AMERICAN WOOD-PRESERVERS' ASSOCIATION

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EFFECT OF HEATING WET WOOD ON ITS SUBSEQUENT DIMENSIONS

By Arthur Koehler[1]

In kiln drying, permanent bending, preservative, and other preparatory processes, wood is frequently heated while wet to temperatures close to and even considerably above the boiling point of water. Under such conditions the wood sometimes checks and undergoes distortion of shape. Mechanical tests have shown that steaming green wood at temperatures above 212° F. may considerably reduce its strength below that of similar unsteamed wood. Much of this loss in strength, however, is regained as the wood dries. With loblolly pine, at least, it was found that on resoaking the previously steamed and dried wood it again was lower in strength than unsteamed green wood, showing thereby that the weakening effect was permanent in the wet wood. This condition was ascribed by Hatt[2] to a permanently raised fiber-saturation point which allowed the cell walls to imbibe more water in the presence of a sufficient amount of moisture than is normally present in the cell walls of green wood, thereby reducing its strength.

If an additional amount of water is imbibed by the cell walls beyond their normal green condition, it should be manifest in additional swelling. Practically no information is available, however, on the effect of steaming or otherwise heating wet wood on its dimensions while wet, on subsequent drying, or on resoaking.

In order to determine in a preliminary way what effect heating wet wood has on its subsequent dimensions, green strips of tangential and of radial shortleaf pine, yellow birch, and an undetermined species of the red oak group were heated at temperatures of 160°, 192°, 212°, and 274° F. The tangential strips of pine and birch were sapwood, but the tangential oak strips and all the radial strips consisted of heartwood and sapwood. All strips were measured before heating, after cooling, in subsequent stages of drying

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[2] Hatt, W. K. Experiments on the strength of treated timber. Forest Service Circular 39, 1906.

and in the resoaked condition. Different strips were used for each temperature treatment except that the same strips were used for the treatments at 192° and 274° without intermediate drying, and, therefore, no data were obtained on the effect of a maximum temperature of 192° on the subsequent dimensions of the dry or resoaked wood.

The strips of wood, which for convenience are termed here as specimens, measured $^3/_8$ inch along the grain, $^1/_2$ inch across the grain in one direction, and about $9^1/_2$ inches in the direction to be measured—tangential or radial. Matched specimens cut adjacently along the grain were used for the different temperature treatments and for controls. For the most part, eight tangential and eight radial specimens were used from each species for each temperature and sixteen for controls from each species for all temperatures, although in a few instances a lesser number was used. Half of the tangential and half of the radial specimens for each treatment were cut from one part of a green bolt and half from another part.

Although the wood appeared to be green when cut into specimens, the specimens were submerged in water for 16 to 48 hours before they were heated in order to insure the presence of surplus water above the normal fiber-saturation point. No appreciable change in dimensions took place as a result of this soaking, and later calculations of the original moisture content showed that it was above 50 per cent in all specimens, and over 100 per cent in many of them. The specimens were heated and cooled above a small quantity of water in closed containers so that they would not dry out sufficiently to shrink during the treatment. Calculations made later on weights taken immediately after removal from the containers showed that there was no significant change in moisture content. The length of the heating period varied with the treatment as follows: For 160°, 16 hours; for 192°, 24 hours; for 212°, $6^3/_4$ hours; and for 274° F., $6^1/_4$ hours. After heating, the specimens were cooled gradually in their containers for a period of about 12 hours.

Measurements of the longest dimensions (tangential and radial) were made immediately after removal of the specimens from the containers. All the heat-treated specimens, except those heated at 212° F., were soaked after their first measurement after heating to insure thorough saturation. Remeasurement after soaking showed no significant change in dimensions.

The heat-treated specimens together with the controls were then dried at a temperature of about 80° F., first in a relative humidity of about 60 per cent and then at about 30 per cent. The specimens were weighed and measured after they had come to equilibrium with each humidity condition. They were then resoaked to see whether any effect of heating on the original dimension would persist on rewetting.

After resoaking, the specimens were again dried at approximately 60 and 30 per cent relative humidities, and then oven dried. Weights and measurements were taken in each stage of drying. All apecimens given a certain treatment were dried at one time and therefore were comparable in moisture content and shrinkage, but specimens receiving different treatments were dried at different times and, since it was impossible to maintain the relative humidity of the surrounding air constant, the moisture content values for different treartments are not directly comparable but close enough to make the corresponding shrinkages comparable in a general way when plotted against the respecive moisture content values, as in Figures 2 to 7.

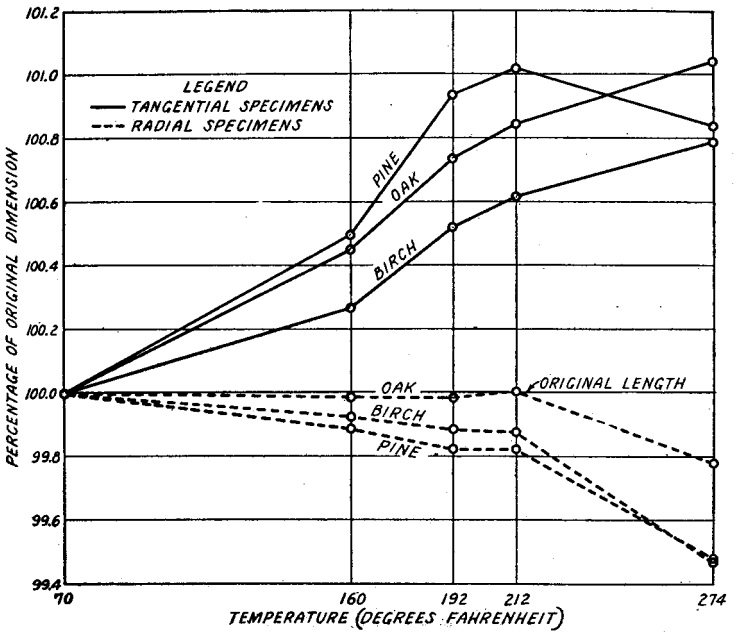

Figure 1.—Effect of heating wet wood at four different temperatures on its dimensions after cooling, in percentage of original dimensions.

Results

Effect of Heat Treatment on Dimensions While Wet

Figure 1 shows the effect of the different temperatures used on the dimensions of the wet wood after cooling to room temperature. No attempt was made to measure the specimens while hot on account of the high temperatures involved. All three species expanded tangentially and contracted radially. The tangential expansion per degree of temperature was greatest between 160" and

192°, whereas the radial contraction was greatest above 212° F. The slight apparently greater radial dimension of the oak at 212" as compared with 192° may be due to experimental error, since the two groups of four specimens each which were used were not consistent in their change in dimension, but the drop in the tangential dimension of shortleaf pine at temperatures between 212° and 274° was consistent for the two groups cut from different portions of a bolt, as were all other major changes in dimensions for all three species.

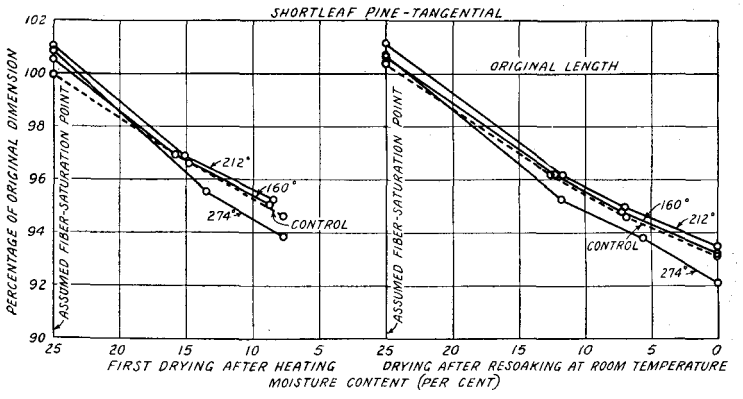

Figure 2.—Tangential dimensions of shortleaf pine in several stages of drying after being subjected to various temperatiire, in percentage of original green length.

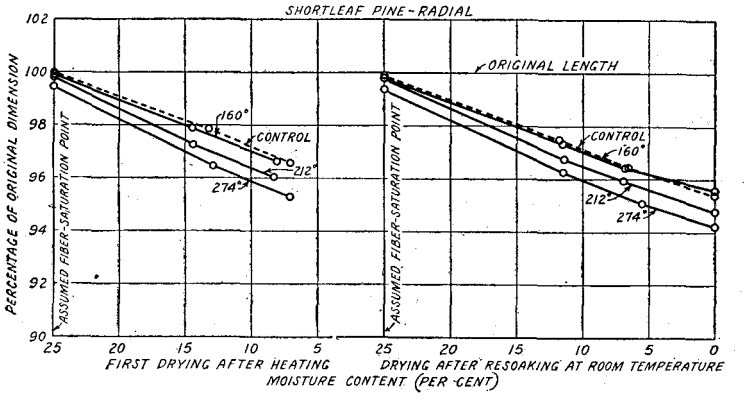

Figure 3.-Radial dimensions of shortleaf pine in several stages of drying after being subjected to various temperatures while wet and after resoaking at room temperature, in percentage of original green length.

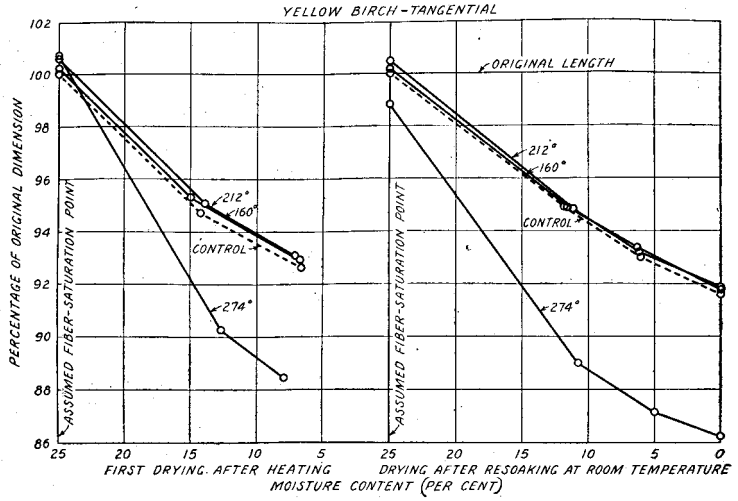

Figure 4.—Tangential dimensions of yellow birch in several stages of drying after being subjected to various temperatures while wet and after resoaking at room temperature, in percentage of original green length.

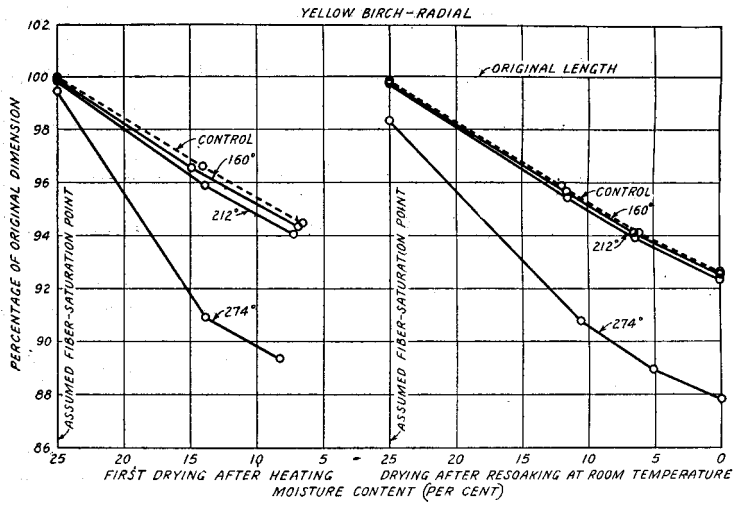

Figure 5.—Radial dimensions of yellow birch in several stages of drying after being subjected to various temperatures while wet and after resoaking at room temperature, in percentage of original green length.

Effect of Heat Treatment on Dimensions When Resoaked

Upon resoaking the specimens after their first drying at 30 per cent relative humidity, the length of many of the control specimens varied appreciably from what it was originally. The tangential pine controls were consistently longer, the birch controls were of

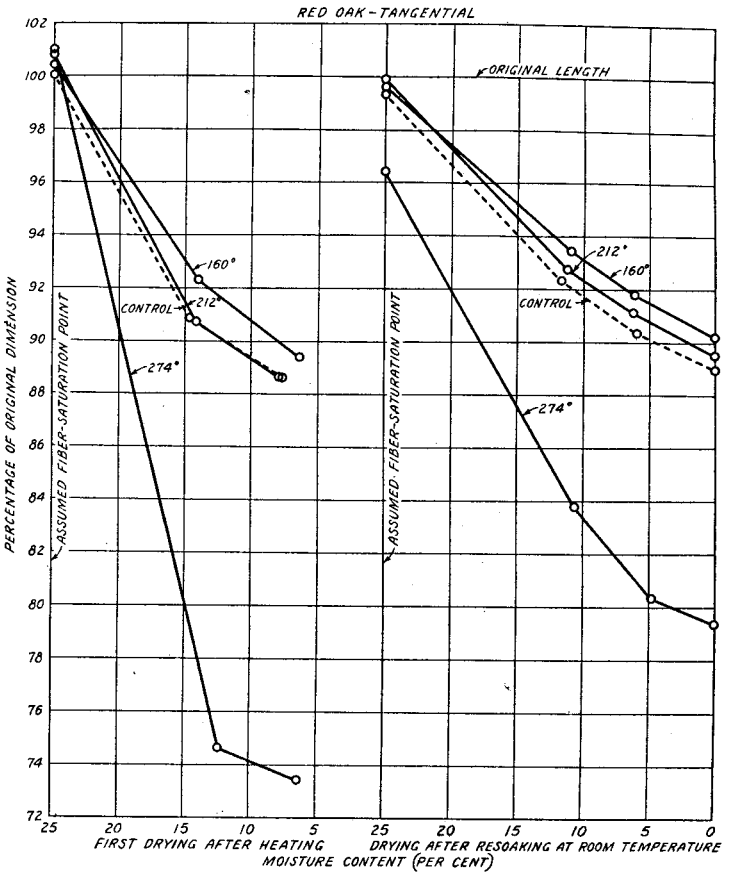

Figure 6.—Tangential dimensions of red oak In several stages of drying after being subjected to various temperatures while wet and after resoaking at room temperature, in percentage of original green length.

about the same length, and the oak controls were consistently shorter than originally. The radial controls were slightly shorter than originally for the three species. These changes in the dimensions of the resoaked control specimens are shown on a small scale in Figures 2 to 7.

In order to determine the effect of heating on the dimensions of the resoaked specimens it is necessary to compare them with the controls as a base, since they had been given the same treatment except for the heating. Figure 8 shows the dimensions of the heat-treated specimens in terms of the controls after soaking. By comparing Figure 8 with Figure 1 it may be seen that for temperatures of 160° and 212° F., the effect of the heat treatments on the original dimensions persisted in a general way in the resoaked wood. For the treatment at 274°, however, the birch and oak specimens showed considerable reduction in size.

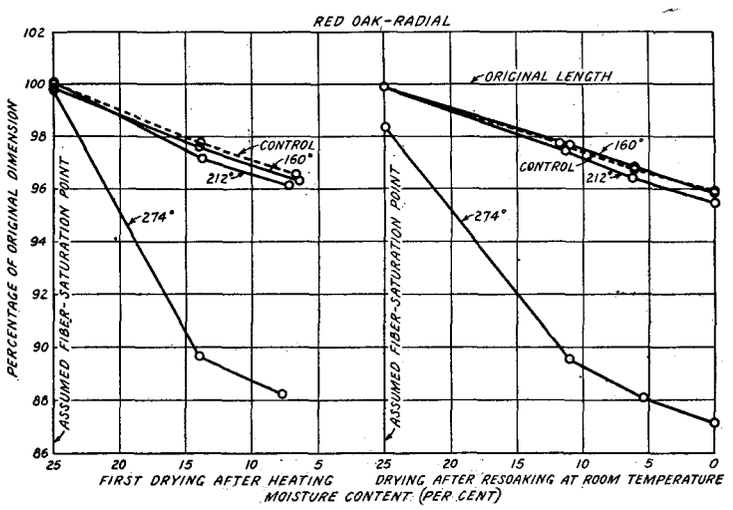

Figure 7.—Radial dimensions of red oak in several stapes of drying niter being subjected to various temperatures while met and after resoaking at room temperature, in percentage of original green length.

Effect of Heating on Dimensions at Different Degrees of Dryness

Figures 2 to 7 show the percentage shrinkage based on the original dimensions in drying the specimens, first to two stages of dryness and then, after resoaking, to approximately the same stages and in addition to the oven-dry condition. It was assumed that shrinkage began at 25 per cent moisture in all cases, although the exact percentage could not be determined from the data and probably varied with the species and treatment given.

It may be seen from the graphs that the specimens heated to 274" F. shrank more than those not heated; in the oak about twice as much tangentially and more than that radially. In the birch and pine the differences were less pronounced.

The specimens heated at 160" and 212" F. did not shrink significantly differently than the controls. What slight differences

occurred were in the same order as to temperature in the first and second drying for each species.

No significant differences in the shrinkage in the first and second drying for comparable moisture content values occurred in the pine and birch, as far as can be determined from the curves in Figures 2 to 5, but all the oak specimens, including the controls, shrank appreciably more the first time, both radially and tangentially.

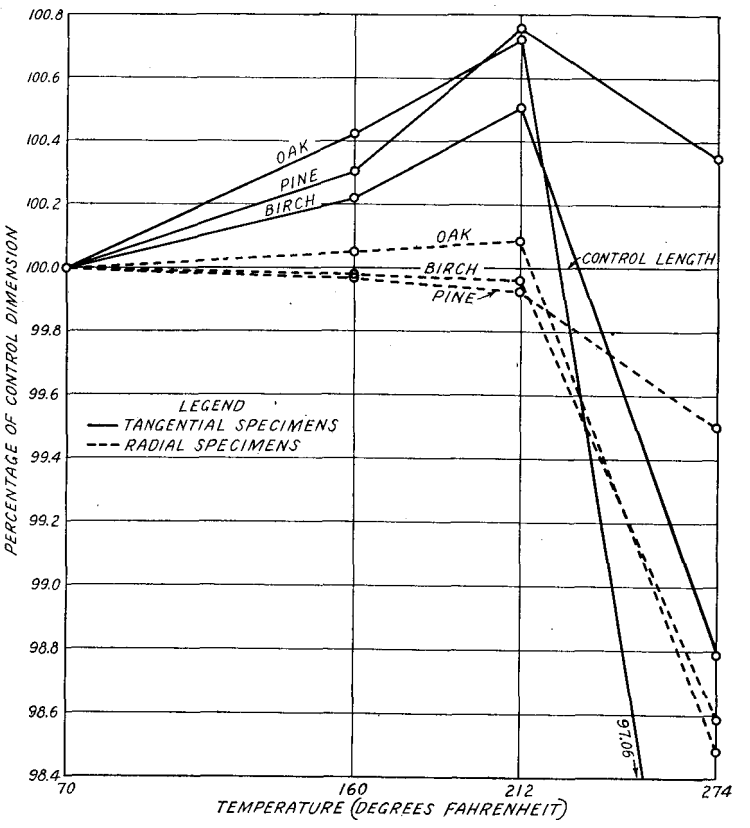

Figure 8.—Effect of heating wet wood at three different temperatures on its dimensions after partial drying and resoaking at room temperature, in percentage of control dimensions.

Discussion

It is extremely significant that the changes in tangential and radial dimensions which occurred in the wet wood as a result of heating are not only different from the usual ratio but of opposite sign. Although the changes in dimensions are relatively small, in such round timber products as poles, piling, posts, veneer bolts,

and even in square-edged timbers containing the pith, severe stresses would be set up when the green wood is heated, on account of the tangential expansion and radial contraction. In a bolt 16 inches in diameter a tangential expansion of 1 per cent would increase the circumference by 1/2 inch. These stresses would supplement similar existing stresses in green wood, for it has been observed in numerous species that in the green condition the outer

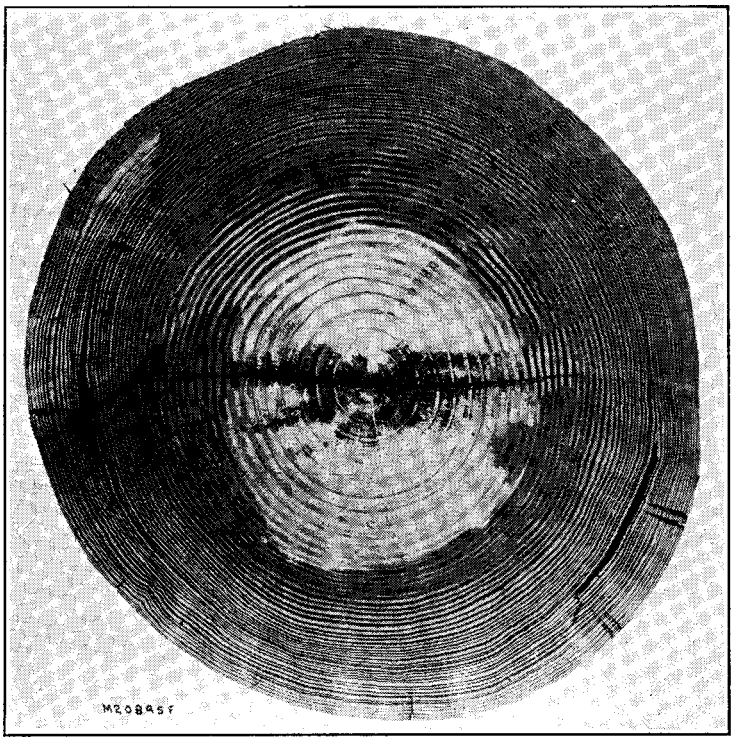

Figure 9.—Internal cracks in green southern pine pole heated to 200° F. for 13 hours and subsequently creosoted.

portion of a log is in compression tangentially, which produces a tensile stress radially. This can be demonstrated by the closing in of the saw cut at the periphery when sawing radially into a green disc, in fact it often is difficult to make such a cut on account of the pinching of the saw that takes place. These combined stresses are in turn supplemented by the greater tangential than radial thermal expansion of wood when heated, and by the fact that the outer portion of a timber becomes heated first, thereby tending to expand the periphery through both swelling and thermal expansion

before the interior expands equally. The result of these stresses would be to form radial cracks near the center or circular cracks farther out. Both of these have been observed in heat-treated round green timber. Figure 9 shows such cracks in a southern pine pole that had been given a preliminary heat treatment (boiling in vacuum) while green of 200" F., for 13 hours before injection of creosote. It has also been observed that veneer bolts which are steamed or placed in hot water to soften them, frequently form radial cracks extending through the core.

Another practical aspect of this phenomena is that plain-sawed lumber, if subjected to high temperatures in a dry kiln while green, would tend to cup with the hollow side toward the center of the tree (the reverse of what takes place in drying). If the lumber has sufficient weight on it so that it can not cup, compression set might result on the bark side, which in turn might increase the amount of checking or the tendency to cup the other way as the lumber dries.

Since the tangential dimension increased considerably more than the radial dimension decreased, there must have been an increase in the external volume of the wood amounting to from 0.2 to 0.8 per cent as a result of the heat treatments.

Such an increase in volume might be brought about in two ways: (1) an increased absorption of moisture by the cell wall, that is, a rise in the fiber-saturation point, thereby causing additional external and presumably internal swelling; or (2) a permanent readjustment of the structure of the wet cell walls under high temperature whereby the outer diameter of the fibers and the size of the fiber cavities are increased in such proportions that there is no increase in the volume of the fiber walls, and hence, no rise in the fiber-saturation point. The former possibility probably agrees more closely with the decrease in strength of steamed green wood and its regain of that loss on drying. An increase in the fiber-saturation point is not contrary to the well-established fact that the moisture content of wood in equilibrium with 100 per cent relative humidity, as determined by extrapolation from lower humidities, decreases with an increase in temperature, which would indicate a lowering of the fiber-saturation point, since one of the definitions of fiber-saturation point is the moisture content of wood when in equilibrium with 100 per cent relative humidity.

The two phenomena differ in that in heating the wet wood a permanent change apparently takes place which persists when the wood is cooled; whereas the reduction in the amount of water held by the fiber walls when exposed at high temperatures to saturated air in the absence of free water is a temporary condition which persists only as long as the temperature is maintained.

The decrease in the radial dimension as a result of heating, while apparently inconsistent with an increased absorption of moisture

by the cell walls, may be due to crooking of the rays or corrugation of the ray cells on account of uneven tangential swelling, in fact, such an effect can be observed under a microscope by treating a thin section of wood with a swelling agent, such as caustic soda. Such distortion of the rays from a more nearly straight line would tend to reduce the radial dimension. There may even be some radial swelling of the rays and surrounding fibers, but it is masked by the crooking of the rays. This explanation assumes that the rays did not swell so much along their length (radially) as the adjacent fibers tend to swell in that direction, otherwise there would be no more reason for uneven tangential swelling shortening the radius than for uneven radial swelling similarly affecting the tangential dimension.

No explanation is offered as to why the radial shortening was accelerated above 212" F., unless it be that the increased plasticity of the wood at that temperature permitted greater deformation of the rays.

The excessive shrinkage of the specimens heated to 274" F., apparently was due to collapse of the fibers in drying, since the specimens of the two hardwood species in particular, and especially of the oak, had the typical caved and shrivelled appearance of collapsed wood. As further evidence that the excessive reduction in length was due to collapse may be cited the fact that most of this reduction occurred somewhere in the initial drying stage, as may be seen from the curves in Figures 2 to 7, which is when collapse occurs. Collapse ordinarily does not occur at temperatures so low as that used in drying the specimens (about 80° F.) but is frequent at higher temperatures, especially in oak.

The fact that these specimens collapsed at the low temperature indicates that their cell walls were more plastic than in normal wood, presumably because they had imbibed more water.

The extremely large shrinkage of the oak and birch heated to 274° F. obviously would be ruinous for practically all uses. Evidently hardwood species are affected much more in that respect by the high temperature treatment. What the reduction in size would have been if the specimens had been dried at higher temperatures, such as are used in dry kilns, is impossible to estimate, but very likely it would have been greater, since collapse occurs more readily at the higher temperatures.

The consistent increase in the tangential direction of the pine control specimens on resoaking in comparison with their original green and soaked dimensions must be due to either a chemical change, or a physical readjustment that occurred as a result of drying, since no appreciable change in dimensions took place when the green specimens were first submerged in water. Whether the difference in the behavior of the birch and oak specimens as compared with each other and with the pine is due to a different in-

trinsic behavior of the different species, or whether it merely is due to greater permanent internal deformation with increasing shrinkage which prevented full resumption of or even expansion over their original size can not be stated without making investigations on wood of the same species but with different inherent shrinkage capacities.

The increase in the tangential dimension of the specimens of all three species heated to 160° and 212° F., based on their controls, similar to the increase in dimensions resulting from the heat treatment, indicates that the heating had a permanent effect on the cell wall. Whether that effect was merely a permanent stretching of the cell during heat treatment which can later be easily duplicated at ordinary temperatures, cannot be stated. In any event, it agrees with the findings already referred to that steamed loblolly pine when dried and resoaked is no stronger than it was after steaming, presumably because of a permanently raised fiber-saturation point.

The failure of both the tangential and the radial specimens heated to 274° F. to return to their original size after soaking very likely is due to permanent deformation of the tissues as the result of the excessive shrinkage or collapse.

Conclusions

Heating wet wood may set up damaging stresses within the wood, especially in pieces containing the pith, on account of the tangential expansion and radial contraction which take place, resulting in radial cracks through the center and circular cracks, or shakes, farther out. The effect increases rapidly with increase in temperature above 160° F., and possibly even with temperatures above a lower limit.

Heating wet hardwoods to temperatures of 274° F. and probably even less, greatly increases their tendency to collapse in drying at ordinary temperatures and would be ruinous for most practical purposes.

Wood should not be soaked in hot water to bring it back to its green dimensions if refinements in measurement are desired. Even soaking the wood in water at room temperature does not insure return to green dimensions.

Whether the larger volumetric size of wet wood after heating is due to additional swelling resulting from a permanently raised fiber-saturation point or to a readjustment of the wood substance without any swelling taking place can not be determined from the data, since they do not show how the external and internal swelling compared.

The fact that the wood which was heated at 274° F. collapsed more easily in drying, together with the earlier findings that steam-

ing green wood reduces its strength considerably favor the theory of an increased fiber-saturation point. The shortening in the radial direction, on the other hand, favors the theory of readjustment.

Determinations of the fiber-saturation point by other methods should be made on heated wood to determine whether and, if so, how much the fiber-saturation point is raised.

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