the temperature increased.

Gas-burning or oil-burning equipment is a convenient boiler accessory for heated storage, especially on those days when heat is required to control the moisture content of the lumber and for no other purpose.

Plate 22 illustrates a portion of the interior of a heated brick building in use by a wholesale distributor of hardwood and softwood lumber. Plate 22, C, shows the arrangement of the wall radiators, and Plate 22, A and B, indicate the method of bulk piling hardwood flooring about 3 inches above the concrete floor and with an occasional layer of stickers to stabilize the pile. If at all feasible to do so, it would be better to pile the stock at right angles to the position shown and several feet from the wall radiators. Such a change in the position of the pile would permit air to circulate more readily under the pile and toward the radiators, thus keeping the lower layers of stock drier and at the same time preventing overdrying of the ends of the boards. This building stores both air-dried and kiln-dried stock; for a quality product, heated storage is desirable from every point of view.

ADDITIONAL DETAILS

SPECIFIC GRAVITY AND WEIGHT OF WOOD

In the last three columns of Table 3 are given the average specific gravity (based on oven-dry weight and green volume) and the weight per cubic foot of green wood and of wood at about 12 per cent moisture content for clear samples of various species growing in the United States. Because of variations in the actual size of pieces of lumber of the same nominal size and for other similar reasons the figures can not be used to calculate accurately the reduction in weight of lumber during seasoning. They are useful, however, in making rough estimates of this factor.

CHANGE IN MOISTURE CONTENT OF LUMBER DURING RAIL TRANSIT

Studies on carload shipments of air-dry western white pine and white fir from the Inland Empire[10] to the Chicago territory have shown negligible changes in moisture content during transit. The moisture-content values at the time of shipment ranged from 15 to 22 per cent and the changes in moisture content during transit ranged from a gain of 0.2 to a loss of 2.4 per cent, the change in most cases being less than 2 per cent. The conclusion was reached that if stock at a satisfactory moisture content is loaded into a tight box car, the stock will reach its destination in practically the same moisture condition.

LITERATURE CITED

(1) FULLAWAY, S. V., JR., JOHNSON, H. M., and HILL, C. L.
1928. THE AIR SEASONING OF WESTERN SOFTWOOD LUMBER. U. S. Dept. Agr. Bul. 1425, 60 p., illus.

(2) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES, THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.

(3) TEESDALE, L. V.
1927. THE CONTROL OF STAIN, DECAY, AND OTHER SEASONING DEFECTS IN RED GUM. U. S. Dept. Agr. Circ. 421, 18 p., illus.

(4) ———
1930. THE KILN DRYING OF SOUTHERN YELLOW PINE LUMBER. Technical Bul. 165. U. S. Dept. Agr., 67 p., illus.

(5) THELEN, R.
1929. KILN DRYING HANDBOOK. U. S. Dept. Agr. Bul. 1136, 96 p., illus.

(6) UNITED STATES DEPARTMENT OF COMMERCE. NATIONAL COMMITTEE ON WOOD UTILIZATION.
1928. SEASONING, HANDLING, AND CARE OF LUMBER (CONSUMERS' EDITION). U. S. Dept. Com., Natl. Com. Wood Utilization Consumers' Subcom. Rpt. 4, 63 p., illus.

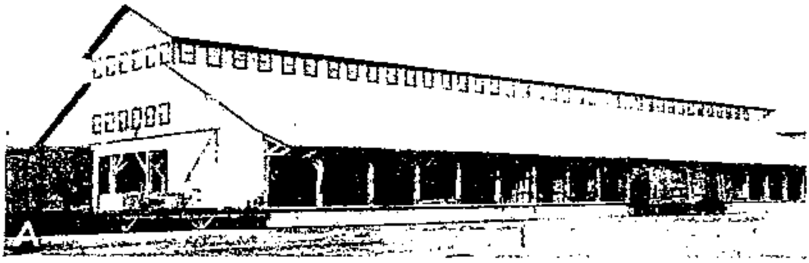
(7) ———
1928. SEASONING, HANDLING, AND CARE OF LUMBER (DISTRIBUTORS' EDITION). U. S. Dept. Com., Natl. Com. Wood Utilization Distributors' Subcom. Rpt. 6, 74 p., illus.

(8) ———
1928. SEASONING, HANDLING, AND CARE OF LUMBER (FABRICATORS' EDITION). U. S. Dept. Com., Natl. Com. Wood Utilization Fabricators' Subcom. Rpt. 7, 96 p., illus.

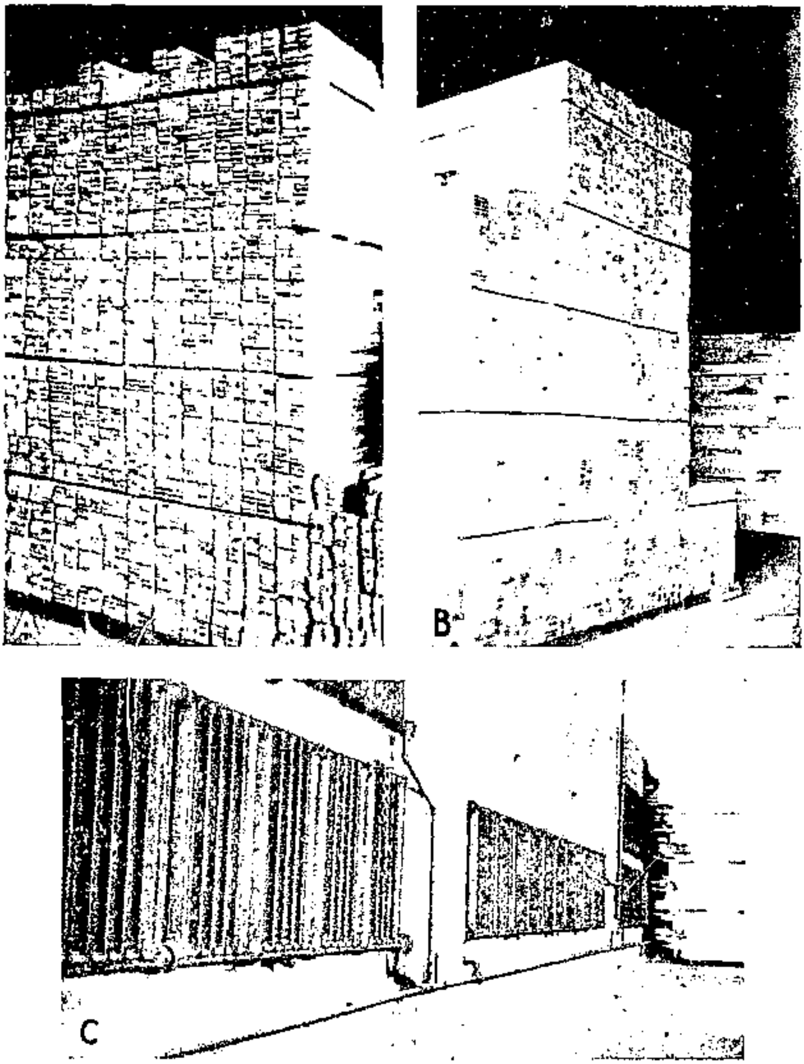
(9) ———
1929. SEASONING, HANDLING, AND CARE OF LUMBER (MANUFACTURERS' EDITION). U. S. Dept. Com., Natl. Com. Wood Utilization Manfrs.' Subcom. Rpt. 9, 126 p., illus.

[10] See footnote 5.

U. S. GOVERNMENT PRINTING OFFICE: 1930



Storage of seasoned lumber under shelter: A, The exterior of a storage shed suitable for air-seasoned lumber, showing its one open side; B, a part of the interior of the same well-built shed. The lumber is bulk piled flat on stringers, with heavy stickers separating successive piles; additional stringers at the ends of the piles might be better practice than the small number now used



Heated storage of finished lumber: A, end-matched oak flooring, bulk piled on stringers with stickers about every 21 layers; B, twine-bound bundles of end-matched maple flooring; C, wall radiators for heating storage space.

END