EFFECT OF SAMPLE GEOMETRY ON EMC AND MOISTURE HYSTERESIS OF RED OAK (*QUERCUS* SP.)

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ABSTRACT

Past researchers have shown that equilibrium moisture content (EMC) is influenced by mechanical stress. It has also been widely demonstrated that the size effect in drying produces varying amounts of stress. This experiment related the internal stress developed during drying to the EMC of red oak (*Quercus* sp.) samples. The results indicated that larger pieces, with larger potential differential stresses, had significantly different EMCs than relatively smaller pieces. The influence of sample size on hysteresis ratio was also examined. The difference between the adsorbing and desorbing EMCs increased with sample size. As sample thickness decreased to 50 μm, the hysteresis ratio reached unity. Thus as internal drying stresses were eliminated from the wood, the hysteresis effect was eliminated. This behavior suggests that differential drying stresses and/or strains are a causal agent for the observed moisture hysteresis in wood.

Keywords: Wood moisture content, drying hysteresis, drying size effect, drying stress, *Quercus* sp.

BACKGROUND

Stamm (1964) and Mason and Richards (1906) have previously shown that the amount of water held by cellulosic materials depends on both the equilibrium relative vapor pressure and the direction from which equilibrium is approached (adsorption or desorption). This difference is generally referred to as "sorption hysteresis." The ratio of the wood equilibrium moisture content (EMC) achieved during adsorption compared to desorption (A:D) is the hysteresis coefficient. Over a complete adsorption-desorption cycle, the A:D ratio is said to range between 0.8 and 0.9, depending upon the species of wood and the air temperature (Skaar 1972). Such ratios indicate that the amount of water contained in wood during and after adsorption is less than the amount contained during and after desorption, for a given temperature and relative humidity combination. Barkas (1949) advanced the theory that internal stress, due to a lack of free shrinking and swelling, is responsible for the hysteresis effect. Libby and Haygreen (1967) empirically showed that the moisture content is a function of mechanical stress within the wood. Simpson (1971) also found that transverse stress in wood can affect moisture content.

OBJECTIVE

The objective was to determine if a variation in the size of the sorption samples, with

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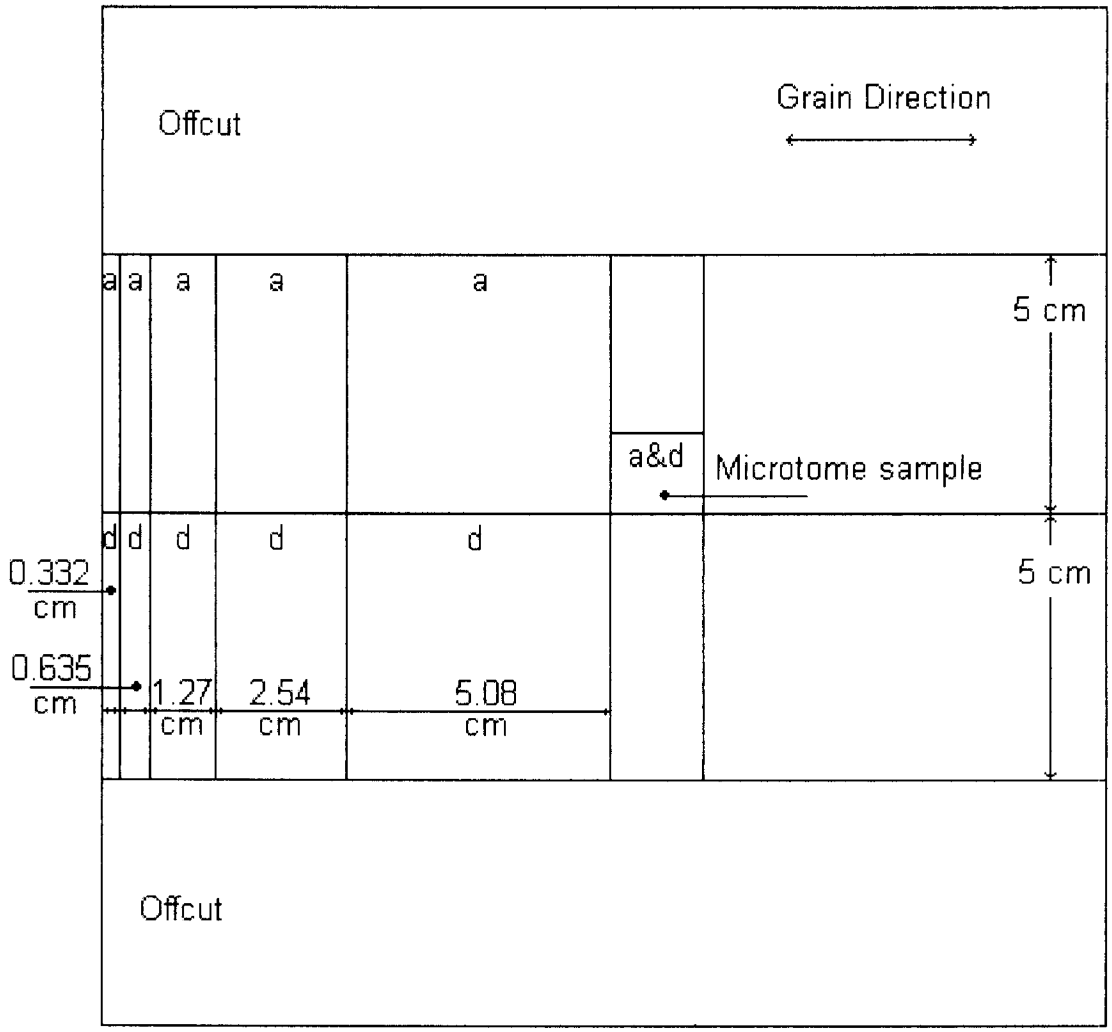

FIG. 1. Schematic illustrating the breakdown of each ~20-cm-long by ~20-cm-wide by 2.54-cm-thick section of red oak. a = adsorption, d = desorption.

the concomitant influence on the associated stresses, modifies the observed hysteresis coefficient.

EXPERIMENTAL

Two red oak boards, one flatsawn and the other quartersawn, were rough green surfaced to 3.18-cm thickness. The 2.44-m-long boards were subsequently green surfaced to 2.54-cm thickness and approximately 20-cm width, in the laboratory. A 20-cm-long section was then taken at mid-length from each board. Approximately 5 cm was then ripped from each edge of the section; thus the middle piece (20 cm long, 10 cm wide, and 2.44 cm thick) was left. This section was then center-ripped to produce two 5-cm-wide side-matched strips.

One strip yielded adsorption samples and the second yielded desorption samples. Next, six samples from each strip were prepared. Five samples were cut across the grain of each strip. The longitudinal lengths of these samples were 0.332, 0.635, 1.27, 2.54, and 5.08 cm, respectively (Fig. 1). Thus, each cross section was 10

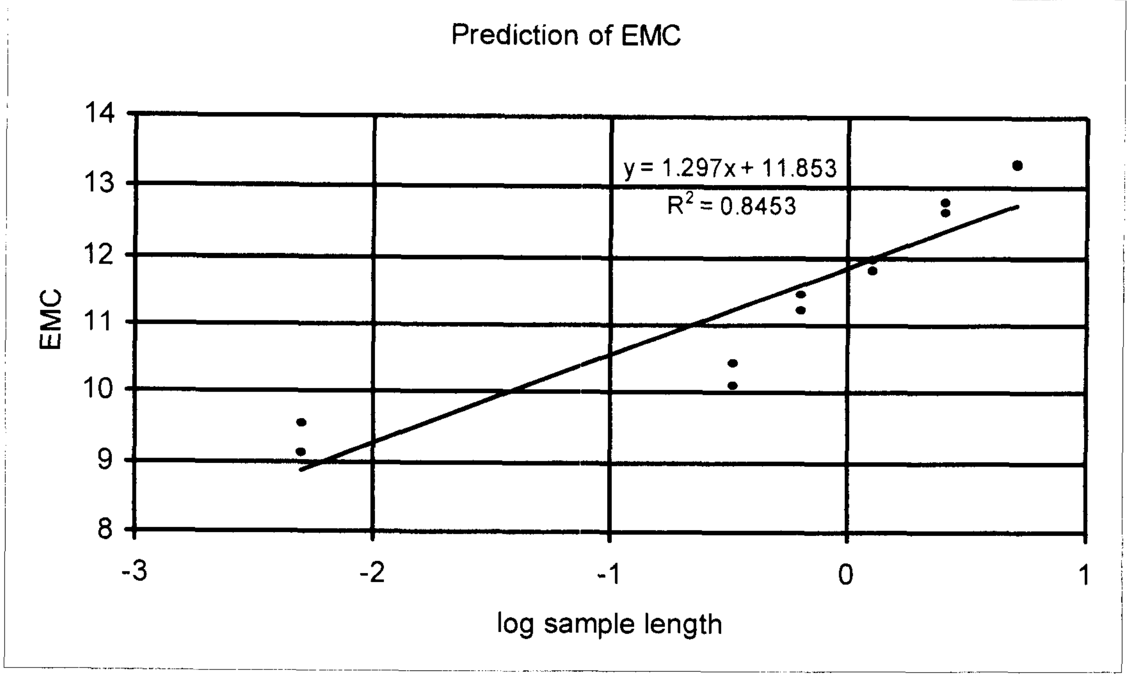

FIG. 2. Plot of EMC by the log of sample length. Logarithmic trend line, prediction equation, and coefficient of determination.

cm wide and 2.44 cm thick. The sixth and final sample (dimensions 1.9 cm along the grain, 1.65 cm wide, and 2.54 cm thick) was used to prepare microtome slices. The 50-μm-thick slices for both adsorption and desorption were taken from this sample. These slices were considered to yield "stress free" EMCs.

Immediately after their production, the desorption samples were wrapped in plastic and stored at 4°C. The adsorption samples were dried at 104°C for 48 h. After 48 h, all of the samples were placed in an environmental chamber maintained at 43.3°C dry bulb and 40.6°C wet bulb temperatures. These conditions correspond to an approximate wood moisture content of 16.2% (Simpson 1991). Air velocity over the samples was approximately 2.5 m/s. All samples were weighed daily to the nearest 0.1 mg. Samples remained in the environmental chamber until they reached constant weight (moisture equilibrium) as determined by linear regression. Microtome slices and the 0.332- and 0.635-cm-long samples reached apparent moisture equilibrium after 24 days. The 1.27-, 2.54-, and 5.08-cm-long sections reached apparent moisture equilibrium after 49 days.

ANALYSIS AND RESULTS

The data were analyzed as a randomized complete block design. The two blocking factors were board type (flatsawn or quartersawn) and sorption nature (adsorption or desorption). The sample geometries were the six different levels of treatment.

Board type was not a statistically significant source of variation in the experiment, *P*-value: 0.90. Thus differentiation between flat- and quartersawn boards was considered unnecessary. Sorption direction, however, was statistically significant at a *P*-value of 0.012. This indicates that by separating the adsorbing and the desorbing samples, experimental error was reduced. Analysis revealed that sample geometry was statistically significant with respect to final sample EMC. From this information, it was con-

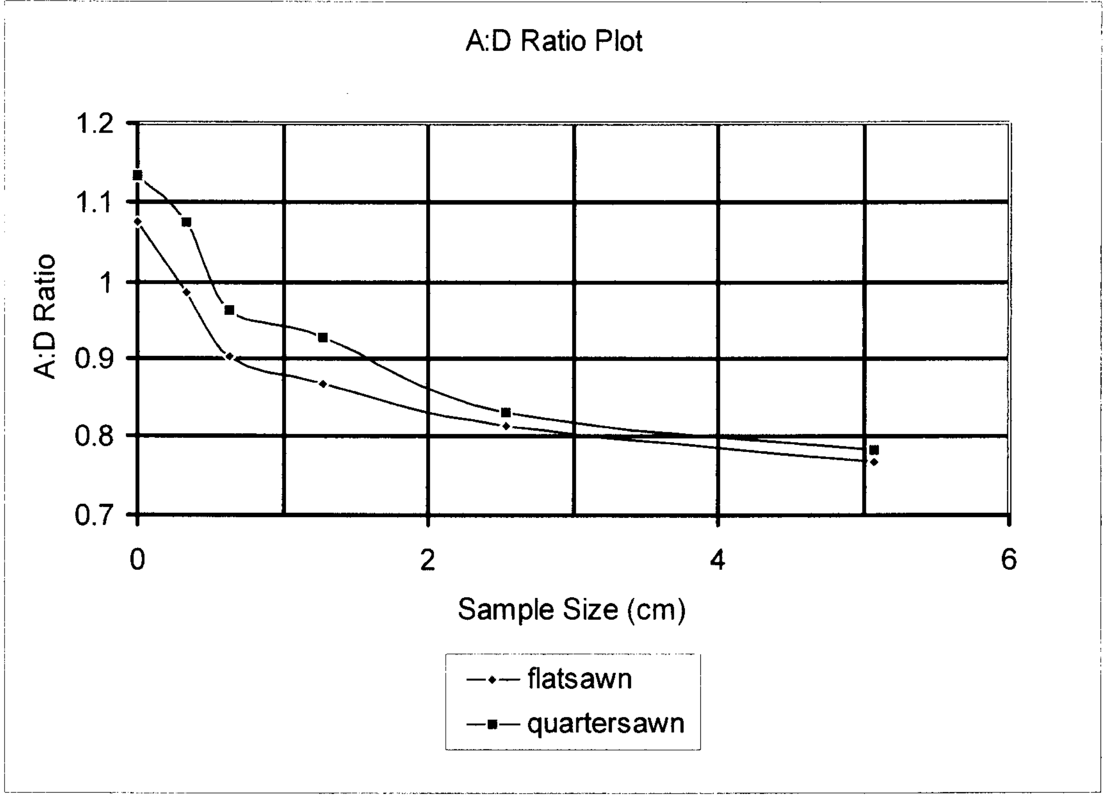

FIG. 3. Plot of A:D ratios by sample sizes. Note, smaller samples have A:D ratios greater than 1.

cluded that internal mechanical stress, caused by differential shrinkage forces during drying, was at a level sufficiently high to change the ultimate moisture potential of the wood.

A simple linear regression equation was computed using the final EMCs and the sample sizes for the desorption samples. Only the desorption samples were used in the regression because of the possibility that the initial drying of the adsorption samples at 104°C had altered their hygroscopicities. Because no statistical difference was detected between the quartersawn and the flatsawn samples, both sets were included in the regression. Figure 2 illustrates the logarithmic relationship between sample geometry and EMC. Figure 2 also contains the prediction equation and the coefficient of determination for the desorption sample model.

A:D ratios were compared among all of the samples. A paired *t*-test indicated that the average differences between the adsorption and the desorption samples' final EMCs were statistically significant, *P*-value: 0.039. Pairs were matched according to size and board type. The average EMC difference between the adsorption and the desorption samples was 0.99%. A: D ratios were then plotted (Fig. 3) according to specimen length. The clear trend is that empirically determined A:D ratio is highly dependent on sample size and A:D ratios greater than one are possible. In this case, the cross sections 0.32 cm along the grain and the microtome slices had A:D ratios that approached and exceeded one, respectively.

CONCLUSIONS

From this experiment, it is apparent that the internal mechanical stresses caused by differential shrinkage and swelling forces during sorption are sufficient to change the wood's ultimate EMC potential. During desorption, the smaller pieces reached final EMCs substantially lower than those attained by larger pieces. The relationship between sample length and EMC appeared to be parabolic; thus the logarithmic form of sample length was used in the linear regression. It is hypothesized that during drying the larger pieces, with higher levels of internal stress, equilibrate at higher moisture contents because the tensile stress in the core of the samples gives the wood a relatively high moisture potential. Additionally, the compression stress in the shell of those pieces likely has a relatively low moisture potential; thus, excess moisture, which is bound in the core of the pieces (due to tensile stress), is less able to diffuse through the shell toward the surface and escape.

The implications of the measured A:D ratios are significant. While some sample variation was likely present, this experiment shows that A:D ratios greater than one are possible when differential drying stresses are eliminated. Although the drying stresses were not quantitatively measured, it is well known that by decreasing sample size (essentially to merely a few cells in thickness) drying stresses reach or approach zero. In this experiment, hygroscopicity was negatively related to sample size (Fig. 3). This information seems to refute the argument (Stamm 1964) that by drying wood, its hygroscopicity is chemically altered by allowing hydroxyl groups to satisfy each other. Rather, it suggests that the commonly observed differences in adsorption and desorption EMCs for wood are closely related to mechanical drying stresses. These results corroborate Barkas's theory regarding stress and hysteresis. Barkas (1949) showed that external mechanical stress influences hysteresis and EMC. Thus, by eliminating mechanical stress (here in the form of internal stress) the hysteresis effect was eliminated.

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