

CONTROL OF INTERIOR DARKENING IN HARD MAPLE

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ABSTRACT

Industrial experience and research have shown that hard maple lumber color changes are very often affected by the temperature and relative humidity conditions the wood is exposed to during drying. For this reason, appropriate kiln schedules should be selected and properly used to control not only surface, but entire board color. In this research study, a technique was developed that successfully demonstrated occurrence of interior darkening of hard maple at particular drying temperature and moisture content conditions. Results show that the critical temperature causing this interior darkening is 110°F, and it particularly develops with elevated temperatures while the MC is at and above the FSP. There appears to be minimal color change when drying below the FSP.

Keywords: Wood color, interior darkening, internal temperature, moisture content, $L^*a^*b^*$ color values, enzyme-mediated processes.

INTRODUCTION

Changes in natural color of hard maple occur as a result of chemical reactions that take place between naturally occurring precursors to stain formation (phenolic extractives) and enzymes present in the wood. These enzyme-mediated processes begin in viable parenchyma cells where tiny globules of amorphous material accumulate and occlude the cell lumens. The size, shape, and texture of the globules vary with species. This material subsequently turns dark upon exposure to high temperatures and slow drying conditions (McMillen 1975, 1976; Forsyth and Amburgey 1991, 1992; Wengert 1992). The darkening is similar to oxidative browning of freshly sliced

fruits and vegetables. It is known that oxidizing enzymes are widely distributed in plants and animals, and they are capable of producing a variety of postmortem discolorations. These findings indicate that the living parenchyma may play a significant role in the formation of oxidative discolorations. Methods for controlling oxidative staining in wood through inactivation of enzymes involved in stain formation may include the use of heat (Bailey 1911; Price 1982) in the form of boiling water, steam, or perhaps electromagnetic energy, dip treatments in antioxidants or reducing agents (Forsyth and Amburgey 1992), and via log fumigation with methyl bromide gas (Schmidt and Amburgey 1994). Although these methods have proven effective, each has practical processing limitations. Because the implementation difficulties of most of these preventive measures,

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many producers of maple lumber control oxidative discolorations by focusing their efforts on development and use of appropriate lumber drying schedules and techniques (Wengert 1992; Smith and Herdman 1998; Smith and Montoney 2000; Smith et al. 2003).

Proper drying of hard maple has become quite important industrially as recent market requirements have been demanding that manufacturers provide lumber that is attractive, and of a specified, uniform, and replicable color (Hardwood Review Weekly 2002). Some have found, however, that while surface color may be satisfactory, the interior of boards is sometimes relatively dark. This phenomenon of dark interior color becomes a major concern during processing operations such as surfacing, resawing, and molding where asymmetrical machining exposes contrasting bright and dark coloration. In this research study, a technique was developed that successfully demonstrated occurrence of interior darkening of hard maple at particular drying temperature and moisture content conditions, and a method for modifying the kiln drying schedule for hard maple lumber to minimize the interior darkening was suggested.

MATERIALS AND METHODS

Hard maple (*Acer saccharum* Marsh.) lumber, as freshly sawn 4/4 in. (thickness) $\times$ 4 in. (width) $\times$ 9 ft (length) boards, was obtained from a sawmill in central New York State. Sixteen-in. long all-clear sapwood specimens were cut from these boards and dried at 90°F-44%RH, 95°F-45%RH, 100°F-46%RH, 105°F-47%RH, 110°F-48%RH, 130°F-52%RH, and 150°F-57%RH (9% equilibrium moisture content conditions), with 1 m/s air velocity in temperature and humidity controlled environmental chambers. Six specimen replicates were dried at each condition. Both ends of each specimen were tightly sealed and insulated with Styrofoam such that their drying behavior was as full-size boards. Internal wood temperature during drying was measured with copper-constantan thermocouples and dataloggers (21X Micrologger, Campbell Scientific Inc.). One-in. samples were

cut from the end of the specimens, using a circular saw with a particularly sharp carbide-tipped blade, at appropriate time intervals for continual determination of interior color during drying.

Interior board color was measured from the interior transverse surface of the samples as they were removed from the specimens being dried at the different conditions. Color data were obtained via imaging with a flat-bed color scanner (HP Scanjet 5370C, Hewlett-Packard Co.), and measured as $L^*a^*b^*$ color space values (L^* is the lightness coordinate, $\sim L^* 0 = \text{black}$, $100 = \text{white}$; and $+a^*$ red, $-a^*$ green, $+b^*$ yellow, and $-b^*$ blue the color coordinates) (CIE 1986) with a spectrophotometer (Microflash 200d, Data-Color International). The spectrophotometer was used with the D65 (daylight, 6500K-color temperature) light source illumination, 10° observer and specular included option, common specifications for measurement of wood, and comparable material color. Both prior and subsequent to sample wafer removal for color determination, each specimen was weighed to determine current average moisture content (AMC). They were then resealed and placed back into their appropriate drying chambers.

RESULTS AND DISCUSSION

Using dataloggers and oven-drying, average core temperature and moisture content (MC) of the six specimens at each drying condition were measured during drying (Fig. 1). Interior color of the transverse surface specimens was imaged (Fig. 2) with the flat-bed color scanner at particular points during drying. $L^*a^*b^*$ values were determined with the spectrophotometer at the same time (Fig. 3 and 4).

Over a period of about 12 days, the specimen boards dried from the fresh green condition to about 10% MC (Fig. 1). Core temperature in the boards reached the dry bulb set point in about 2 to 4 days. As would be expected, the specimens at higher temperatures dried faster. The effects of temperature on interior darkening are shown in Fig. 2. Drying at 90°F resulted in virtually no color change, while interior darkening occurred immediately at 150°F and 130°F dry bulb temper-

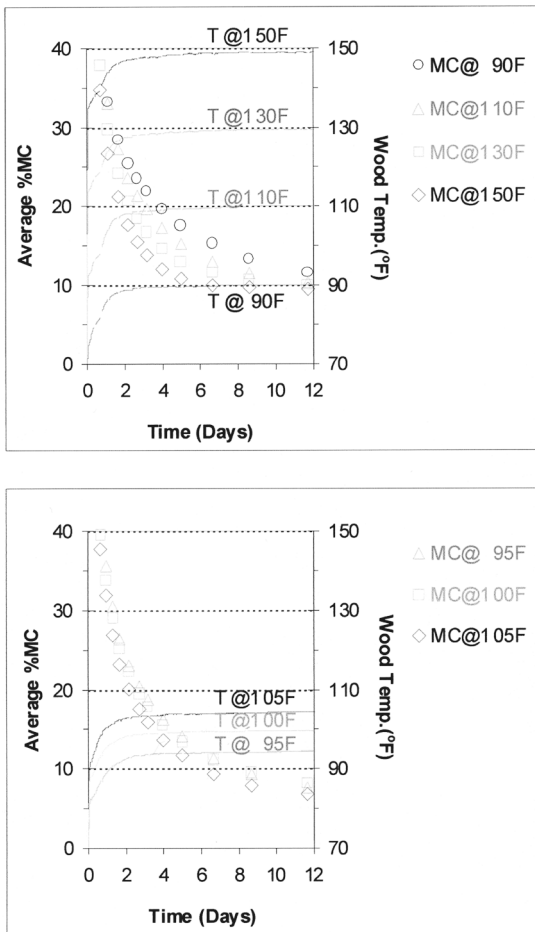


FIG. 1. Core temperature and average %moisture content of 1-in. thick hard maple at 90°, 95°, 100°, 105°, 110°, 130°, and 150°F, and 9% equilibrium moisture content (EMC) drying conditions.

ature. At 110°F, interior darkening became noticeable during about 2 to 5 days' drying, when AMC changed from 25 to 15%. At these average MC values, core moisture would be at and passing through fiber saturation point (FSP, ~30% MC) values. Very little difference in core $L^*a^*b^*$ color values was found between 95° and 105°F dry bulb temperature drying conditions (Fig. 4). Drying above 110°F (Fig. 3), however, resulted in core darkening. This was particularly noticeable with the L^* "lightness" values, which changed much more than a^* or b^* "color" values during drying.

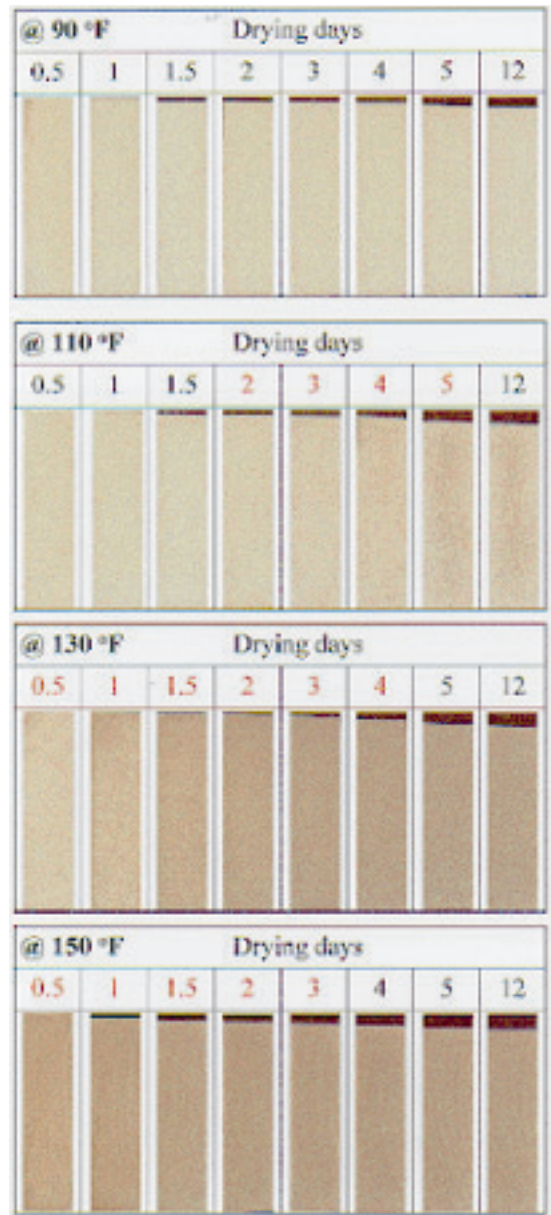


FIG. 2. Scanned transverse plane color images of hard maple dried at 90°, 110°, 130°, and 150°F, 9% EMC, from 0.5 through 12 days; the increasing black areas with drying time are due to tangential shrinkage.

The critical temperature causing interior darkening in hard maple seems to be around 110°F. During drying at this temperature, L^* values started to decrease as core temperature reached plateau,

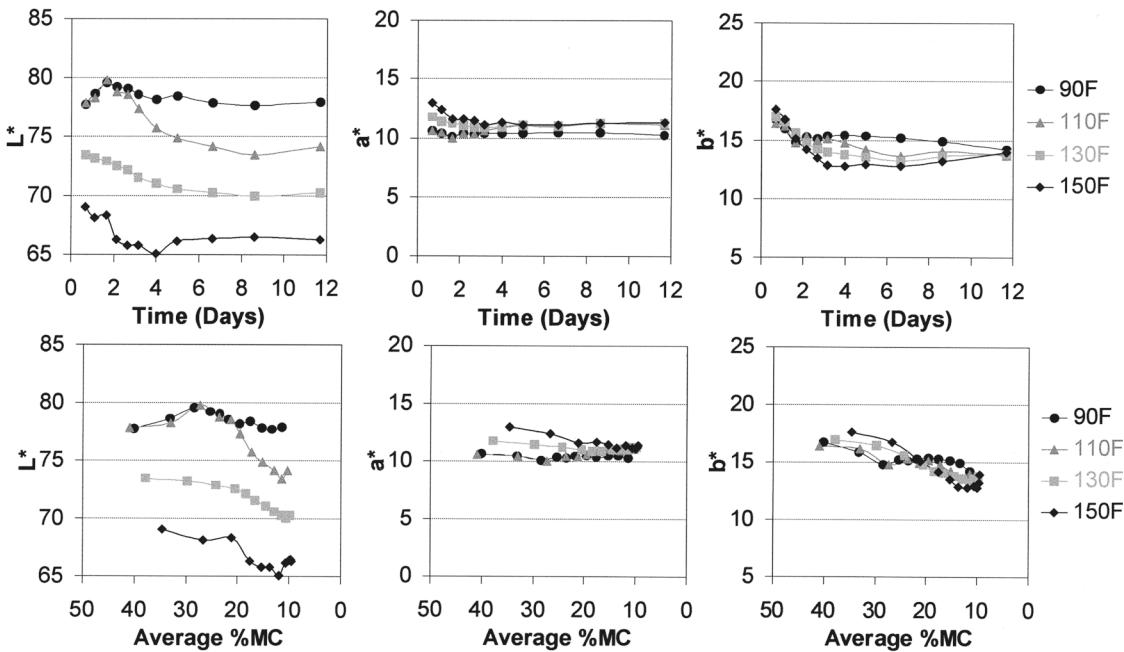


FIG. 3. Interior transverse surface L*a*b* color values of hard maple during drying at 90°, 110°, 130°, and 150°F.

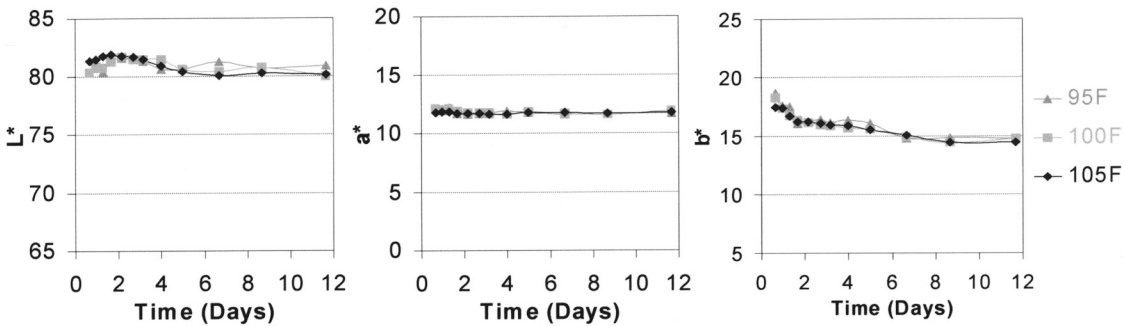


FIG. 4. Interior transverse surface L*a*b* color values of hard maple during drying at 95°, 100°, and 105°F.

while average MC was over 20% (Figs. 1 and 3). The wood darkened, with decreasing core transverse face L* values virtually immediately when dried above 130°F (Figs. 2 and 3). At 150°F drying, interior darkening ended after about 3 days, when AMC was about 15%. Comparably, when drying at 130°F, the interior darkening ended after about 4 days' drying, again when AMC was about 15%. While drying at 110°F, interior darkening started after about 2 days, when the AMC was

about 25%, and core MC was still above FSP. This darkening continued at 3 days' drying, when AMC was about 20% and expected core MC was around FSP, and ended after about 5 days' drying, when %AMC was about 15%, and core MC was lower than FSP (Figs. 2 and 3). Drying below 110°F dry bulb temperature did not result in any interior darkening (Figs. 2, 3, and 4). From the results of this work, it appears that interior darkening develops in hard maple if tem-

peratures are above 110°F when the MC is at and above the FSP, and that there are minimal changes in color once drying is below the FSP. It is known that the reactivity of oxygen in liquid water is higher than in air. It is believed that the increased darkening at elevated temperature when above FSP is due to this higher oxygen reactivity with high temperature, resulting in an increase in the oxidation of naturally present chemicals in the wood.

Dry kiln schedule T8-C3 is the USDA FPL recommended "normal" kiln schedule for 4/4-in. hard maple (Simpson 1988). It was developed to allow rapid drying while at the same time avoiding conditions severe enough to cause checking. However, because of the application of a high dry bulb temperature, 130°F, during the early stage of drying, both surface and interior darkening is likely to occur. Use of schedule T3-C5 has been specifically recommended for "white" maple (Wengert 1992). It has a lower dry bulb temperature, 110°F, during the early stage of drying, from green to 30% AMC, and is thus better at avoiding wood color darkening. However, its use of 120°F dry bulb temperature from 30% to 25% AMC, 130°F from 25% to 20% AMC, and 140°F from 20% to 15% AMC, very likely results in interior darkening. This typically may not be noticed superficially, as the surface of boards has dried sufficiently below FSP before being exposed to elevated temperature to remain bright. Results of this study suggest that in order to maintain a bright interior color in hard maple, kiln schedules should be modified to keep an internal wood temperature lower than 110°F until AMC is below 20%. This recommendation may also be relevant for other "white woods" such as soft maple and white ash.

CONCLUSIONS

It appears that interior darkening develops in hard maple with elevation of temperatures when the MC is at and above the FSP, and that minimal color change develops when drying is below the FSP. This would seem to indicate that presence of reactive oxygen with free moisture, in addition to elevated temperature, is an important component

in the development of wood color darkening during drying. Keeping an internal wood temperature lower than 110°F until core MC reaches FSP is recommended to maintain bright interior color in hard maple. The technique of end-sealing and insulating boards with Styrofoam, developed and demonstrated in this study, made for similar MC and internal temperature conditions at any location along the wood length at any time during drying. This method has proven useful in determining MC, temperatures, and drying time critical to development of interior darkening, by facilitating continual measurement of color change by removal of samples for color analysis while the main specimen continues to dry as a normal board. The flat-bed color scanner and spectrophotometer were both shown to be quite useful and important tools in being able to both communicate and analyze color and color change during lumber drying. The results from this study are expected to facilitate manufacture of increased lumber quality and value.

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