THE EFFECTS OF PREVIOUS DRYING ON SHRINKAGE AND MOISTURE CONTENT OF SOME SOUTHERN BOTTOMLAND HARDOODS

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ABSTRACT

Three logs for each of nine southern hardwood species were obtained, and specimens were separated into heartwood and sapwood. Specimens were dried from the initial green condition to oven-dry and then resaturated and dried again to oven-dry. A simple linear regression analysis was performed to determine the relationship between volumetric shrinkage and moisture content of never-dried and previously-dried specimens. The average fiber saturation point was 33.3 (33.6 for sapwood and 32.9 for heartwood) for never-dried specimens and 29.4 (28.2 for sapwood and 30.6 for heartwood) for previously-dried specimens. An average of 86% of the variability in volumetric shrinkage of never-dried specimens can be attributed to moisture content, and 90.5% of the variability in volumetric

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shrinkage of previously-dried specimens can be attributed to moisture content. Highly significant
differences for the species factor were found to exist at an equilibrium moisture content of 90% relative
humidity (RH) and 75% RH for both never-dried and previously-dried specimens. Volumetric shrink-
age differed significantly for species and wood-types at 90%, 75%, and 0% RH for previously-dried
wood and 75% and 0% RH for never-dried wood. A t-test revealed significant differences between
volumetric shrinkage of never-dried and that of previously-dried wood for both wood-types of two
species and one wood-type of three others.

Keywords: Equilibrium moisture content, fiber saturation point, shrinkage.

INTRODUCTION

The utilization of the southern bottomland hardwoods has lagged behind the southern
yellow pines largely because of poorer tree form and longer rotation ages. Hardwood
anatomy is much more complex than that of softwoods and thus hardwood properties, such
as shrinkage, can often be more complex. Previous researchers interested in hardwood hy-
groscopicity have mainly focused on adsorption and desorption isotherms and on conse-
quent dimensional change (Stamm 1964; Koll-
showed that good estimates of fiber saturation
point (FSP) can be made by measuring equi-
librium moisture content (EMC) and dimen-
sional changes at several relative humidities
(RH). The ratio of EMC to swelling is rela-
tively constant, and when this relationship is
extrapolated to maximum swelling (or to zero), the EMC is at FSP.

The difference in FSP between never-dried
wood and previously-dried has not been wide-
ly reported in the literature. Feist and Tarkow
(1967) reported the FSP of never-dried and
once-dried Sitka spruce (Picea sitchensis
Bong. Carr.) wood to be 40% and 31%, re-
spectively. Their methodology included soak-
ing green wood in polyethelene glycol with a
molecular size sufficiently large enough to
prohibit penetration into the wood structure.
They included data from 1957 to 1964 (Stamm 1964; Koll-
showed that good estimates of fiber saturation
point (FSP) can be made by measuring equi-
librium moisture content (EMC) and dimen-
sional changes at several relative humidities
(RH). The ratio of EMC to swelling is rela-
tively constant, and when this relationship is
extrapolated to maximum swelling (or to zero), the EMC is at FSP.

This present study has expanded on previous
investigations of southern hardwoods hygroscopicity by (1) including other southern
bottomland hardwood species, (2) exam-
ing the correlation between S, and MC of heartwood and sapwood of never-dried and
previously-dried wood, and (3) addressing
the differences in some hygroscopic properties of never-dried and previously-dried southern hardwoods. These differ-
ences, especially for (FSP), have not been
widely reported.

MATERIALS AND METHODS

Sample preparation

Three, defect-free 4.88-m sawlogs, without
eccentric growth rings, were selected for each
of nine southern bottomland hardwood species
in the log yard at Plaquemine Hardwoods in
Plaquemine, LA. Tree age was unknown for all
species. All logs came from a 200-km radius
of Baton Rouge, LA. A 15.24-cm-thick disk
was cut 15.24 cm from the end of all logs. The disks were reduced in size, and eight specimens measuring 3.81 cm × 3.81 cm × 1.27 cm were obtained from both heartwood and sapwood regions of all disks. In species without a definite heartwood/sapwood transition, heartwood samples were simply taken from the center of the disk and sapwood samples near the edge. No heartwood samples contained pith.

Measurements

All shrinkage values were determined from the ratio of change in dimension from the swollen condition to oven-dry condition to swollen dimension, expressed as a percentage. Volumetric shrinkage was estimated from the summation of radial and tangential shrinkage, which has been shown to give a reliable and close approximation to the true volumetric shrinkage (Choong 1969a). The green radial and tangential specimen dimensions were measured to the nearest 0.001 in. (0.00254 cm) with a dial caliper, and green weight was measured to the nearest 0.01 g with a digital balance. Specimens were then conditioned in an Aminco chamber at 32°C and decreasing nominal relative humidities of 90%, 75%, 50%, 20% and approximately 0% before oven-drying at 105°C for 24 hours. Specimen dimensions and weights were recorded at equilibrium prior to each humidity change and in the oven-dry condition. All specimens were rehydrated in water until repeated weighings showed constant weight and thus the maximum MC had been achieved. These previously-dried samples were dried again using the same process as previously described.

Properties measured included (EMC) at various RH conditions, and radial, tangential, and volumetric dimensions. The experimental design was a completely randomized design. Data were analyzed by analysis of variance and simple regression techniques (Steel and Torrie 1980) in accordance with SAS programming procedures (SAS Institute 1989). All regression lines were fitted to three data points at 0%, 20%, and 90% RH.

RESULTS AND DISCUSSION

Equilibrium moisture content (EMC)

Data from never-dried and previously-dried specimens conditioned at 90% RH and 75% RH were included in an analysis of variance (ANOVA) to determine the effect of species and wood-type (Table 1). The sources of variation (SOV) were nearly identical in terms of significance for both never-dried and previously-dried wood. One exception was the highly significant species and wood-type factors for volumetric shrinkage at 90% RH for previously-dried wood. These terms were not significant for never-dried wood at the same conditions.

The species factor was highly significant for EMC at 75% RH and 90% RH (Table 1). These findings are in agreement with those of Choong and Manwiller (1976), who found significant species differences in EMC at 85% RH and 71% RH of 22 hardwoods with 6-inch diameters from southern pine sites. Apparently the relationship between EMC and high RHs is the same for wood from both juvenile and mature trees.

Volumetric shrinkage (Sv)

Highly significant differences ($P < 0.01$) were detected among species and wood-type for both never-dried and previously-dried
specimens conditioned at 0% and 75% RH (Table 1). Although density values were not obtained from the samples, the relationship of density and shrinkage of different wood types is well documented in the literature (Choong et al. 1989; Shupe et al. 1995a, b, 1996). An interesting phenomenon occurred with the never-dried and previously-dried specimens conditioned at 90% RH. All SOVs were not significant for the never-dried specimens at 90% RH, but all SOVs were highly significant \( (P < 0.01) \) for previously-dried wood at 90% RH (Table 1). These specimens were well below FSP even at 90% RH. Consequently, hygroscopic properties change and the amount of bound water will be less, due to the effects of heat treatment during oven-drying. The heat treatment reduces the number of hydroxyl groups available for hydrogen bonding.

Table 2 presents regression equations of the relationship between volumetric S, and MC for not previously-dried specimens. The S, data of the not previously-dried specimens was compared to that of the previously-dried specimens using a t-test (Table 3). The t-test results are mixed. The S, of willow, American elm, and white ash sapwood differed significantly; yet the heartwood of these species was statistically similar for never-dried and previously-dried specimens. Tupelogum and sweetgum differed significantly for both heartwood and sapwood. Choong and Manwiller (1976) found correlation coefficients between S, and MC of \(-0.994\) for white ash, \(-0.996\) for sweetgum, and \(-0.999\) for American elm and tupelo.

### Fiber saturation point (FSP)

The fiber saturation point, the MC at which cell lumens are void of water but cell walls are totally saturated, cannot be determined exactly since there is no sharp change in the MC-RH relationship at that point. Because the wood is likely to be in a stressed condition, the values for volumetric shrinkage obtained at the oven-dry condition tend to deviate from a straight line and were not used in determining shrinkage intersection points (Choong and Manwiller 1976). However, the shrinkage intersection point (IP), which measures apparent FSP, was derived by plotting the linear pattern of S, against MC and extrapolating this line to zero shrinkage (Kelsey 1956; Wangaard 1957; Stamm 1959). The shrinkage points at 20%, 50%, 75%, and 90% RH were used in deriving regression equations and apparent FSP values.

The apparent FSP as determined from the IP ranges from 26.4% to 42.5% for never-dried woods (Table 2) and from 26.0% to 33.3% for previously-dried woods (Table 3). It has previously been proposed that wood with a large extractive content may display an abnormally low FSP (Nearn 1955; Higgins 1957; Wangaard 1957; Spalt 1958; Wangaard
### TABLE 2. Regression equations of the relationship between volumetric shrinkage ($S_v$) and moisture content (MC) for never-dried bottomland Louisiana hardwood species and their intersection points.

<table>
<thead>
<tr>
<th>Species/Wood-type</th>
<th>Scientific name</th>
<th>Regression of $S_v$ on MC</th>
<th>$r^2$</th>
<th>Intersection point1 (%)</th>
<th>FSP2</th>
<th>FSP3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Sapwood</td>
<td>Salix nigra Marsh</td>
<td>8.974–0.211 (MC)</td>
<td>0.67</td>
<td>42.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willow Heartwood</td>
<td></td>
<td>11.485–0.373 (MC)</td>
<td>0.96</td>
<td>30.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cottonwood Sapwood</td>
<td>Populus deltoides Bartr. ex Marsh.</td>
<td>11.259–0.404 (MC)</td>
<td>0.85</td>
<td>27.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cottonwood Heartwood</td>
<td></td>
<td>14.527–0.426 (MC)</td>
<td>0.87</td>
<td>34.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tupelogum Sapwood</td>
<td>Nyssa aquatica L.</td>
<td>12.163–0.353 (MC)</td>
<td>0.95</td>
<td>34.4</td>
<td></td>
<td>31.2</td>
</tr>
<tr>
<td>Tupelogum Heartwood</td>
<td></td>
<td>15.840–0.415 (MC)</td>
<td>0.88</td>
<td>38.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweetgum Sapwood</td>
<td>Liquidambar styraciflua L.</td>
<td>14.975–0.370 (MC)</td>
<td>0.92</td>
<td>40.4</td>
<td>30.9</td>
<td>32.6</td>
</tr>
<tr>
<td>Sweetgum Heartwood</td>
<td></td>
<td>16.167–0.439 (MC)</td>
<td>0.83</td>
<td>36.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-poplar Sapwood</td>
<td></td>
<td>15.463–0.497 (MC)</td>
<td>0.84</td>
<td>31.1</td>
<td>29.0</td>
<td>27.7</td>
</tr>
<tr>
<td>Yellow-poplar Heartwood</td>
<td></td>
<td>12.402–0.405 (MC)</td>
<td>0.82</td>
<td>30.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sycamore Sapwood</td>
<td>Platanus occidentalis L.</td>
<td>12.107–0.421 (MC)</td>
<td>0.84</td>
<td>28.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sycamore Heartwood</td>
<td></td>
<td>14.729–0.429 (MC)</td>
<td>0.66</td>
<td>34.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American elm Sapwood</td>
<td>Ulmus americana L.</td>
<td>13.107–0.382 (MC)</td>
<td>0.92</td>
<td>34.3</td>
<td>26.7</td>
<td>30.7</td>
</tr>
<tr>
<td>American elm Heartwood</td>
<td></td>
<td>14.122–0.424 (MC)</td>
<td>0.95</td>
<td>33.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft maple Sapwood</td>
<td>Acer saccharinum L.</td>
<td>10.954–0.347 (MC)</td>
<td>0.93</td>
<td>31.6</td>
<td>26.3</td>
<td>28.9</td>
</tr>
<tr>
<td>Soft maple Heartwood</td>
<td></td>
<td>12.450–0.393 (MC)</td>
<td>0.81</td>
<td>31.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White ash Sapwood</td>
<td>Fraxinus americana L.</td>
<td>11.919–0.377 (MC)</td>
<td>0.81</td>
<td>31.6</td>
<td>27.9</td>
<td>29.0</td>
</tr>
<tr>
<td>White ash Heartwood</td>
<td></td>
<td>14.804–0.581 (MC)</td>
<td>0.99</td>
<td>26.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 This intersection point is equivalent to the apparent fiber saturation point.
2 FSP determined from average of adsorption and desorption data from stemwood of 6-in. trees (Okeh 1976).
3 Average FSP determined from shrinkage data of 6-in. stemwood (Choong and Manwiller 1976).
4 Values represent red maple (Acer rubrum L.).
5 SW = sapwood.
6 HW = heartwood.
### Table 3

Regression equations of the relationship between volumetric shrinkage ($S_v$) and moisture content (MC) for previously-dried bottomland Louisiana hardwood species and their intersection points.

<table>
<thead>
<tr>
<th>Species/Wood-type</th>
<th>Regression of $S_v$ on MC</th>
<th>$r^2$</th>
<th>Intersection point* (%)</th>
<th>$r$-test$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Sapwood</td>
<td>8.695–0.282 (MC)</td>
<td>0.88</td>
<td>30.8</td>
<td>**</td>
</tr>
<tr>
<td>Heartwood</td>
<td>11.924–0.399 (MC)</td>
<td>0.98</td>
<td>29.9</td>
<td>NS</td>
</tr>
<tr>
<td>Cottonwood Sapwood</td>
<td>10.896–0.386 (MC)</td>
<td>0.84</td>
<td>28.2</td>
<td>NS</td>
</tr>
<tr>
<td>Heartwood</td>
<td>14.337–0.430 (MC)</td>
<td>0.91</td>
<td>33.3</td>
<td>NS</td>
</tr>
<tr>
<td>Tupelugum Sapwood</td>
<td>11.909–0.426 (MC)</td>
<td>0.96</td>
<td>27.9</td>
<td>*</td>
</tr>
<tr>
<td>Heartwood</td>
<td>15.294–0.482 (MC)</td>
<td>0.95</td>
<td>31.7</td>
<td>*</td>
</tr>
<tr>
<td>Sweetgum Sapwood</td>
<td>13.648–0.453 (MC)</td>
<td>0.94</td>
<td>30.1</td>
<td>**</td>
</tr>
<tr>
<td>Heartwood</td>
<td>15.320–0.465 (MC)</td>
<td>0.95</td>
<td>32.9</td>
<td>*</td>
</tr>
<tr>
<td>Yellow-poplar Sapwood</td>
<td>15.288–0.517 (MC)</td>
<td>0.86</td>
<td>29.6</td>
<td>NS</td>
</tr>
<tr>
<td>Heartwood</td>
<td>12.277–0.429 (MC)</td>
<td>0.94</td>
<td>28.6</td>
<td>NS</td>
</tr>
<tr>
<td>Sycamore Sapwood</td>
<td>11.783–0.447 (MC)</td>
<td>0.80</td>
<td>26.3</td>
<td>NS</td>
</tr>
<tr>
<td>Heartwood</td>
<td>14.670–0.504 (MC)</td>
<td>0.73</td>
<td>29.1</td>
<td>NS</td>
</tr>
<tr>
<td>American elm Sapwood</td>
<td>12.384–0.468 (MC)</td>
<td>0.92</td>
<td>26.1</td>
<td>**</td>
</tr>
<tr>
<td>Heartwood</td>
<td>13.983–0.459 (MC)</td>
<td>0.96</td>
<td>32.9</td>
<td>NS</td>
</tr>
<tr>
<td>Soft maple Sapwood</td>
<td>10.770–0.380 (MC)</td>
<td>0.87</td>
<td>28.3</td>
<td>NS</td>
</tr>
<tr>
<td>Heartwood</td>
<td>12.219–0.398 (MC)</td>
<td>0.84</td>
<td>30.7</td>
<td>NS</td>
</tr>
<tr>
<td>White ash Sapwood</td>
<td>10.837–0.409 (MC)</td>
<td>0.91</td>
<td>26.4</td>
<td>**</td>
</tr>
<tr>
<td>Heartwood</td>
<td>14.546–0.560 (MC)</td>
<td>0.99</td>
<td>26.0</td>
<td>NS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>sapwood</td>
<td>0.89  = 28.2</td>
</tr>
<tr>
<td>heartwood</td>
<td>0.92  = 30.6</td>
</tr>
</tbody>
</table>

1. This intersection point is equivalent to the apparent fiber saturation point.
2. $r$-test was conducted to compare volumetric shrinkage of never-dried and previously-dried wood.
* Denotes significance at alpha = 0.05.
** Denotes significance at alpha = 0.01.

and Granados 1967; Feist and Tarkow 1967; Choong 1969b; Shupe et al. 1996). In this study, we found never-dried specimens to have an average apparent FSP of 33.3%, (33.6% for sapwood and 32.9% for heartwood), and previously-dried specimens to have an average apparent FSP of 29.4% (28.2% for sapwood and 30.6% for heartwood).

Table 2 also presents FSP values from previous research projects by Okoh (1976) and Choong and Manwiller (1976) on stemwood of 6-in. trees. Our FSP values are consistently higher than those reported by the other researchers. We determined FSP using wood specimens obtained from sawlogs. Okoh (1976) determined FSP from adsorption and desorption data, and Choong and Manwiller (used) derived FSP from shrinkage data.
Moreover, it is known that FSP values may also vary according to the experimental procedure used by Koch (1985). The slope of the shrinkage-MC curve can be considered an indicator of dimensional stability. A wood that exhibits a low slope (e.g., 0.211 for never-dried willow sapwood) would have high stability, whereas a steep slope (e.g., 0.581 for never-dried white ash heartwood) would indicate less dimensional stability.

For example, previously-dried specimens can be attributed to MC, and 90.5% of the variability in S, of previously-dried specimens can be attributed to MC. Significant differences in EMC for both never-dried and previously-dried wood species were found to exist at RH conditions of both 90% and 75%.

If the slope of the shrinkage-MC curve indicates a degree of dimensional stability, then species that have similar slopes for sapwood and heartwood should indicate good lumber stability (i.e., less bow, cup, twist, etc.). For example, previously-dried sweetgum (slope = 0.453 and 0.465 for sapwood and heartwood, respectively) and American elm (slope = 0.468 and 0.459 for sapwood and heartwood, respectively (Table 3). After kiln-drying, we would expect these species to show good stability with minimal warp. Shrinkage performance does not always correlate well with wood density if large fibril angles, aspirated pits, or high extractive concentrations are present (Kollman and Côté 1968).

In contrast, soft maple (slope = 0.380 and 0.398 for sapwood and heartwood, respectively) is dimensionally stable but has low slope. Therefore, it will display less shrinkage per unit MC change. It should not be mixed with sweetgum and American elm because these two species have higher rates of dimensional changes than soft maple.

CONCLUSIONS

This research has shown that there is a strong relationship between S, and MC of heartwood and sapwood of southern hardwoods for both never-dried and previously-dried specimens. The average apparent FSP as determined from the IP was 33.3% (33.6% for sapwood and 32.9% for heartwood) for never-dried specimens and 29.4% (28.2% for sapwood and 30.6% for heartwood) for previously-dried specimens. An average of 86.0% of the variability in S, of never-dried specimens can be attributed to MC, and 90.5% of the variability in S, of previously-dried specimens can be attributed to MC. Significant differences in EMC for both never-dried and previously-dried wood species were found to exist at RH conditions of both 90% and 75%.

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