Effect of Heat on the Decay Resistance of Wood[1]

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How does commercial heating, involved in certain stages of wood manufacturing or processing, affect the natural heartwood decay resistance of wood? — the Navy Department, Bureau of Ships, wanted to know.

The U. S. Forest Products Laboratory, Madison, Wisconsin, provided them with the answers. Although the heating was conducted largely under controlled laboratory conditions, a brief supplementary appraisal was made of Douglas-fir that was actually kiln dried.

HEAT IS UTILIZED AT SOME stage in the production of many wood products. For example, it is used in the kiln drying of lumber and the hot-air drying of veneer, in hot-press gluing, and in steam bending. Because the resistance of the more durable woods to decay is due to fungus-inhibitory extractives of the wood, questions arise from time to time as to whether a particular commercial heating process may reduce decay resistance by alteration or destruction of these extractives.

Inquiry in this regard was made recently by the Navy Department concerning the effects of any boat application to which several woods that are used or considered for boat building might ordinarily be subjected while the boat is under construction. This inquiry prompted the present study, in which the heartwood of nine species of wood was heated to various levels in a dry or a wet atmosphere and then tested for decay resistance by a standard laboratory procedure.

Experimental Procedure

Selection of Wood Samples: Dry board sections were obtained for the study from mill-run lumber of angelique *(Dicorynia paraensis)*[3], Alaska-cedar *(Chamaecyparis nootkatensis)*[4], Atlantic white-cedar *(Chamaecyparis thyoides)*, baldcypress *(Taxodium distichum)*, Douglas-fir *(Pseudotsuga menziesii)*, true mahogany *(Sweitenia* sp.), redwood *(Sequoia sempervirens)*, white oak *(Quercus alba)*, and western redcedar *(Thuja plicata)*. Where more than one board of a species was used, boards were taken from places in the stock pile sufficiently far apart that each might be safely assumed to have come from a different tree. This was done because, as a rule, the natural preservatives of a durable wood may be highly variable among different trees of the species. The numbers of boards or trees taken to represent the different woods were: Alaska-cedar and white oak, 6 to 9; angelique, 6; Atlantic white-cedar, baldcypress, redwood, and western redcedar, 1 each; and Douglas-fir and mahogany, 2 to 3. Only heartwood was retained in each case, since it is only the heartwood that had significant decay resistance.

The samples were sawed into $^3/_4$-inch cubes. Blocks to be given heat treatment and those to serve as unheated controls were always board matched.

Heating: So-called "dry" heating — in a dry atmosphere — was accomplished by placing the blocks in temperature-regulated ovens. So-called "wet" heat was applied for the most part by steaming the blocks after they had been conditioned in a humidity room to a moisture content of about 20 percent on a dry-wood basis. Steaming at 180° and 212° F. was done in an autoclave, and at higher temperatures in a small pressure-treating cylinder. The atmosphere during steam heating was considered to be essentially saturated. Temperatures above 212° were 275°, 300°, and 350° F., although not all of these were included each time. Periods of heating used in most cases were 1, 24, and 48 hours, but in a few cases additional periods of $^1/_4$, $^1/_2$, and 6 hours were included.

This was not a continuous study but was conducted as three separate investigations. All temperatures and heating periods were not applied to each

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[3] For samples of angelique the writers are indebted to French Guiana Timbers, Inc., New York.

[4] For samples of Alaska-cedar, the writers are indebted to: Canadian Forest Products, Elburne Sawmills Division, Vancouver, B.C.; Chambers Lumber Co., Chicago, Ill.; Ehrlich-Harrison Co. Seattle Wash: General Hardwood Co., Tacoma, Wash.: J. Fyfe Smith Co.. Vancouver, B.C.; Winde-McCormick Lumber Co., Charlestown, Mass.

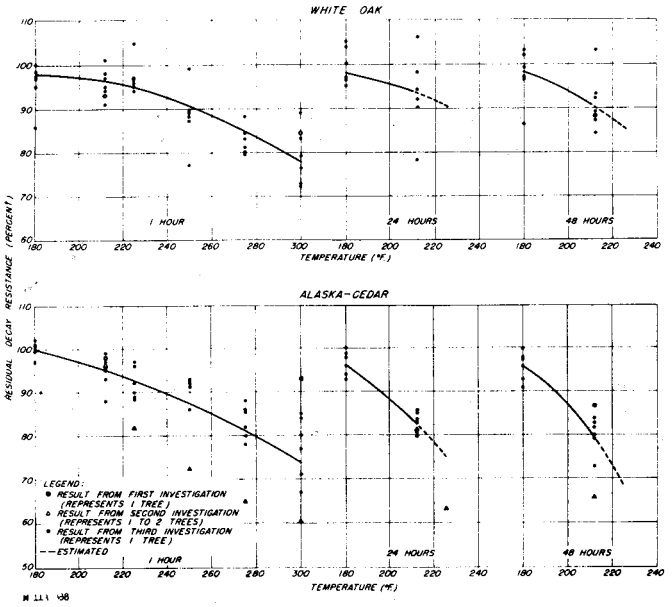

Fig. 1. —Examples illustrating the manner of graphically deriving the relation between residual decay resistance and temperature of wet heat.

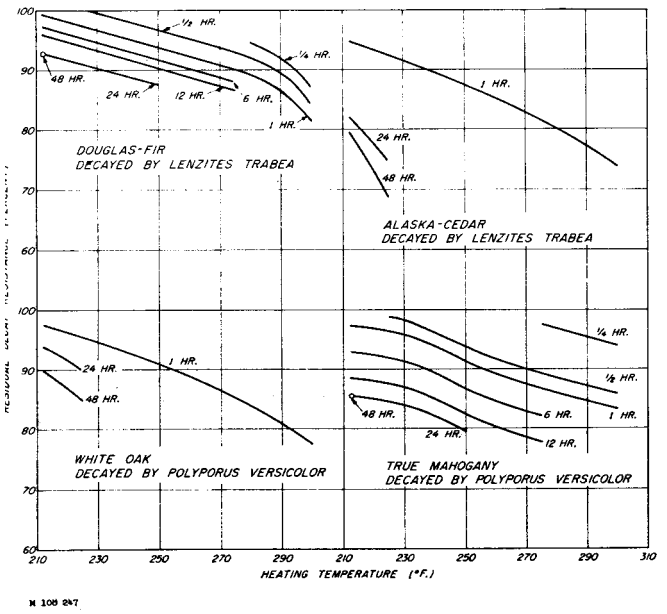

Fig. 2. —Relation between residual decay resistance and temperature of wet heat in four woods.

species. As a result, certain variations in associations of variables had to be considered in analyzing results.

Determining Decay Resistance: The variously heated and the unheated control blocks were evaluated for decay resistance by the laboratory soil-block method. This is a standard accelerated test employing pure cultures of decay fungi. French-square bottles of 8-ounce capacity were half filled with garden soil. On top of the soil in each bottle was placed a sapwood wafer ("feeder block") of pine for use with the blocks of coniferous species and of sweetgum for use with the blocks of hardwood species. The bottles thus prepared were autoclaved, inoculated with a test fungus. and incubated for 3 weeks. The $^3/_4$-inch specimens then were placed on feeder blocks, one to a bottle. These specimens had been dried, weighed, and briefly sterilized while dry by heating them in an autoclave for 15 minutes at 212° F. After 12 weeks of incubation, the blocks were removed and again dried and weighed. Drying of the blocks before and after exposure to the fungus and all incubation were done in a room maintained at 80° F. and 70 percent relative humidity. Details of the foregoing and other pertinent decay procedures were the same as prescribed by the standard ASTM test for preservatives (1)[3].

The decay fungi used throughout the study were *Lenzites trabea* (Madison 617) for assaying the softwood blocks and *Polyporus versicolor* (Madison 697) for assaying the hardwoods. These are standard test fungi, which in a large number of studies have proved their general suitability for appraising decay resistance.

Measuring Stability of Decay Resistance: The amount of decay in the test blocks during the 12-week incubation period was measured by the percentage loss in dry weight of wood. The loss in a fixed period of time also constituted a measure of the relative decay susceptibility of the wood. Conversely, the percentage of original weight retained by a block provided a measure of the decay resistance of the wood. The decay resistance was thus quantitatively calculated by:

$$\text{Index of resistance} = 100\,\frac{\text{Final dry weight}}{\text{Initial dry weight}} \qquad (1)$$

or

$$\text{Index of resistance} = 100\text{-percent weight loss} \qquad (2)$$

The effects of heating on the decay resistance of the respective woods were measured by the percentage of initial decay resistance retained by the wood after heating. This quantity, which will be referred to as the residual decay resistance or simply the residual resistance, was derived thus:

$$\text{Percent residual resistance} = 100\,\frac{\text{Final index of resistance}}{\text{Initial index of resistance}} \qquad (3)$$

The average results obtained with white oak subjected to wet heat at 212° F. are cited in Table 1 as examples of calculated data.

Results of Dry Heating

Dry heating reduced the decay resistance of the woods by comparatively small amounts (Table 2). The residual resistance did not fall below 90 percent except slightly in three instances where the temperature was elevated to 300° or 350[3] F. for 48 hours.

The insignificant reductions in decay resistance caused by dry heat do not justify distinguishing among the nine woods in this respect other than to note that angelique, baldcypress, Douglas-fir, and white oak exhibited slightly more stability of decay resistance than the other woods.

Results of Wet Heating

Trends of Heating Effect: Wet heating caused various reductions in decay resistance according to the temperature, duration of heating, and wood species. Loss of resistance in some woods was considerable with the more severe heating schedules. The relations of residual resistance to temperature were established graphically in the manner shown in Figure 1 for white oak and Alaska-cedar. The downward trends of resistance approached linearity in relation to both increased temperature (Figure 2) and increased duration of heating (Figure 3). Certain differences among the woods in rate of change caused by heating are indicated, but these cannot be viewed with too much significance because of the limited data supporting them.

Resistance of Various Woods as Affected by Wet Heating: In Table 3 are summarized the effects of wet heat involving the principal temperature-time combinations, in terms of the residual (percentage of original) resistance remaining after heating. These residuals can be used for a number of comparisons among the different woods, temperatures, and periods of heat application. Small losses of decay resistance from heating at 180° F. for periods up to 48 hours are indicated, and generally small losses at 212° F. maintained for 1 hour. The greatest losses caused by an hour of heating at 212° F. were near 10 percent (residual 90 percent) and occurred in the Atlantic white-cedar, redwood, and western redcedar. A temperature of 212° F. maintained for 48 hours caused losses of 1 to 27 percent. The severest heating, 300° F. for 1 hour, caused losses of resistance in eight of the woods amounting to 17 to 32 percent. Only the angelique remained at near normal level of resistance. The practical significance of these various percentage changes is discussed in detail later.

The relative susceptibility of the respective woods to change in decay resistance with wet heat tended to be similar for all levels of heating, as shown in Figure 4. This suggests, of course, that a wood bearing a certain relation to another with respect to change in decay resistance induced by the mildest heating tends to bear the same relation in its response to the most severe heating. It is possible, consequently, to group the woods according to their relative susceptibility to alteration by wet heat without regard to specific temperatures or periods of heating. Such a grouping, in which the species are assigned to four groups of heat susceptibility defined according to Figure 4, is as follows:

Group I (least susceptible)	Group III
Angelique	White oak
	Mahogany
	Western redcedar
Group II	Group IV
Baldcypress	Redwood
Douglas-fir	Atlantic white-cedar
	Alaska-cedar

The group placement of a particular species was determined by its occurrence at least twice in that group in Figure 4.

Besides considering the relative effect of wet heat on the different woods, it also is useful in certain connections to know how it affected the actual, or absolute, levels of resistance. For example, if the woods are rated according to the four commonly recognized classes of decay resistance—highly resistant, resistant, moderately resistant, and slightly resistant—does a certain kind of heating shift a wood entirely out of its normal class? Whether this would be likely depends on the initial or normal class as well as on the loss of resistance.

Classes of resistance to decay by the test fungi employed, before and after heating, are shown in Table 4. The classes of resistance shown in the table for the normal, unheated wood were known by reputation and from earlier testing for baldcypress (4); Douglas-fir (7) (12); oak (13); mahogany (8), and western redcedar (7) (10). The classes shown for heated woods were determined according to established levels of weight loss produced by the test fungus used, thus:

Percent weight loss in test	Index of resistance	Indicated resistance class
0–10	90-100	Highland resistant
11–24	76- 89	Resistant
25–44	56– 75	Moderately resistant
45 or more	55 or less	Slightly resistant

For most purposes, it is of no particular advantage to deal with smaller differences than are represented by these classes.

A study of Table 4 reveals that the decay resistance of none of the three woods heated at 180° F. for up to 48 hours was lowered sufficiently to take a wood out of its normal class of resistance.

At 212° F., the same was true of woods in heat-susceptibility groups I and II, but the more susceptible woods—of groups III and IV—were variously lowered in class depending upon the heating time. In those groups, heating for 1 hour lowered the resistance of all but the white oak and mahogany a half to a full class. The latter two woods remained in the resistant class. Heating at 212° F. for 24 or 48 hours seemed to have no significant further effect on the western redcedar, but it lowered the resistance of the woods of group IV an additional half to one class, and caused the first noticeable damage to the white oak and mahogany (reductions of one half to one class). Such effect as the 48-hour heating may have had beyond that produced in 24 hours was not noticeable in the woods of group III. Heating at 212° F. for 48 hours probably caused the woods of group

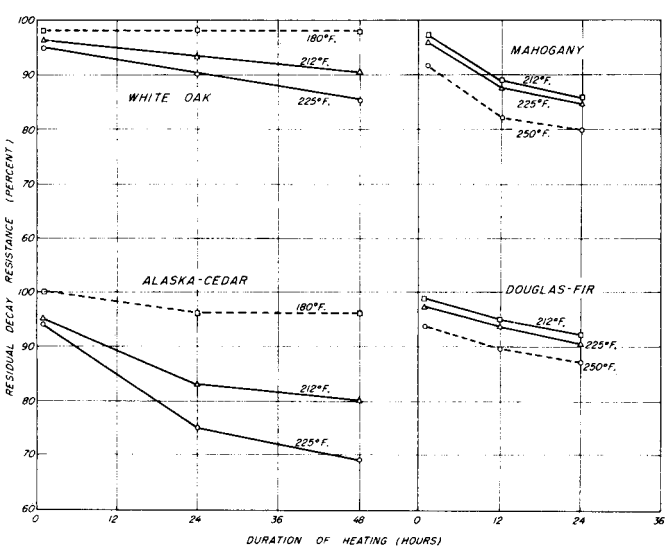

Fig. 3. —Relation between residual decay resistance and duration of heating in four of the woods.

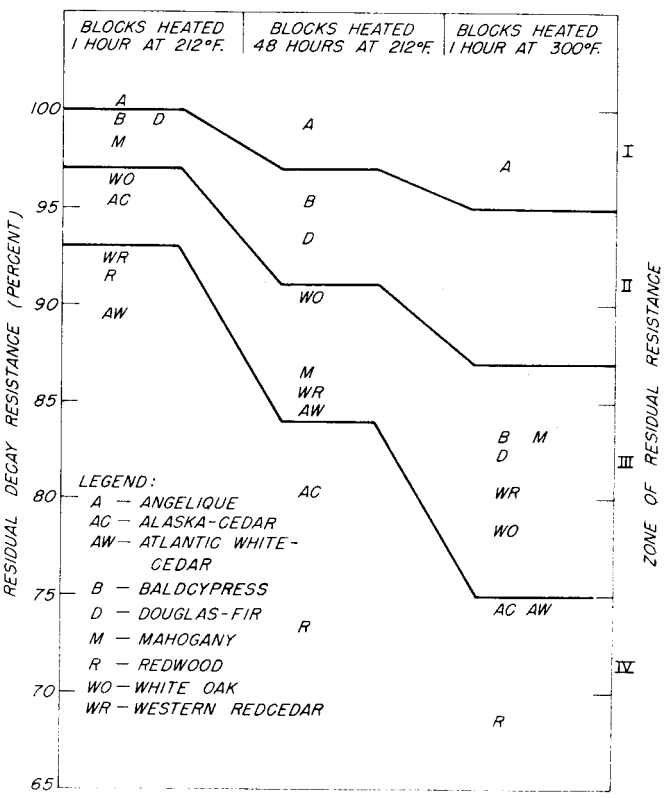

Fig. 4. —Graphic evidence that the relative susceptibility of the woods to lowering of decay resistance by wet heat was substantially independent of the severity of heating.

Table 1. —INDEX OF DECAY RESISTANCE AND RESIDUAL DECAY RESISTANCE OF WHITE OAK

Calculation	Period of heating: 0 (control blocks) Percent	1 hour Percent	24 hours Percent	48 hours Percent
Weight loss from decay	20	23	26	27
Index of resistance[1]	80	77	74	73
Residual resistance[2]	--	96	93	91

[1]Formula (2).
[2]Formula (3).

Table 2. —RESIDUAL DECAY RESISTANCE, OR PERCENT OF ORIGINAL DECAY RESISTANCE, REMAINING IN HEARTWOOD SAMPLES OF THE NINE DIFFERENT WOODS AFTER THEY WERE SUBJECTED TO VARIOUS APPLICATIONS OF DRY HEAT

Wood	Heating period Hours	Residual resistance after heating: 212° F. Percent	300° F. Percent	350° F. Percent
Alaska-cedar	1	--	100	97
	48	95	85	85
Angelique	1	Not tested, but by inference from the wet-heat results the dry-heat values would be 98 or higher.		
	48			
Atlantic white-cedar	1	95	94	--
	48	94	--	--
Baldcypress	1	96	99	--
	48	99	--	--
Douglas-fir	1	--	100	104[1]
	48	99	100	107[1]
Mahogany (true)	1	90	95	95
	48	93	87	104[1]
Redwood	1	95	97	--
	48	94	--	--
Western redcedar	1	95	93	--
	48	94	--	--
White oak	1	98	99	--
	48	99	116[1]	--

[1]Values greater than 100 reflect experimental error, not actual increases in resistance.

IV to drop no more than about one-half class in resistance below the level reached after 24 hours.

Heating at 225° F. for 1 or 24 hours seems to have altered the classes of resistance little more than the corresponding heating at 212° F. A 48-hour period of heating, however, caused a slightly greater reduction in class at 225° F. than at 212° F. At 300° F., applied for 1 hour, only the angelique, the single representative of group I, maintained its original resistance classification. Five of the other nine woods, including the group II woods, baldcypress and Douglas-fir, which had not been affected by the lesser heating, were made one class less resistant than normal, and the western redcedar, Alaska-cedar, and redwood were made one and a half to two classes less resistant. It is interesting to note that only the redwood seems to have suffered no further loss in resistance beyond the relatively large amount incurred at 212° F.

Comparison with Past Results of Heat Studies

There have been a number of earlier studies of heat effects on the decay resistance of wood, but none so comprehensive as those here reported. The observations drawn from the earlier studies, where comparable, were in general agreement with those reported here.

Boyce (2) found that dry heat at 212° F. or steam heat at 250° F., applied to air-dried heartwood for 20 minutes, had no measurable effect on the decay resistance of Sitka spruce, Douglas-fir, baldcypress, or western redcedar. In a similar study of the effect of short-term heating, Chapman (5) found that the decay resistance of shortleaf pine *(Pinus taeda)* sapwood was reduced to a residual resistance of approximately 95 percent by steam heating for 30 minutes at 212° F., and to 86 percent by heating for 5 minutes at 244° F.

Scheffer (9) observed that steam heating of green post wood for as long as 8 hours at 212° F. did not noticeably affect the decay resistance of mesquite *(Prosopis juliflora* var. *velutina)* heartwood or sapwood, but it lowered slightly the resistance of both the heartwood and sapwood of Utah juniper *(Juniperus osteosperma).* The residual resistance of the juniper heartwood to the more damaging test fungi was about 93 percent. In appraising the possibility that commercial steaming of sweetgum *(Liquidambar styraciflua)* might reduce its decay resistance, Scheffer and Lindgren (11) observed an average loss in decay resistance of the sapwood corresponding to a residual—resistance of about 90 percent when the green wood was steamed for 33 hours at 155° to 160° F.

In decay tests made on beech wood steamed for 12 hours, Eeckhaut (6) obtained evidence of losses in resistance of air-dried wood but not of green wood. His findings appear to contradict the evidence uncovered in the present studies, which showed that the presence of moisture in wood favors, rather than hinders, the lowering of decay resistance by heat. It is difficult to account for this contradiction.

Buro (3) caused the decay resistance of pine sapwood and beech wood to increase in decay resistance with heating. This heating was of an extreme type, however, so that the results are not comparable with the others. The wood was heated under molten metal, and the resistance was increased at the expense of losses in wood substance of 8 to 10 percent. The same kind of result was obtained by Stamm, Burr, and Kline (15) in studies of wood heated in metal.

An additional point must be noted here about the findings of Chapman (5) and those of Scheffer and Lindgren (11). In both investigations, decay resistance was found to have been reduced by temperatures below 180° F. or by heating periods of 30 minutes or less. From the results here reported, this mild heating would not be expected to produce a measurable effect. The specimens used, however, differed; sapwood was used in the earlier studies, heartwood in those here reported. Sapwood of all species has relatively little decay resistance, and heating apparently made some of the cellulose more assimilable by fungi. In decay-resistant heartwoods, a comparable effect on the cellulose would hardly be noticed because of the dominant effect of the natural preservatives in determining the decay resistance.

The relative order of susceptibility to loss of decay resistance among the different woods was broadly similar with dry and wet heating. The angelique, baldcypress, and Douglas-fir were least affected by both forms of heating. White oak was more or less intermediately affected, and the susceptibility of the mahogany, western redcedar, Atlantic white-cedar, Alaska-cedar, and redwood was increased most.

The fact that dry heat was much less deleterious to decay resistance than wet heat suggests that the effect of the heat is not primarily one of driving off volatile preservative constituents. Rather, it seems that the heat acts more to bring about a chemical change in the preservatives, which is accomplished largely in the presence of water.

It possibly is of some significance that the four woods most susceptible to loss of decay resistance were all softwood (coniferous) species. The only softwood exhibiting above-average heat tolerance was baldcypress. Three of the more susceptible softwoods were cedars, which have an aroma. Loss of the volatile materials, however, does not seem to be the chief factor involved. This conclusion is supported by the fact that redwood,

though nonaromatic, suffered the greatest losses of resistance.

Conclusions need not be particularly qualified in regard to the practical aspects of heating for the following reasons. 1) the woods were reasonably consistent in retaining most of their normal decay resistance when subjected to dry heat (Table 2); 2) the trends of resistance loss with we: heating (Figures 2 and 3) were basically similar; and 3) the woods tended to maintain essentially their normal class of decay resistance under the more moderate wet-heating schedules (Table 4).

If these data are to be appraised more closely, it should be kept in mind that none of the woods were represented by samples of a large number of trees. There was not the same number of trees, moreover, to represent each of the species which was sampled. Because of their larger numerical basis, the data for angelique, Douglas-fir, white oak, mahogany, and Alaska-cedar deserve more weight than those for the other woods.

Indicated Effects of Industrial Heating on Decay Resistance

The effect on the tested woods of heat to which wood is subjected in certain commercial processing operations or stages of manufacturing may be judged from the present data. For this purpose, the dry-heat data of Table 2 and the wet-heat data of Tables 3 and 4 especially are applicable.

With respect to both the temperatures reached and the moisture condition of the wood, an industrial heating process usually is far from uniform. In drying lumber or veneer, for example, the temperature in the wood and the moisture content vary with the stage of drying. Some assumptions as to temperature and moisture usually must be made, therefore, when appraising the influence of a particular process involving heat suspected of being severe enough to materially lower decay resistance. This is done in appraising the effects on decay resistance of temperature applications to wood described in the following typical examples.

Wet Heat: Wet heat is involved when veneer bolts are heated to prepare them for cutting. The bolts are submerged in water at 160° to 180° F. for 2 or more days. Inasmuch as decay resistance of Alaska-cedar, a group IV wood (Table 4), was little harmed by steam heating for 48 hours at 180° F., it is unlikely that heating of veneer bolts of any of the woods would be seriously detrimental.

Wet heat, of course, is also used in the steaming of boat frames to facilitate bending. A temperature of 212° F. is applied for 1/2 hour per inch of thickness. Bent frames have a common upper limit of thickness of about 4 inches. Such a frame, therefore, might be steamed for 2 hours. Judging from the data given in Tables 5 and 4 for 1 hour of heating at 212° F., steaming at atmospheric pressure for 2 hours might be expected to reduce significantly the decay resistance of only the woods in susceptibility groups III and IV, and perhaps then only the cedars and redwood.

Wet Heat Followed by Dry Heat: A combination of wet and dry heat is used in kiln drying. The initial heat necessarily is wet because the stock is green and the relative humidity of the drying air is kept comparatively high. In the later stages of drying, the heat is essentially dry because the lumber has lost its free water and the relative humidity is kept comparatively low. To dry 4/4 oak, an initial temperature of about 110° F. may be applied for 16 days. After the first 10 to 12 days, the humidity is gradually lowered. After the 16th day, the temperature is gradually increased to 140° F. over a period of 6 days; and finally the temperature is raised to 180° F. for 4 days. Dry heat is used the first 3 of the 4 days, then wet heat is used for conditioning the final day.

Although moderate heat is generally used in drying Douglas-fir, in some cases the schedule for 4/4 Douglas-fir Clears may be 180° F. increasing to 200° F. over a period of 90 hours, followed by conditioning at 200° F. for 4 to 10 hours. For 8/4 Douglas-fir in the upper grades, it might be 145° F. increasing to 175° F. for 192 hours, followed by conditioning at 180° F. for 10 hours. During the conditioning periods, relative humidities as high as 85 percent may be used.

In estimating the effect of such kiln drying on decay resistance, temperatures lower than 200° F. are of chief significance, since they relate to the wood while it is in a wet condition and thus is more susceptible to heat effects. Higher temperatures, if applied, are involved only after the wood

Table 3.—RESIDUAL DECAY RESISTANCE, OR PERCENT OF ORIGINAL DECAY RESISTANCE, REMAINING IN HEARTWOOD SAMPLES OF THE NINE DIFFERENT WOODS AFTER THEY WERE SUBJECTED TO VARIOUS APPLICATIONS OF WET HEAT

Wood	Heating period Hours	Residual resistance after heating							
		180° F.		212° F.		225° F.		300° F.	
		Range Percent	Average Percent	Range Percent	Average Percent	Range Percent	Average Percent	Range Percent	Average Percent
Alaska-cedar[1]	1	97–102	100	88– 99	95	82– 97	95	60–93	74
	24	93–100	96	80– 86	83	------	75[2]	------	--
	48	91–100	96	66– 87	80	------	69[2]	------	--
Angelique[3]	1	99–102	101	99–103	101	98–102	101	93–98	97
	24	99–102	101	98–100	100	------	--	------	--
	48	96–103	100	94–100	99	------	--	------	--
Atlantic white-cedar[4]	1	------	--	------	89	------	--	------	74
	48	------	--	------	84	------	--	------	--
Baldcypress[4]	1	------	--	------	99	------	--	------	83
	48	------	--	------	95	------	--	------	--
Douglas-fir[5]	1	------	--	------	99	------	97	------	82
	24	------	--	------	93	------	91	------	--
	48	------	--	------	93	------	--	------	--
Mahogany (true)[5]	1	------	--	------	98	------	96	------	83
	24	------	--	------	86	------	85	------	--
	48	------	--	------	86	------	--	------	--
Redwood[4]	1	------	--	------	91	------	--	------	68
	48	------	--	------	73	------	--	------	--
Western redcedar[4]	1	------	--	------	92	------	--	------	80
	48	------	--	------	85	------	--	------	--
White oak[1]	1	86–100	98	91–101	96	94–106	95	72–89	78
	24	95–105	98	78–106	93	(2)	90	------	--
	48	86–103	98	84–103	90	(2)	85	------	--

[1]Average values are estimated from smoothed curves through the plotted data (Figure 2). Each represents material from at least six trees. A total of eight to nine trees are represented in some of the values for 212°, 225°, and 300° F.
[2]Value estimated from projected curve (Figure 2).
[3]Average values represent evidence on material from six trees.
[4]Average values represent material from one tree.
[5]Average values are estimated from smoothed curves. The testing was on material from two to three trees.

Table 4.—CLASSIFICATION OF THE DIFFERENT WOODS FOR DECAY RESISTANCE FOLLOWING VARIOUS EXPOSURES TO WET HEAT[1]

Heat-susceptibility group[2] and wood species	Unheated (normal wood)	Heat applied and associated class of resistance: Heated to 180° F.			Heated to 212° F.			Heated to 225° F.			Heated to 300° F.
		1 hr.	24 hr.	48 hr.	1 hr.	24 hr.	48 hr.	1 hr.	24 hr.	48 hr.	1 hr.
Group I (least effect):											
Angelique	High	High	High	High	High	High	High	High	----------	----------	High
Group II:											
Baldcypress (second growth)	Moderate to resistant	----------	----------	----------	Moderate to resistant	----------	Moderate to resistant	----------	----------	----------	Slight to moderate
Douglas-fir	Moderate	----------	----------	----------	Moderate	Moderate	Moderate	Moderate	Moderate	----------	Slight
Group III:											
White oak	Resistant	Resistant	Resistant	Resistant	Resistant	Moderate to resistant	Moderate to resistant	Resistant	Moderate to resistant	Moderate	Moderate
Mahogany (true)	Resistant	----------	----------	----------	Resistant	Moderate	Moderate	Resistant	Moderate	----------	Moderate
Western redcedar	High	----------	----------	----------	Resistant	----------	Resistant	----------	----------	----------	Moderate to resistant
Group IV:											
Atlantic white-cedar	Resistant	----------	----------	----------	Moderate to resistant	----------	Moderate	----------	----------	----------	Moderate
Alaska-cedar	High	High	High	High	Resistant to high	Resistant	Moderate to resistant	Resistant to high	Moderate	Moderate	Moderate
Redwood	High	----------	----------	----------	Resistant	----------	Moderate	----------	----------	----------	Moderate

[1]Classes assigned according to an established scheme of classification, based on laboratory testing, as described in the text.
[2]Groups according to Figure 4.

has dried to a point where the subsequent heating environment is dry. The fact that the woods subjected to 48 hours of wet heat at 180° F. retained no less than 96 percent of their original decay resistance (Table 3), even in the case of Alaska-cedar, a representative of group IV, makes it seem likely that most woods would tolerate the same heating fully as well.

This indirect evidence as to the effect of 180° F. and actual data on the effect of 212° F. on Douglas-fir (Tables 3 and 4), indicate that the foregoing kiln schedule for 4/4 stock of this wood (180° F. progressing to 200° F. in 90 hours) will not significantly affect its decay resistance. It could hardly be expected, moreover, that the schedule for the 8/4 Douglas-fir would affect its resistance consequentially. Although this schedule is considerably longer (drying phase, 192 hours), the initial temperatures are much milder (145° to 175° F.). For the same reason, it is even less likely that the oak would be much affected by the kiln schedule described for it (principal drying temperature 110° F.).

Results of decay tests made on Douglas-fir heartwood stock that was kiln dried corroborate the foregoing conclusions. Little or no loss of resistance to decay by *Lenzites trabea* was indicated for stock dried at 120° F. for 159 hours, 150° F. for 137 hours, 153° F. for 260 hours, or 180° F. for 65 hours. At higher temperatures, drops in resistance were indicated as follows: 202° F. for 164 hours, residual resistance 87 percent; 210' F. for 51 hours, residual resistance 96 percent, and for 98 hours, 94 percent. These higher temperatures are considerably above the principal ones usually used in drying Douglas-fir. Judging from the results of laboratory heating and the results of the actual kiln heating, therefore, it appears unlikely that the decay resistance of Douglas-fir would be affected by ordinary kiln drying.

A combination of wet and dry heat also is used in veneer drying. A common drying schedule consists of 300° to 325° F. for 20 minutes. For approximately half of this time the veneer contains free water and the wood temperature remains at 212° F. Through the remaining time, in which the high temperatures are developed, the wood is exposed to essentially dry heat. Inasmuch as the total time of heating is only about 20 minutes, and particularly since the temperature of the wet phase is only 212° F., such veneer drying could hardly affect the decay resistance of even a group IV wood significantly.

Dry Heat: Dry heat is brought to bear on wood in the course of hot-press gluing. A typical plywood schedule is 300° to 325° F. for 5 to 15 minutes. In laminating 4- by 4-inch boat frames, a common schedule is 150' F. for 5 to 15 minutes, and one for 12- by 14-inch frames is 150° F. for 36 hours. Juding from the information on the effects of dry heat, given in Table 2, gluing with these combinations of temperatures and times would have little effect on the resistance of any of the woods.

Dry heat is also used in bag molding, and a common schedule is 275° F. for 20 to 30 minutes. As with hot-press gluing, such heating is not severe enough to effect a material change in decay resistance.

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