MINIMIZING WOOD SHRINKAGE AND SWELLING

Effect of Heating in Various Gases

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Abstract

The hygroscopicity and subsequent swelling and shrinking of dry wood is decreased by heating in various gases above thermal decomposition temperatures. Greater reductions in hygroscopicity are obtained in an oxidizing than in a reducing atmosphere for the same heating conditions, but by increasing the temperature equal reductions in hygroscopicity can be obtained in reducing atmospheres. The darkening of the wood on heating appears to vary directly with the resulting reduction in hygroscopicity, regardless of heating conditions. Soaking in water after heating has but a slight tendency to restore the original hygroscopicity. Heating wood in water-saturated atmospheres has no permanent effect upon the swelling and shrinking.

It has long been recognized that excessive heating of wood reduces its hygroscopicity. Tiemann (9) found that heating air-dry wood in superheated steam to about 150° C. for 4 hours reduced the subsequent moisture absorption by 10 to 25 percent with but relatively small reductions of the strength except for red oak which showed a reduction in crushing strength and modulus of rupture of about 60 percent. An unpublished Forest Products Laboratory report of 1916 shows that heating black gum in dry air at 205° C. for 6 hours reduced the subsequent hygroscopicity to almost one-half of its original value with only a slight accompanying decrease in its strength. Koehler and Pillow (4) and Pillow

1Presented before the Cellulose Division, American Chemical Society, Chapel Hill, N. C., Apr. 12, 1937.

2Betts, N. D. The Effect of High Temperature on Certain Properties of Wood. File No. 2E468, Forest Products Laboratory.
(5) heated air-dry Sitka spruce and ash to 138°C. for 1 to 8 days and obtained reductions of the equilibrium moisture content at several different relative humidities for the longer time of heating of 30 to 40 percent with accompanying reductions of the crushing strength of 15 to 25 percent and reductions of the toughness of 50 to 75 percent. Data of Greenhill (2) for the relationship between maximum strength of beech in tension perpendicular to the grain and the moisture content at different temperatures indicate that the loss of strength on heating of the wood decreases with a decrease in moisture content to a negligible value for very dry wood. Although the temperature range covered by these data is below the temperatures required to obtain appreciable antishrink efficiencies, they indicate the possibility of less loss in strength occurring if the wood is adequately seasoned at normal kiln temperatures before subjecting it to the higher temperatures required to reduce its subsequent swelling and shrinking.

The purpose of this preliminary research was to confirm this loss of hygroscopicity of wood which occurs on heating, to determine its permanence, and how it is affected by the medium in which heating occurs.

Sections of white pine 9 cm. long in the tangential direction (the direction of maximum swelling), 2 cm. radially, and 0.5 cm. in the fiber direction, were used in these tests. The short dimension in the fiber direction insured rapid attainment of moisture equilibrium, and made possible the cutting of a number of adjacent sections from the wood with a minimum variation of structure from section to section. Four specimens were suspended in a small steel bomb that was heated on the outside by an electrical resistance coil and lagged with asbestos insulation. The temperature was determined with a thermocouple inserted in a well in the wall of the bomb. The temperature was controlled manually to about 2° C. When the specimens were heated in other gases than air the bomb was evacuated and the gas admitted several times to insure the elimination of air. The moisture content of the wood used in the tests was about 6 percent. When the heating was done in the presence of water vapor a large excess of water over that necessary to saturate the specimens was placed in the bottom of the bomb.

Table 1 gives the effect of heating the white pine sections in different dry atmospheres upon the subsequent swelling and shrinking. Measurements were made of both the tangential dimension change and the weight change occurring when the specimens were alternately brought to equilibrium with 30 and 90 percent relative humidity in humidity rooms held at 26.7°C. The specimens were given two weeks' exposure at each relative humidity which proved adequate for the attainment of equilibrium. The antishrink efficiencies are calculated on the basis of the reduction in dimensional change or weight change between 90 and 30 percent relative humidity referred to the corresponding change for the control. The sections heated in dry atmospheres were soaked in water for five days after the humidity cycles were complete and then subjected again to the humidity change cycles. Only the second subsequent humidity cycle was used in the calculations as the first would involve a higher desorption curve due to
the soaking and thus give results affected by the sorption hysteresis (10). The same is true for sections heated in the presence of water. The first cycle gave appreciable negative efficiencies because of this hysteresis effect.

Heating the sections for as short a time as 15 minutes at 165°C, a temperature at which thermal decomposition is just becoming appreciable, gave definite antishrink efficiencies in all the dry gases. Increasing the temperature and the time of heating increased the antishrink efficiency. In each case the efficiency was greater in an oxidizing atmosphere than in a reducing atmosphere. Subsequent soaking of the sections in water reduced the antishrink efficiency by a relatively constant amount regardless of the heating conditions. Sections heated in the presence of water vapor gave very small uncorrelatable antishrink efficiencies after the first cycle, part of the values being positive and part negative (average antishrink efficiency 0.25 percent, mean deviation 1.1 percent). These values for all the temperatures and times may be considered within experimental error of being zero; that is, heating in water vapor has no effect upon the antishrink efficiency after the first humidity change cycle.

The sections heated at 165°C were but slightly darkened without a perceptible difference in appearance between the sections heated in the different gases. The darkening was more appreciable after heating for 2 hours at 205°C, and still more so after the time was increased to 6 hours. In each of these cases the darkening obtained by heating in the different gases increased in the following order: Hydrogen, illuminating gas, air, and oxygen. The specimens heated to 260°C in hydrogen, however, were as dark as those heated for 6 hours at 205°C in oxygen. The darkest specimens were about the color of unfinished walnut. The antishrink efficiency appears to parallel the darkening of the wood, irrespective of the temperature and the gas used.

Although part of the antishrink efficiency may be due to oxidation in the cases where the wood was heated in air and oxygen, it is hard to imagine this being a major factor as equal efficiencies can be obtained by heating in hydrogen at a slightly elevated temperature. The phenomenon can best be explained on the basis of the effect being one of thermal decomposition. Loss of water of constitution is the first thermal reaction. If this loss were due to the formation of an ether linkage between two adjacent cellulose chains through adjacent hydroxyl groups, the loss in hygroscopicity could be readily explained. Not only would the hygroscopicity be reduced because of the substitution of the less hygroscopic ether group for the more hygroscopic hydroxyl groups, but also because of the parallel bonding of the cellulose chains. Staudinger (8) has shown that the formation of such bridges between the chains in polystyrene resins with para-divinylbenzene cuts down the swelling tremendously, even when only enough para-divinylbenzene is used to form a single bridge for several thousand molecules of monomeric styrene. Just an occasional cross link evidently cuts down appreciably the tendency for water to be taken up between the structural chains. The formation of
ether linkages between the hygroscopic hydroxyl group not only explains the decreased hygroscopicity of wood heated in dry atmospheres, but also the fact that heating in the presence of a large excess of water vapor causes no change in hygroscopicity. The presence of an excess of water vapor would depress the thermal reaction in which water is evolved according to the principle of LeChatelier and thus markedly reduce the tendency to form the ether bridges. If the change in hygroscopicity were merely a physical change, such as that postulated by Urquhart (10) to explain hysteresis, soaking of the specimens in water should largely restore their original hygroscopicity. This investigator believes that the free hydroxyl groups of cellulose, which are originally satisfied to a large extent by water, draw closer together on drying and finally mutually satisfy one another. Although these bonds are only partially broken on rehumidification they should be largely broken on soaking in water and the active groups again satisfied by water. The reversible part of the antishrink efficiency, that is, the difference between the antishrink efficiency obtained directly after heating and that subsequent to soaking in water is practically constant regardless of heating conditions. This part is undoubtedly due to a physical effect such as that given by Urquhart (10). The physical mutual satisfaction of hydroxyl groups evidently increases until the free water is rather completely removed, but does not increase on further heating.

These preliminary results indicate that the antishrink efficiency resulting from the excessive heating of dry wood in several common gases is sufficiently great and permanent to warrant a more extensive investigation in which the strength properties are simultaneously studied. Although this method of minimizing the swelling and shrinking of wood does not appear to be so effective as methods previously described (1, 3, 6, 7), its possible value rests on the fact that it would be relatively inexpensive.

**Literature Cited**

Table 1.—Effect of heating dry wood in various gases and subsequent soaking in water for 5 days upon the antishrink efficiency

<table>
<thead>
<tr>
<th>Gas</th>
<th>Temperature</th>
<th>Time</th>
<th>Antishrink efficiency before soaking in water</th>
<th>Antishrink efficiency after soaking in water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C.</td>
<td>Hours</td>
<td>Weight basis</td>
<td>Tangential dimension basis</td>
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<td>Hydrogen</td>
<td>165</td>
<td>0.25</td>
<td>5.9</td>
<td>6.3</td>
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<td></td>
<td>205</td>
<td>2.00</td>
<td>16.0</td>
<td>17.0</td>
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<tr>
<td></td>
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<td>2.00</td>
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<td>.25</td>
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<td>205</td>
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<td>28.0</td>
<td>30.0</td>
</tr>
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</table>

1 In terms of retardation of the dimension and weight changes, for the average of four specimens, per unit change of the untreated controls when alternately brought to equilibrium with 30 and 90 percent relative humidity.

2 Based upon the second humidity change cycle as the first is appreciably affected by hysteresis (10).