Prevention of Sapwood Discoloration in Hardwood Lumber

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EXECUTIVE SUMMARY

Hardwood lumber drying in the South is subject to hot and humid weather that promotes enzymatic stain in sapwood. Research has long studied the problem and certain remedies have been proposed. Chemical dipping is the most commonly used method of preventing enzymatic stain. However, its application is only topical and does not prevent stain. A private operator, Danny Elder of Jasper, Texas, developed, through trial and error, a pre-drying treatment method called the Elder Process. The claimed benefits of the Elder Process include prevention of enzymatic stain; darkening sapwood color which more closely match that of heartwood and increases color consistency of lumber; reduce drying degrade; and reduction in air drying time.

At the request of the local hardwood industry, the Texas Forest Service conducted a study to verify these claims. 13.3 thousand board feet of freshly sawn southern red oak boards were divided into four different treatment groups:

a) Chemically dipped, not Elder Process treated (DNP);

b) Chemically dipped, Elder Process treated (DP);

c) Not chemically dipped, Elder Process treated (NDP); and

d) Not chemically dipped, not Elder Process treated (control group, NDNP).

The emphasis was on comparing the Elder Process to chemical dipping. The other groups were created to quantify any interaction between the groups.

To quantify the change of color caused by the Elder Process, a Minolta CR-13 Color Reader was used to record the color difference between sample boards from these four treatment groups. To study the effect of the Elder Process on drying defects and drying degrade, all lumber was surfaced on both sides and then a National Hardwood Lumber Association inspector graded the kiln-dried lumber. Each board was graded with and without drying defects. Drying defects such as check and split, sap stain, sticker mark, and mineral stain were also recorded on both sides of the boards. To verify the effect of the Elder Process on air drying rate, air drying rates from two groups of boards (DP and DNP) were measured and compared.

The color readings using the CIELAB color space for the pre-drying treatments clearly showed that the Elder Processed lumber had a brighter color with an orangey tint in the sapwood. This was closer to the color of the heartwood and showed improved color consistency between the sapwood and heartwood. The $\Delta E2000$ color values between treatment groups showed that the Elder Process had a significant effect on sapwood color changes during lumber drying while chemical dipping did not. Heartwood color was not affected by treatment. Although the Elder Process used in this study enhanced the color of sapwood to more closely resemble the color of heartwood, the colors of heartwood and sapwood remained different. A study on changing the parameters of the Elder Process to further enhance the color of the sapwood might be beneficial.

The Elder Process was very effective in minimizing enzymatic stain on sapwood and reducing drying degrade. The chemically dipped-only treatment had little effect in combating enzymatic stain on sapwood and drying defects, and the combination of chemical dipping and the Elder Process did not have significant advantage over the Elder Process-only treatment.

The ability of the Elder Process to reduce drying defects over the chemical dipping treatment translated into potential financial gains. This study clearly showed that the Elder Process minimizes enzymatic stain and reduces drying degrade. The potential financial gains from the

reduced drying defects and degrade may help the southern hardwood industry compete more effectively with northern hardwood and Appalachian hardwood industries that have less enzymatic stain problem. However, the financial gains from this study were theoretically calculated based on the difference in drying degrade among treatment groups. Further study on the market acceptability of the Elder Processed lumber is necessary to better understand the real financial gain.

The air drying stage of the tests was conducted in a drying shed, which was subject to the particular weather conditions at the time. The air drying conditions were less than ideal because of insufficient airflow in the drying shed and the often-humid climate. This means that it is possible for the non-Processed groups to receive less enzymatic stain than they did in this test. On the other hand, this test showed the effectiveness of the Elder Process despite the poor air drying condition. Also, the test was conducted during a cooler winter season, a time that is more favorable to air drying than the hot, humid East Texas summer time.

The comparison of air drying rates for the two groups of lumber (DP and DNP) did not show that the Elder Process had any significant effect on air drying rate. However, since air drying is dependant on climatic conditions, this conclusion may not apply to air drying under a different climatic condition.

Finally, sweetgum is a major hardwood species in East Texas. Anecdotal evidences suggested that the Elder Process might have the potential to substantially reduce drying defects for sweetgum lumber, which is susceptible to excessive warping and cupping during the drying process, making it a more valuable product. A study to evaluate the benefits of the Elder Process on drying sweetgum lumber and thus making it a more valuable product is warranted.

ACKNOWLEDGEMENTS

We would like to thank Ward Timber Company for providing green lumber, Elder Hardwood for providing facility and expertise in hardwood drying and the Elder Process, and the National Hardwood Lumber Association (NHLA) for providing grading service to this project. Hill Country Hardwood, and the Jasper District of the Texas Forest Service provided valuable assistance to this project. The cooperation of the Jasper Economic Development Corporation and the Deep East Texas Council of Governments was also important to the success of this project. Burl Carraway and Marilynn Grossman of the TFS edited the report.

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INTRODUCTION

Lumber drying is a crucial element for producing value-added products from hardwood. The wood must be dried to a homogenous moisture content with as little degrade or loss of quality as possible. Drying degrade can occur as a result of drying defects such as warp, checks and splits, and enzymatic stain. This study examines a lumber pre-drying treatment method, the Elder Process, that claims to prevent enzymatic stain from developing during the drying process.

Enzymatic stain is produced by slowly dying parenchyma cells that darken when oxidized. A suggested control for enzymatic stain is to place freshly-sawn lumber immediately on stickers and dry at temperatures above 70ºF with good air circulation (Taylor 1996). The hot and humid climate of East Texas means that proper air drying conditions are very difficult to attain and some form of stain-preventing treatment must be used.

Common industry practice is to dip lumber in a chemical solution to kill parenchyma cells and prevent enzymatic stain. Two shortcomings of this process are: 1) chemical penetration using this process is limited, which means that discoloration can occur in sapwood despite treatment (Forsyth and Amburgey 1992); and 2) handling of lumber dipped in toxic chemicals is hazardous (Amburgey and Kitchens 1999).

In light of environmental and safety concerns, Amburgey and Kitchens (1999) patented a mechanical treatment for providing control or elimination of non-microbial (enzymatic) staining in lumber sapwood. The method applies a compression and/or vibration force to the surface of freshly-cut lumber to prevent or reduce enzymatic stain (Amburgey and Kitchens 1999). Although this process can be integrated into the production chain, application time depends on lumber characteristics (e.g. knots) and can slow production levels considerably.

A private operator, Danny Elder of Jasper, Texas, frustrated by continuous staining in sapwood, developed and patented the Elder Process that allegedly kills all the stain-producing enzymes. The process uses a controlled heating medium to heat wood to over 120ºF (preferably 150ºF) while maintaining a near-zero degree wet-bulb depression.

With the Elder Process, after a predetermined heating duration (from 2 to 36 hours), lumber is cooled using a fluid that is at least 30ºF (50ºF ideal) less than the temperature of the heated lumber and a relative humidity at least 10% (preferably 20%) less than the relative humidity of the treatment chamber (Elder 2002). This rapid cooling has a favorable thermal gradient allowing for rapid evaporation of water and leading to a 5% to 10% moisture content loss within the first day (Elder 2002).

The heat (from 130ºF to 170ºF) and high relative humidity (near 100%) generated by the heating medium (and applied for an extended period of time) increases permeability (Kiln-Direct.com 2001, Chen 1975) and relaxes internal tensions in wood. These combined effects of the Elder Process allegedly can greatly reduce drying defects such as cup, twist, and check, and shortens drying time (Elder 2002). For the Elder Process to be effective, it is recommended that newly felled timber be sawn into lumber and processed within two weeks.

An alleged ancillary benefit of the uniform heating fluid in the Elder Process is that the sapwood color is darkened by the movement of tannins and extractives found in the heartwood. This result is similar to that of steamed walnut, where the sapwood color darkens and contrasts less with heartwood (Lebove 2005).

OBJECTIVES

Interested in improving the appearance of southern red oak, the hardwood industry in East Texas asked the Texas Forest Service to verify that the Elder Process prevents the development of enzymatic stain. The objectives of this study were to:

- Verify that the Elder Process prevents enzymatic stain from developing
- Compare color of sapwood and heartwood for similarity
- Quantify degrade to compare recovery
- Verify effect of Elder Process on air drying time

MATERIALS AND METHODS

The Elder Process was designed as an environmentally friendly and highly effective alternative to chemical dipping. Prior to the test, it was decided to compare the Elder Process to chemical dipping, since it is the most widespread stain-preventing treatment. For convenience, Elder Process treated lumber is referred to as "Processed" lumber and chemically dipped lumber is referred to as "Dipped" lumber.

Species

A valuable commercial species, southern red oak (*Quercus falcata*) was chosen for this study because it is one of the more prevalent hardwood species in the southern U.S. and is affected by enzymatic stain.

At maturity, southern red oak is a medium-size tree, usually from 70 to 80 feet high with a normal diameter of 2 to 3 feet. In forest stands, it develops a long, straight trunk and upward-reaching limbs that form a high, rounded crown (**fig. 1**). Natural pruning is excellent in well-stocked stands. Maximum age attained is about 150 years.

Seventy percent of the average tree's green weight is in stem material to a 4-inch top, and 30 percent is in crown material. Total tree wood has an average specific gravity of 0.604, average moisture content of 74 percent, and average green weight of 66 lb/ft^3.

Southern red oak can be found on dry, infertile soil in stands of mixed hardwoods and pine from New Jersey and southern Illinois in the North to Texas and central Florida in the South (**fig. 2**).

Figure 1. Typical Southern red oak tree

Figure 3 shows the equilibrium moisture content of the area considered for southern red oak growth. The equilibrium moisture content is highest along the southern coastal states, reaching up to 13% in certain areas. These areas are subjected to high temperatures and high relative humidity, which, as mentioned above, are ideal conditions for the development of enzymatic stain.

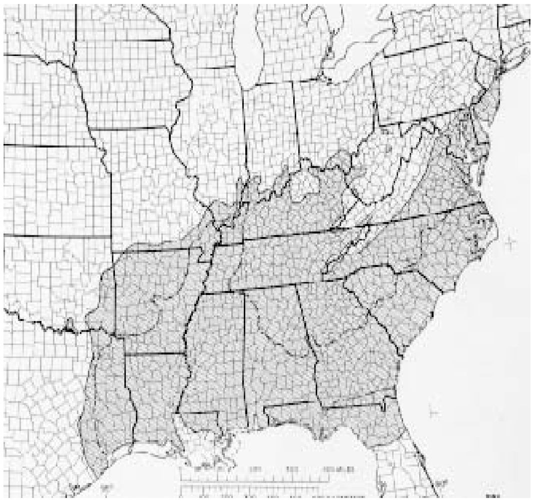

Figure 2. Southern red oak distribution (USFS)

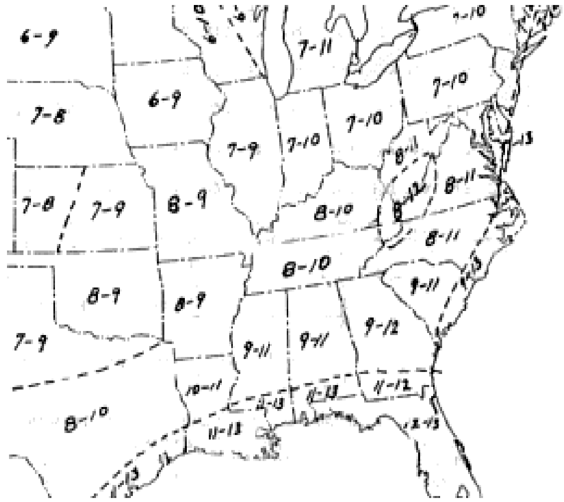

Figure 3. Equilibrium moisture content throughout the United States (adapted from the US Department of Agriculture, Forest Products Laboratory)

Lumber

There were 13.3 thousand board feet (MBF), or 2,371 total boards, of freshly-sawn southern red oak lumber used for this study (**Table 1**). The lumber was sawn in November, 2004 in Northeast Texas and the study was conducted in Southeast Texas. The lumber was stacked into 24 packs, with about 80 to 120 boards per pack. The lumber was 4/4 inch thick, 6 to 12 inches wide, and 8 to 12 feet long.

All grading in this study used the National Hardwood Lumber Association (NHLA) standard grades, including FAS, No. 1 Common (No. 1C), No. 2A Common (No. 2AC), and No. 3A Common (No. 3AC). FAS 1-face (F1F) was graded as FAS, in accordance with the NHLA grade rules for surfaced lumber (NHLA 2003). A certified grader from Ward Timber Company graded the green lumber and a NHLA inspector graded the dry lumber. Seven packs of lumber with FAS green grade and 17 packs of lumber with No. 1C green grade were tested. Four different combinations of the two treatments were applied to the lumber for each grade. These four combinations were:

- Chemically dipped, not Elder Process treated (DNP)
- Not chemically dipped, Elder Process treated (NDP)
- Chemically dipped, Elder Process treated (DP)
- Not chemically dipped, not Elder Process treated (control group, NDNP)

All lumber packs were randomly assigned to the treatment types. However, equal numbers of lumber packs were not used for each treatment. Priority was given to the DNP and NDP groups since the difference between chemical dipping and the Elder Process was the main interest. The

DP and NDNP groups were assigned one pack for each treatment for both FAS and No. 1C green grades (**Table 1**).

Table 1. Test samples by treatment type

Unit: board foot

Item	DNP	NDP	DP	NDNP	All
	Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)	
Board Feet	6,076	4,748	1,531	994	13,349
# of boards	1,067	919	217	168	2,371
# of Packs	11	9	2	2	24
FAS	4	1	1	1	7
No. 1C	7	8	1	1	17

The lumber used in this study was sawn from freshly cut logs or logs submerged under water with minimum or no enzymatic stain. Green lumber was put on stickers within two days of sawing. Eleven packs (DP and DNP) of FAS and No. 1C lumber were chemically dipped at the sawmill immediately after sawing. Thirteen packs (DP and NDP) of lumber were treated with the Elder Process for 36 hours. Two packs (NDNP) were left untreated as the control group. All lumber was air-dried under the same drying shed. After 89 days of air drying, all lumber was kiln-dried in the same drying kiln for 15 days.

Figure 4 shows the air drying sheds. Each was 50-feet long with a center aisle and three rows of lumber stacked on both sides. Sheds had a 20-foot-high ceiling with a total lumber capacity of 80,000 bf per shed. Ceiling fans hung over the center aisle to maintain a 40 feet per minute airflow.

Once the lumber reached approximately 30% moisture content, it was moved to a 48,000 bf dry kiln that used indirect fire to produce steam. Air velocity was 120 feet per minute.

The drying schedule was for southern lowland oak, as detailed in **Table 2**. Drying conditions for this experiment started at 100ºF with an 8º depression because initial moisture content was estimated at 33 percent.

Figure 4. Air drying shed with ceiling fans to ensure continuous airflow

Table 2 indicates moisture content (MC) range, dry bulb (DB) temperature, temperature depression (Depression), relative humidity (RH) in the kiln, and equilibrium moisture content (EMC).

Table 2. Drying schedule for lowland red oak 4/4, 5/4, 6/4

MC %	DB (ºF)	Depression (ºF)	RH (%)	EMC (%)
Green to 40	100	3	89	19.0
40 to 35	100	4	86	17.5
35 to 30	100	8	73	13.1
30 to 25	110	10	70	12.0
25 to 20	120	25	40	6.6
20 to 15	130	50	10	2.0
15 to final	150	50	8	2.9
Equalize	150	40	28	4.2
Condition	150	10	76	11.8

Note: adapted from Dry Kiln Operator's Manual, Agricultural Handbook 188

After kiln drying, all lumber was surfaced on both sides and then graded. Each board was given two grades. One grade was the grade of the dry lumber with all drying defects (if any), and the other grade was the grade of the dry lumber without taking into account any drying defects. The grader had no prior knowledge about the treatment received by each pack of lumber during grading.

Along with the two grades, pack number, board feet, original green grade, pre-drying treatment type, percent sapwood on both sides, and drying defects on both sides were also recorded. Recorded drying defects included percent sap stain, total length of check and split, numbers of sticker mark, and percent mineral stain. Each board was also identified for its good side and bad side, with the good side of each board always having an equal or better grade than the bad side of the same board.

Color

Since no historical data were available for the tests performed, large, randomly chosen samples of 40 boards for each of the four treatment groups were created to verify the change in color. Twenty boards were selected outright while the other 20 were sawn into matched pairs for measuring difference between Processed and non-Processed lumber. The lumber was chosen from FAS grade to reduce the influence of the non-drying defects on color.

To quantify the change of color caused by the Elder Process, a Minolta CR-13 Color Reader was used. The CR-13 was selected because it can be calibrated and uses the L*a*b* – or CIELAB – color space. CIELAB allows the specification of color perceptions in terms of a three-dimensional space (**fig. 5**). The L*-axis is known as the lightness and extends from 0 (black) to 100 (white). The other two coordinates, a* and b*, represent redness-greenness and yellowness-blueness respectively. The a* and b* axes have no specific numerical limits. Higher a* means more reddish color and less greenish color. Higher b* means more yellowish color and less bluish color. Samples for which a* = b* = 0 are achromatic and thus the L*-axis represents the achromatic scale of grays from black to white.

The principal advantage of using the CIELAB color space is its uniformity in the associate chromaticity diagrams (**fig. 5**). This is very important in estimating the magnitude of difference between two color stimuli. One way to analyze the color readings is to look at each value for L*, a* and b* separately and measure the impact of each value on their respective spectrum. When comparing two color points in three-dimensional space, the perceived color difference can be measured using the Euclidian distance ΔE2000 (CIE 2001). Although the significance of color difference is subjective, it is generally agreed upon that a color difference (ΔE2000) value greater than 1 indicates a perceptible difference of the two color points (Luo et al. 2001).

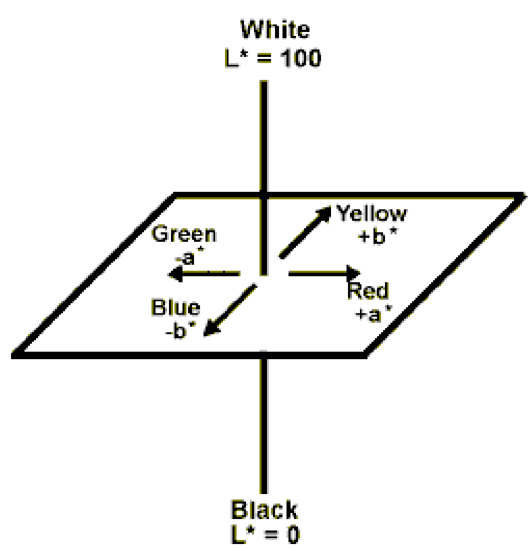

Figure 5. CIELAB color space (HunterLab, 1996)

Readings were taken at 2-foot intervals lengthwise and 3-inch steps widthwise, as shown in **Figure 6**.

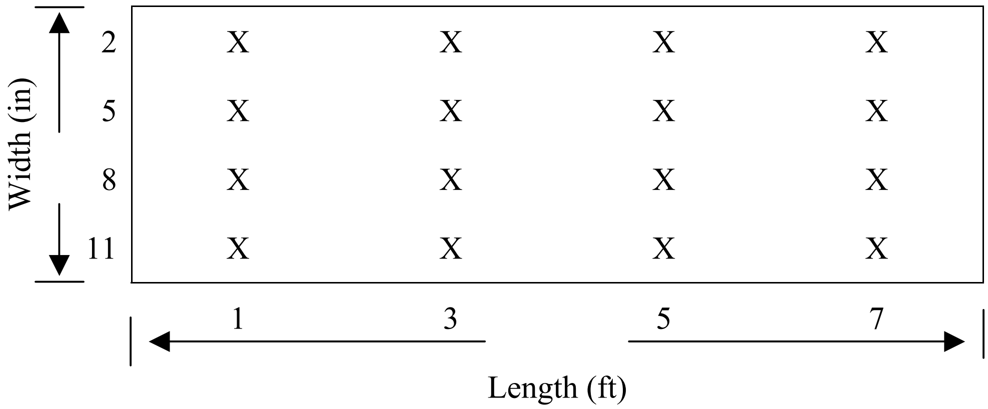

Figure 6. Disposition of color readings

The color of each board was measured at the center of each square area determined in **Figure 6** to measure color of Processed, Dipped, or non-treated lumber. Presence of heartwood or sapwood in measurement location was noted as well as CIELAB values. Color was then averaged for each category and color difference was calculated using an Excel spreadsheet developed by Sharma (2004).

Drying Defects and Drying Degrade

All drying defects such as enzymatic stain, checks, sticker marks, and mineral streak were observed and noted by the NHLA inspector for both sides of every board. The inspector calculated the relative area of enzymatic stain on each board surface. This allowed for analysis the enzymatic stain area relative to whole board and sapwood only and comparison of the values for each treatment. The inspector also calculated the relative area of mineral stain, check length, and number of sticker marks on each board surface. **Figure 7** shows drying defects such as checks, sticker marks, enzymatic stain, and mineral streak, respectively, that were observed in this study.

Drying defects cause drying degrade. Any potential lumber drying degrade can be obtained by comparing the grades with and without drying defects.

Splitting and checking result from the lumber's reaction to wet and dry moisture cycles. Exposed surface areas expand when wet by rainfall and contract when dried by the sun. This continual process sets up stresses that can cause cracks and grain separation (checking). Protecting lumber from the elements with proper covers during storage and at the building site can help minimize warp and crack.

Enzymatic stain of the sapwood also occurs when drying is too slow. The resulting change in color decreases the available clear area.

Sticker mark occurs under the drying sticks when the drying is too slow. The wood cells create chemicals that eventually turn color during drying.

Mineral stain is introduced from mineral deposits contacted by the roots of the tree. The mineral is pumped into the tree and stains the wood. This problem is soil related and there is no means of preventing its occurrence.

a) 

b) 

c) 

d) 

Figure 7. Images of a) drying checks, b) enzymatic stain, c) sticker marks, and d) mineral streak

No warp or cup was observed in this study after the lumber was surfaced. Warp in lumber is any deviation of the face or edge of a board from flatness or any edge that is not at right angles to the adjacent face or edge. Warp can be traced to differences between radial, tangential, and longitudinal shrinkage in the piece as it dries. Warp is aggravated by irregular or distorted grain and the presence of abnormal types of wood, such as juvenile wood or reaction wood.

Cup is a form of warp in which the board deviates from a flat surface across the width of the board. Cupping can often be reduced by running boards through a planer, but the cup often springs back as the board leaves the planer (especially with thinner stock such as 1-inch thick boards).

Air Drying

To verify the effect of the Elder Process on air drying rate, air drying time was measured by comparing drying rates from two groups of boards (DP and DNP). Both groups were from chemically dipped lumber to eliminate the potential efforts of chemical dipping on air drying rate.

Air drying sample sizes (n) were determined using historical green lumber data concerning moisture content:

$$\boxed{n = \left(\frac{Z \times \sigma}{x - \mu} \right)^2} \qquad \textbf{Equation 1}$$

where n is the sample size, Z is the standard normal set at the significant level of 95% ($Z = 1.645$), σ is the standard deviation ($\sigma = 7.6$), $x - \mu$ is the detection level at which change is observed ($x - \mu = 2$).

With the above parameters, the sample size was established at 40 boards to verify moisture content/drying curve (weight basis) for the air-dried boards. The number of boards was independent of lumber grade (i.e. FAS lumber has the same MC distribution as No. 1C lumber). This resulted in randomly selecting 40 Processed boards and 40 non-Processed boards. Initial moisture content was determined by cutting approximately 1-inch-wide samples, five inches from the lumber ends. These samples bore the board number and the letter A or B for either extremity. The samples and sample boards were immediately weighted after being sawn to assure most accurate results.

All boards were weighed on a weekly basis to establish air-drying time and drying rates for each group. Weekly local temperature and relative humidity were averaged using Internet data for Jasper County-Bell Field (KJAS) airport (www.wunderground.com).

RESULTS AND DISCUSSION

Color

Color was mapped before and after lumber drying. This data allowed for comparisons to verify that lumber had similar color before air drying, to measure differences in color between heartwood and sapwood, and to quantify heartwood and sapwood color among the different groups. **Table 3** indicates the average L*a*b* color readings recorded after the experiment for each group and the ΔE2000 value for the average heartwood and sapwood within each group.

The data were averaged using at least 69 sapwood and 168 heartwood data points. **Figure 8** shows the corresponding colors. Lumber grade did not affect color and vice verse. Initial color data was disregarded because moisture (i.e. water) affected board color in different ways, leading to high variability in color within a group and among the different groups.

Table 3. Color comparison between different groups of dry lumber

	Heartwood			Sapwood			
Treatment	L*	a*	b*	L*	a*	b*	ΔE2000
DNP	64.1 *(2.8)*	13.1 *(2.0)*	19.6 *(1.0)*	66.4 *(2.8)*	9.6 *(1.9)*	18.0 *(1.3)*	3.3
NDP	63.7 *(3.1[1])*	13.0 *(1.7)*	19.3 *(1.1)*	67.1 *(2.6)*	11.1 *(1.2)*	20.7 *(1.1)*	3.5
DP	63.9 *(3.1)*	13.4 *(1.7)*	19.5 *(1.1)*	67.6 *(2.7)*	11.3 *(1.4)*	20.9 *(1.3)*	3.8
NDNP	64.6 *(2.9)*	12.6 *(2.0)*	19.5 *(1.1)*	66.9 *(2.7)*	9.4 *(1.0)*	18.4 *(1.3)*	3.2

Figure 8. Average color readings for heartwood and sapwood of NDP, DP, DNP, and NDNP lumber

The values in **Table 3** represent average values and indicate that the average heartwood and sapwood had noticeable color differences (ΔE2000 > 1), regardless of the treatment received. The red oak heartwood always has a darker red color than the sapwood. The average L*a*b* color readings showed that the average sapwood had a higher L*, lower a*, and higher b* values than the average heartwood, indicating that the average sapwood had a lighter, lesser reddish, and more yellow tint than the average heartwood. However, the heartwood had similar color among the different treatments, confirming the fact that the heartwood color was not affected by processing type.

The non-Processed sapwood had slightly darker color (L*) and a greener tint (a*) and was less yellow (b*) making the difference between heartwood and sapwood colors more contrasting. The Processed sapwood lumber had a brighter (L*) color and a more orange tint (a*b*), which was closer to the color of the heartwood. The change in color between the Processed and non-Processed lumber could be due to the presence of enzymatic stain. Enzymatic stain has a grey-blue tint that would help explain the shift in color.

The color data were averaged and then compared statistically using a t test to determine if there was a significant difference ($\alpha \leq 0.05$) for each comparison. When comparing the similarities between the colors, a ΔE2000 value greater than 1 indicates a noticeable difference. **Table 4** presents the ΔE2000 values of heartwood and sapwood for the paired treatment groups. There was no significant difference in heartwood color between the paired groups as none of the ΔE2000 value of the paired groups for heartwood is greater than 1. This was the expected result because heartwood is not affected by enzymatic stain, as there are no living enzymes in the dead cells at the core of the tree.

The ΔE2000 value of the paired groups for sapwood showed the Elder Process had a significant effect in changing sapwood color while chemical dipping did not. Among the six pairs of treatment groups, the ΔE2000 values of two pairs for sapwood were smaller than 1, indicating no significant color differences. These two pairs were either all Processed (NDP vs. DP), or all non-Processed (DNP vs. NDNP), regardless of whether they were dipped. The ΔE2000 value of the other four paired groups, which mixed Processed and non–Processed pairs (NDP vs. DNP, NDP vs. NDNP, DP vs. NDNP, and DP vs. DNP) were all bigger than 1, indicating significant difference in sapwood color between the two treatments within each pair.   The only consistent factor present in all the four pairs was that one group in each pair was Processed, and the other one was not, regardless if either of the two was chemically dipped.

Table 4. ΔE2000 color value for paired treatment groups by heartwood and sapwood

Treatment Groups	*Heartwood*	*Sapwood*
NDP vs. DNP	0.3	1.7
NDP vs. NDNP	0.8	1.6
NDP vs. DP	0.4	0.5
DP vs. NDNP	0.8	1.8
DP vs. DNP	0.3	2.0
DNP vs. NDNP	0.5	0.6

Dry Defects and Drying Degrade

Sapwood and Heartwood

The presence of sapwood is not a defect in the NHLA's grade rules (NHLA, 2003). However, high-end users such as cabinet makers, furniture and flooring manufacturers prefer heartwood because of color consistency. Sapwood has a color that is brighter and less orange-red than heartwood (**fig. 9**). This difference in color is judged to be too contrasting to be properly integrated, and there is not enough sapwood surface area to produce sapwood-only products.

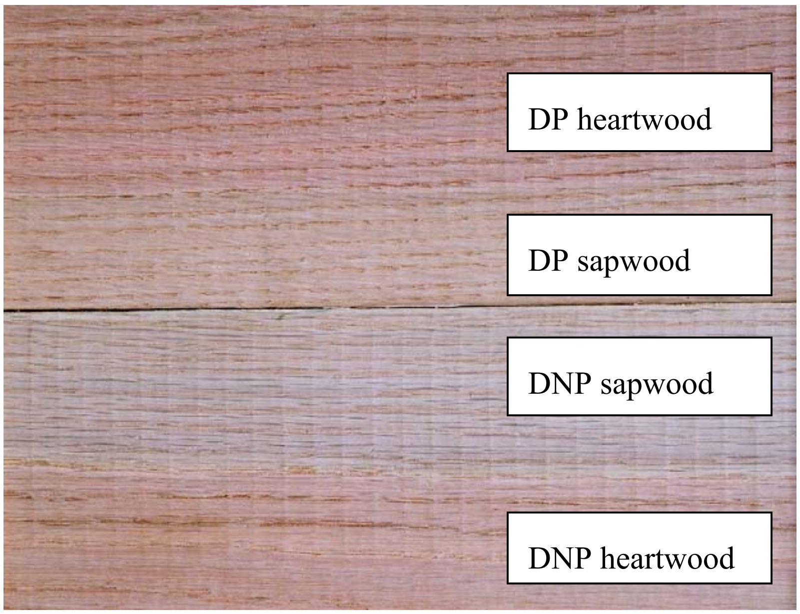

Figure 9. Color comparison for heartwood and sapwood from a typical DP board and a typical NDP board

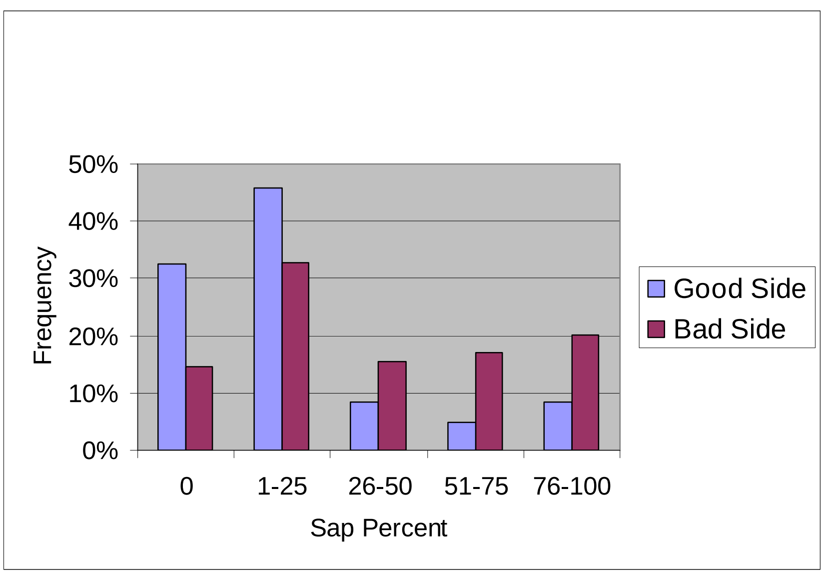

Figure 10. Frequency of boards by sap percent on both sides of the boards

Figure 10 shows the frequency of boards by sapwood percent on both sides of the boards. The horizontal axis of the figure indicates the sap percent of each board in five sap percent categories (0-100%). The vertical axis indicates the percent of boards belonging to each of the five sap-percent categories. There were substantially more boards with less sapwood (0, and 1-25) on the good side of the boards than the bad side of the boards and fewer boards with more sapwood (26-50, 51-75, and 76-100) on the good side of the boards than the bad side of the boards.

The mean of the sapwood percent was computed by grade type (**Table 5**). The mean of the sapwood percent was 20.2% on the good side of the boards and 44.3% on the bad side of the boards. Comparing the mean of the sapwood percent by grade on both sides of the boards, three observations can be made. First, there was less sapwood on the good side of the boards than on the bad side of the boards for every grade in **Table 5**. By definition, the quality of the board on the good side was better on average than the bad side of the board.

Table 5. Mean of sapwood percentage by three types of grades

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC	ALL
Good Side					
Green Grade	19.6%	20.4%			20.2%
Dry Grade w/o Drying Defects (GWOD)	17.5%	22.6%	13.8%	20.6%	20.2%
Dry Grade w/ Drying Defects (GWD)	15.8%	13.7%	19.4%	69.4%	20.2%
Bad Side					
Green Grade	36.9%	46.8%			44.3%
Dry Grade w/o Drying Defects (GWOD)	33.3%	48.3%	44.3%	55.1%	44.3%
Dry Grade w/ Drying Defects (GWD)	30.5%	38.7%	53.9%	87.2%	44.3%

Second, for FAS grade, the mean sapwood percent decreased from green grade to dry grade without drying defects (GWOD), and decreased again from GWOD grade to dry grade with drying defects (GWD). This was true for both sides of the boards. For the good side of the FAS boards, the mean of sapwood percent decreased from 19.6% for green grade, to 17.5% for GWOD grade, and to 15.8% for GWD grade. For the bad side of the FAS boards, the mean of sapwood percent decreased from 36.9% for green grade. This was because the strictness of grading increases from the green grade to the GWOD grade, and from the GWOD grade to the GWD grade. The GWOD grade was stricter than the green grade mostly because the dry wood grading is based on the good side of the boards and the green wood grading was based on the bad side of the board. In this study, the green lumber and dry lumber was graded by two different graders, which might have contributed to the difference in green grade and the GWOD grade. The consideration of drying defects made the GWD grade stricter than the GWOD grade.

Third, from GWOD grade to GWD grade, the amount of sapwood decreased for FAS and No. 1C, and increased for No. 2AC and No. 3AC. This is also true for both sides of the boards. The main reason for this observation was the lumber degrading caused by the sap stain in the sapwood, as will be discussed later in this report.

Enzymatic Stain

Enzymatic stain is also called sap stain because it only occurs on sapwood. The lumber was examined for enzymatic stain after the lumber was treated (or not), air dried, kiln dried, and surfaced. This allowed for clear notation of any sapwood discoloration. The difference between the Processed and non-Processed lumber was distinct. The Processed sapwood lumber had an orange-red tint and pale wood rays, whereas the non-Processed sapwood lumber had an unpleasant grayish tint and dark wood rays that sharply contrasted with the wood (**fig. 9)**.

Sap stains on both sides of each board were recorded as the percent of the total surface area. **Figure 11** depicts the frequency of boards by treatment type and stain percent on the good side of the boards. **Figure 12** depicts the frequency of boards by treatment type and stain percent on the bad side of the boards. The differences in sap stain percent among the four groups on both sides of the boards were very clear. In terms of having more boards in categories with less sap stain percent, and less boards in categories with more sap stain percent, the DP group was better than the NDP group, better than the DNP group, and better than the NDNP group. There is a distinct difference between Processed groups (DP and NDP) and non-Processed groups (DNP and NDNP). The bad side of the boards had more boards with more sap stains and fewer boards with less sap stains than the good side of the boards for each treatment type, and the comparisons among the treatment types on the both sides were consistent with each other.

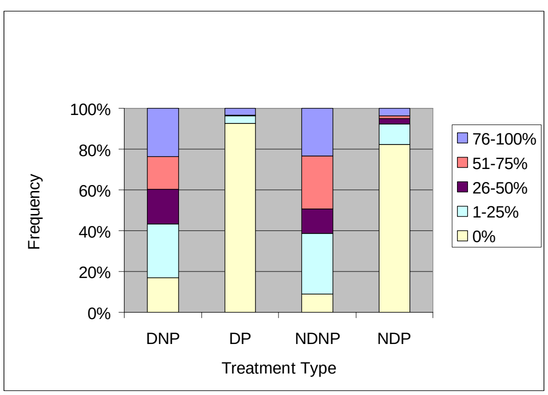

Figure 11. Frequency of boards by treatment type and sap stain percent on the good side of the boards

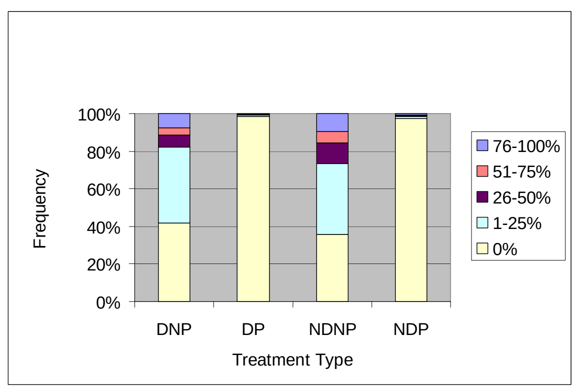

Figure 12. Frequency of boards by treatment type and sap stain percent on the bad side of the boards

Since heartwood does not develop sap stain, it is important to know the percent of sap stain in the sapwood area. This indicator helps account for the impact of the potential difference in sapwood areas among treatment types. **Figure 13** shows the frequency of boards by treatment type and sap stain/sapwood percent on the good side of the boards, and **Figure 14** shows the frequency of boards by treatment type and sap stain/sapwood percent on the bad side of the boards. The sap stain/sapwood percent refers to the percent of sap stain area over sapwood area for each board. Most of the sapwood (over 95% for 7 out of 8 groups on both sides) was either completely stained or completely not stained. Partially stained sapwoods consisted of only a very small percentage of the boards with sapwood.

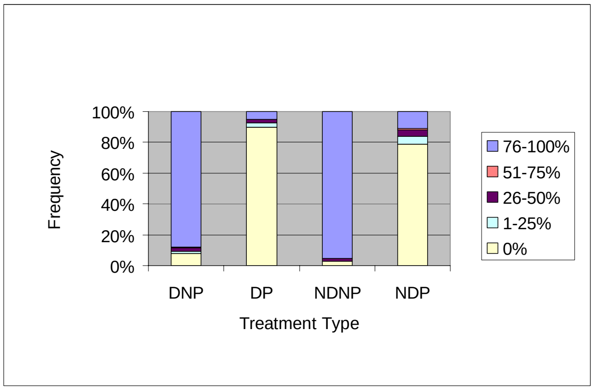

Figure 13. Figure frequency of boards by treatment type and sap stain/sapwood percent on the good side of the boards

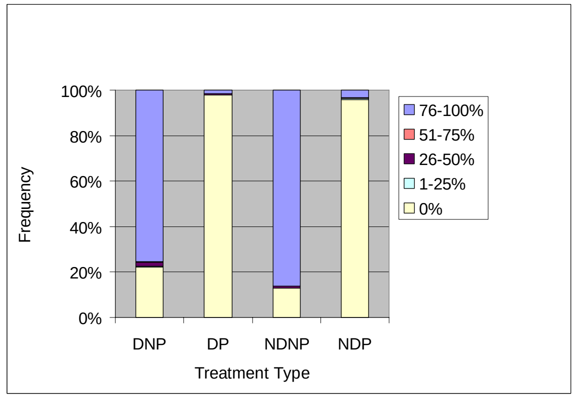

Figure 14. Figure frequency of boards by treatment type and sap stain/sapwood percent on the bad side of the boards

The means of both sap stain percent and sap stain/sapwood percent by treatment type for both the good and bad sides of the boards are displayed in **Table 6**. The mean sapwood percent by treatment type was also included in the table to give some clues about the difference between sap stain percent and sap stain/sapwood percent in the same category. The mean sap stain percent for all groups was 9.1% on the good side of the boards and 25.7% on the bad side of the boards.

The mean sap stain/sapwood percent for all groups was 41.2% on the good side of the boards and 50.7% on the bad side of the boards.

Table 6. Mean of sap stain percentages by treatment type

Item	DNP	NDP	DP	NDNP	ALL
	Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)	
Good Side					
Sap Stain Percent	17.5%	1.3%	0.9%	23.4%	9.1%
Sap Percent	20.4%	18.7%	23.3%	24.8%	20.2%
Sap stain/sapwood Percent	76.5%	3.6%	1.7%	86.7%	41.2%
Bad Side					
Sap Stain Percent	46.8%	7.6%	4.1%	52.7%	25.7%
Sap Percent	50.9%	38.4%	39.1%	53.1%	44.3%
Sap stain/sapwood Percent	89.7%	13.9%	6.3%	96.4%	50.7%

The comparison of the mean sap stain percent among the four treatment types showed that the combination of chemical dipping and the Elder Process and the Elder Process only treatment are very effective in reducing sap stain. For the DP group, the mean sap stain percent was 0.9% on the good side and 4.1% on the bad side. For the NDP group, the mean sap stain percent was 1.3% on the good side and 7.6% on the bad side. Although using both treatments was better than using the Elder Process only, the difference between the two groups was insignificant.

The group with chemical dipping only treatment came in a distant third in reducing sap stain. For the DNP group, the mean of the sap stain percent was 17.5% on the good side and 46.8% on the bad side.

The control group with no treatment had the most sap stain among the four groups. For the NDNP group, the mean sap stain percent was 23.4% on the good side and 52.7% on the bad side. The stain-reducing effect of chemical dipping was very small compared with the control group. The DNP group had only 5.9% less mean sap stain percent on the good side, and 5.9% less mean sap stain percent on the bad side than the NDNP group.

As shown in **Table 6**, there was a distinct difference between the groups that were treated with the Elder Process (DP and NDP) and the groups that were not treated with the Elder Process (DNP and NDNP). The former fared substantially better in reducing sap stains. The NDP vs. NDNP, and NDP vs. DNP comparisons revealed that the Elder Process is much more effective than chemical dipping in reducing sap stain.

The comparison of the mean sap stain/sapwood percent among the four treatment types supported the conclusions from the comparison of the mean sap stain percent among the four treatment types. The DP group had the smallest mean stain/sapwood percent, with 1.7% on the good side, and 6.3% on the bad side. The mean sap stain/sapwood percent for the NDP treatment type was 3.6% on the good side, and 13.9% on the bad side. The mean sap stain/sapwood percent for the DNP group was 17.5% on the good side and 89.7% on the bad side, substantially bigger than that of the DP group and the NDP group on both sides. The NDNP group had the biggest mean sap stain/sapwood percent amongst the four groups with 86.7% on the good side and 96.4% on the bad side.

By definition, the mean of sap stain/sapwood percent was bigger than the mean of sap stain percent in the same category. The means of sap stain percent and sap stain/sapwood percent on the good side of the boards were always better than that of the bad side of the boards according to **Table 6**.

The mean sap stain percent by grade type is given in **Table 7**. The mean sap stain/sapwood percent by grade was given in **Table 8**. The three observations from comparing the mean sapwood percent by grade on both sides of the boards can generally be applied for both sap stain percent and sap stain/sapwood percent as well. First, the sap stain percent and the sap stain/sapwood percent on the good side of the boards were bigger than on the bad side of the boards for every grade in the two tables. Second, for FAS grade, the mean sap stain percent and sap stain/sapwood percent decreased from green grade to GWOD grade, and decreased again from GWOD to GWD grade. This was true for both sides of the boards. Third, from GWOD grade to GWD grade, the sap stain percent decreased for FAS and No. 1C, and increased for No. 2AC and No. 3AC. This was also true for both sides of the boards. The fundamental reason for these three observations was that sap stain was the main reason for drying degrade as will be explained later.

Table 7. Mean of sap stain percent by grade type

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC	ALL
Good Side					
Green Grade	3.7%	10.9%			9.1%
Dry Grade w/o Drying Defects (GWOD)	3.1%	12.4%	4.1%	7.9%	9.1%
Dry Grade w/ Drying Defects (GWD)	0.3%	1.2%	11.9%	67.7%	9.1%
Bad Side					
Green Grade	13.9%	29.6%			25.7%
Dry Grade w/o Drying Defects (GWOD)	12.8%	29.9%	28.2%	31.4%	25.7%
Dry Grade w/ Drying Defects (GWD)	8.5%	15.7%	42.6%	84.2%	25.7%

Table 8. Mean of sap stain/sapwood percent by grade type

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC	ALL
Good Side					
Green Grade	19.4%	46.8%			41.2%
Dry Grade w/o Drying Defects (GWOD)	17.3%	45.9%	51.5%	35.7%	41.2%
Dry Grade w/ Drying Defects (GWD)	7.0%	25.5%	66.6%	94.5%	41.2%
Bad Side					
Green Grade	30.6%	56.4%			50.7%
Dry Grade w/o Drying Defects (GWOD)	30.2%	54.4%	63.4%	56.3%	50.7%
Dry Grade w/ Drying Defects (GWD)	23.6%	40.6%	75.3%	95.2%	50.7%

Mineral Stain, Check, and Sticker Mark

Mineral stain on both sides of each board was recorded as a percentage of the total surface area. According to existing literature (USDA 1999, Cassens 1991), there is no reason to believe that the mineral stain should respond to either chemical dipping or the Elder Process. **Figure 15** reports the frequency of boards by mineral stain percent on both sides of the boards. Most of the boards had 25% or less mineral stain on either side of the board. Only less than 0.5% of the boards had 26-50% mineral stain. There were no boards with more than 50% mineral stain on the either side of the board.

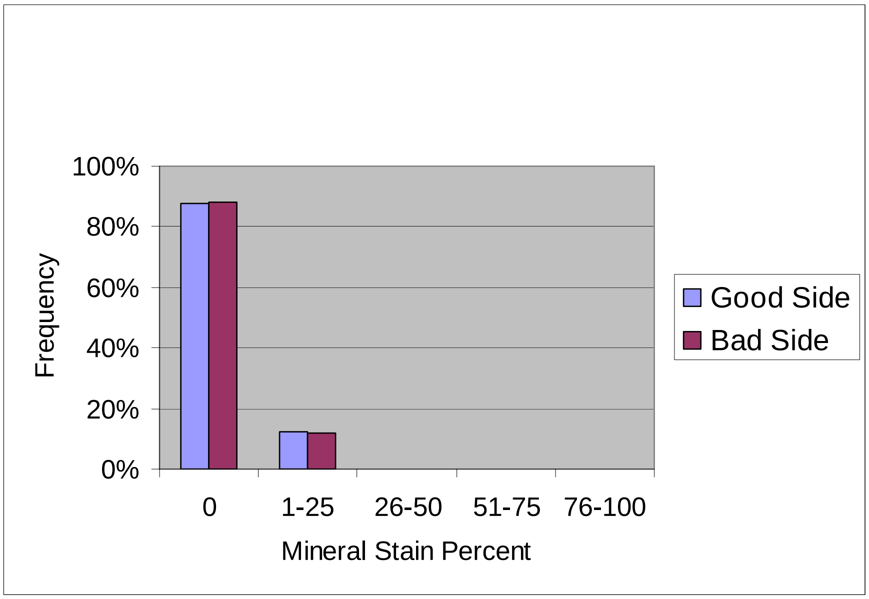

Figure 15. Frequency of boards by mineral stain percent on both sides of the boards

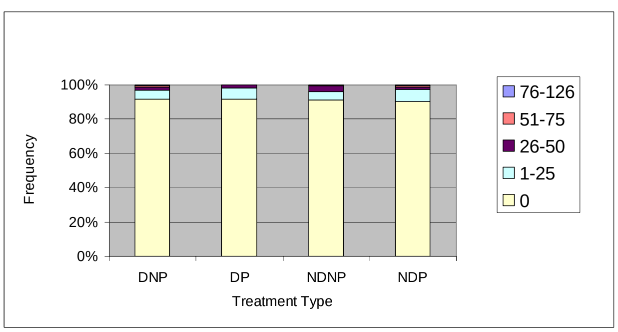

Figure 16. Frequency of boards by treatment type and check length on the good side of the boards

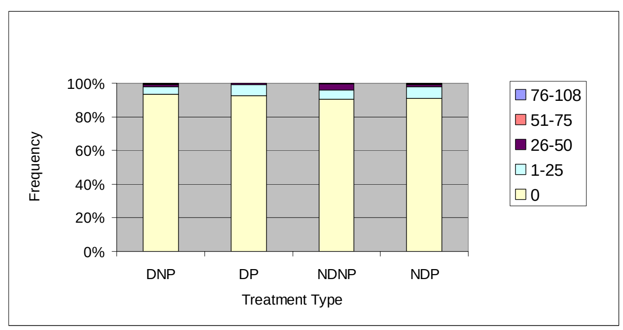

Figure 17. Frequency of boards by treatment type and check length on the bad side of the boards

Checks and splits were recorded as total length in inches for each board. In the case of multiple checks or splits on one board, the lengths were added to form one reading. Multiple checks or splits on one board were rare. **Figures 16** and **17** depict the frequency of boards by treatment type and check length in inches on good and bad sides of the boards, respectively. The difference in board frequency distribution by check length on either side of the boards among the four treatment types were fairly small. All treatment groups had over 90% boards check-free. Most of the rest of the boards had checks less than 50 inches long.

The number of sticker marks was recorded for both sides of each board. **Figures 18** and **19** describe the frequency of boards by treatment type and the number of sticker marks on both sides of the boards. There was almost no sticker mark presented on either side of the boards for both the DP group and the NDP group. There were 2.7% and 0.6% of the boards on the good side with 1 - 8 sticker marks in the DNP group and the NDNP group, respectively. On the bad side of the boards, the DNP group had 8.2% of the boards with 1 - 6 sticker marks and the NDNP group had 4.2% of the boards with 1 - 6 sticker marks.

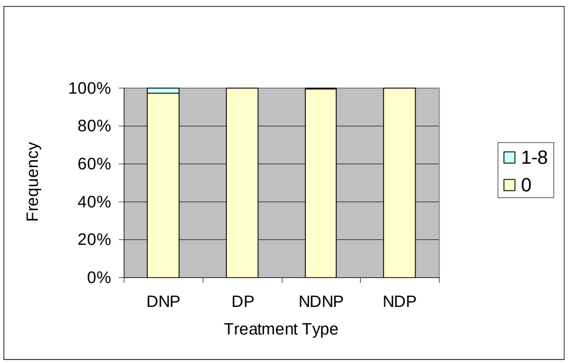

Figure 18. Frequency of boards by treatment type and number of sticker marks on the good side of the boards

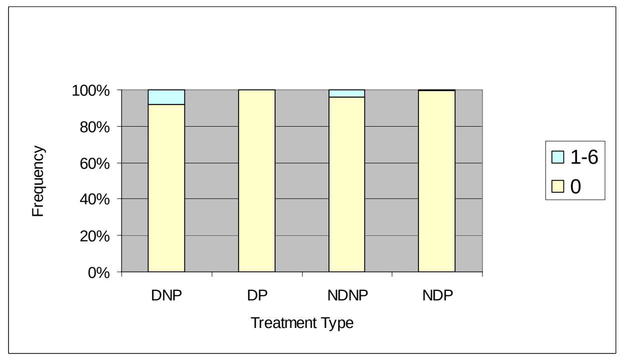

Figure 19. Frequency of boards by treatment type and number of sticker marks on the bad side of the boards

Table 9. Mean of mineral stain percent, number of sticker marks, and check length by treatment type

Item	DNP	NDP	DP	NDNP	ALL
	Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)	
Good Side					
Mineral Percent	0.45%	0.30%	0.99%	0.24%	0.42%
# of Sticks	0.075	0.002	0.000	0.024	0.032
Length of Checks (inch)	1.55	1.72	1.11	2.21	1.63
Bad Side					
Mineral Percent	0.34%	0.44%	1.19%	0.17%	0.45%
# of Sticks	0.244	0.007	0.000	0.131	0.107
Length of Checks (inch)	2.35	2.36	1.56	2.29	2.28

The means of mineral stain percent, number of sticker marks, and check length by treatment type are presented in **Table 9**. The means of mineral stain percent, number of sticker marks, and check length by grade type are presented in **Tables 10, 11, and 12**, respectively. Because mineral stain and sticker marks were not significant contributing factors for degrading in this study, there was no meaningful pattern for the mean mineral stain percent and the mean number of sticker marks in **Tables 10 and 11**. Although check length was a significant contributing factor for degrading as will be explained later, the number of boards with checks or splits was so small, therefore the mean value in **Table 12** is not very meaningful.

Table 10. Mean of mineral stain percent by grade type

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC
Good Side				
Green Grade	0.09%	0.53%		
Dry Grade w/o Drying Defects (GWOD)	0.16%	0.53%	0.35%	0.16%
Dry Grade w/ Drying Defects (GWD)	0.18%	0.57%	0.35%	0.28%
Bad Side				
Green Grade	0.17%	0.54%		
Dry Grade w/o Drying Defects (GWOD)	0.26%	0.54%	0.34%	0.32%
Dry Grade w/ Drying Defects (GWD)	0.28%	0.65%	0.32%	0.04%

Table 11. Mean number of sticker marks by grade type

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC
Good Side				
Green Grade	0.000	0.042		
Dry Grade w/o Drying Defects (GWOD)	0.000	0.050	0.003	0.000
Dry Grade w/ Drying Defects (GWD)	0.000	0.014	0.029	0.214
Bad Side				
Green Grade	0.007	0.141		
Dry Grade w/o Drying Defects (GWOD)	0.004	0.153	0.081	0.000
Dry Grade w/ Drying Defects (GWD)	0.004	0.064	0.212	0.357

Table 12. Mean of check length by grade type

Board Side & Grade Type	FAS	No. 1C	No. 2AC	No. 3AC
Good Side				
Green Grade	1.37	1.72		
Dry Grade w/o Drying Defects (GWOD)	1.08	1.70	2.34	0.63
Dry Grade w/ Drying Defects (GWD)	0.55	1.75	2.56	1.51
Bad Side				
Green Grade	1.70	2.48		
Dry Grade w/o Drying Defects (GWOD)	1.34	2.53	2.93	0.32
Dry Grade w/ Drying Defects (GWD)	0.62	2.69	3.37	1.53

Statistical Tests for Drying Defects

With the above discussions about drying defects, one question still left to answer is whether these defects are statistically different by treatment type. To answer this question, two-way ANOVA tests were performed for each drying defect variable discussed above for both sides of the boards. ANOVA, or Analysis of Variance, is a statistical procedure that detects the amount of variation in a process and determines if the variation is significant or is caused by random noise.

In this case, it is of interest to know if all the differences in drying defects by treatment type are statistically significantly different at the 95% significant level. The null hypothesis (H_0) is that a drying defect is the same across all treatment types. Because all the pre-drying treatments were conducted by packs instead of individual boards, it is also of interest to know if the packing causes any difference in drying defects. The probabilities that the F statistics are bigger than their critical values for a two-way ANOVA are listed in **Table 13**.

A probability smaller than 5% indicates that the difference of a particular drying defect is significant by treatment type or pack. All probability values for pack were smaller than 5%, indicating that all drying defects by pack were significantly different. These differences could be due to the positioning of the packs in pre-drying, air drying, and kiln drying. The probability for sapwood percent on the good side of the boards was slightly more than 5%, indicating that the difference among the sapwood percent by treatment type on the good side of the boards was not significant. The probability for sapwood percent on the bad side of the boards was zero, indicating that the difference among the sapwood percent by treatment type on the bad side of the boards was significant. The probabilities for sap stain percent and sap stain/sapwood percent on both sides of the boards were zero, indicating that the treatments caused significant difference in sap stain percent and sap stain/sapwood percent on both sides of the boards. On the other hand, the treatments did not seem to have affected the mineral stain, check/split, and number of sticker marks in any significant way.

Table 13. Probability of F-statistics for two-way ANOVA tests

Board Side	Grade Type	Prob > F	
		Treatment	Pack
Good Side			
	Sapwood (%)	5.18%	0
	Sap Stain (%)	0	0
	Sap Stain/Sapwood (%)	0	0
	Mineral Stain (%)	96.03%	0
	Check/Split (inches)	66.23%	0.31%
	Number of Sticker marks	100%	2.29%
Bad Side			
	Sapwood (%)	0	0
	Sap Stain (%)	0	0
	Sap Stain/Sapwood (%)	0	0
	Mineral Stain (%)	73.80%	0
	Check/Split (inches)	46.67%	0
	Number of Sticker marks	100%	0

Drying Degrade

Table 14 lists degrading due to drying defects by grade in board foot and **Table 15** lists degrading due to drying defects by grade in percentage. FAS and No. 1C grades in GWOD accounted for 87% of the total volume and were included in this degrading analysis. There was not enough volume of No. 2AC and No. 3AC in GWOD to analyze them in a statistically meaningful way.

The tables show that the NDP treatment type performed the best in reducing degrading. For all 2,073 bf of FAS GWOD lumber in this group, 2.1% was reduced one grade or more. For all 3,433 bf of No. 1C NDP lumber in this group, 3.1% was reduced one grade or more. The DP treatment type was the close second in reducing degrading. For all 561 bf of FAS NDP lumber in this group, 4.3% was reduced one grade or more. For all 808 bf of No. 1C GWOD lumber in this group, 3.8% was reduced one grade or more. As will be shown later, the difference in degrading between NDP and DP groups were not statistically significant.

The DNP treatment type was a distant third in reducing degrading. Among 402 bf of FAS GWOD lumber in this group, 11.7% was reduced one grade or more. Among 3,467 bf of No. 1C GWOD lumber in this group, 35.9% was reduced one grade or more.

Table 14. Degrading due to drying defects by grade

Unit: board foot

Dry Grade without Drying Defects (GWOD)	Dry Grade with Drying Defects (GWD)	DNP	NDP	DP	NDNP
		Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)
FAS	FAS	355	2,030	537	183
	No. 1C	30	30	24	86
	No. 2AC	17	0	0	41
	NO. 3AC	0	13	0	40
	ALL	402	2,073	561	350
No. 1C	No. 1C	2,223	3,327	777	256
	No. 2AC	664	80	13	147
	No. 3AC	580	26	18	132
	ALL	3,467	3,433	808	535

As expected, the NDNP treatment type fared far worse than the other three groups. Among 350 bf of FAS GWOD lumber in this group, 47.7% was reduced one grade or more. Among 535 bf GWOD lumber in this group, 52.1% was reduced one grade or more.

Table 15. Degrading percent due to drying defects by grade

Dry Grade without Drying Defects (GWOD)	Dry Grade with Drying Defects (GWD)	DNP	NDP	DP	NDNP
		Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)
FAS	FAS	88.3%	97.9%	95.7%	52.3%
	No. 1C	7.5%	1.4%	4.3%	24.6%
	No. 2AC	4.2%	0.0%	0.0%	11.7%
	NO. 3AC	0.0%	0.6%	0.0%	11.4%
No. 1C	No. 1C	64.1%	96.9%	96.2%	47.9%
	No. 2AC	19.2%	2.3%	1.6%	27.5%
	No. 3AC	16.7%	0.8%	2.2%	24.7%

The lumber value lost due to drying defects can be computed using the lumber degrading information and dry lumber prices by grade. The prices for kiln-dry 4/4" southern red oak lumber by grade in **Table 16** was for April 8, 2005, from Hardwood Review Express (Hardwood Publishing Company, Inc. 2005).

Table 16. Prices for kiln-dry 4/4" southern red oak by grade

Unit: $/MBF

Grade	Price
FAS	1470
No. 1C	795
No. 2AC	640
No. 3AC	537

The value lost due to drying degrade in **Table 17** was computed by applying the lumber prices by grade in **Table 16** to the lumber drying degrade percentages in **Table 15**. The NDP group had the least value loss due to drying degrade. It lost $16/MBF, or 1.1% of its original value, in the FAS GWOD grade and $6/MBF, or 0.7% of its original value, in the No. 1C GWOD grade. The DP group was a close second. This group lost $29/MBF, or 2.0% of its original value, in the FAS GWOD grade and $8/MBF, or 1.0% of its original value, in the No. 1C GWOD grade. Again, the differences between the first and second groups are not statistically significant. The DNP group lost $85/MBF, or 5.8% of its original value, in the FAS GWOD grade and $73/MBF, or 9.2% of its original value, in the No. 1C GWOD grade. The NDNP group lost the most value due to drying degrade. It lost $370/MBF, or 25.2% of its original value, in the FAS GWOD grade and $106/MBF, or 13.4% of its original value, in the No. 1C GWOD grade.

Table 17. Value lost due to drying degrade

Unit: $/MBF

Dry Grade without Drying Defects (GWOD)	Dry Grade with Drying Defects (GWD)	DNP	NDP	DP	NDNP
		Dipped, non-Processed	Non-dipped, Processed	Dipped and Processed	Control Group (No treatment)
FAS		1,470	1,470	1,470	1,470
	FAS	1,298	1,440	1,407	769
	No. 1C	59	12	34	195
	No. 2AC	27	0	0	75
	No. 3AC	0	3	0	61
	Total	1,385	1,454	1,441	1,100
	Lost Value	85	16	29	370
No. 1C		795	795	795	795
	No. 1C	510	770	764	380
	No. 2AC	123	15	10	176
	No. 3AC	90	4	12	132
	Total	722	789	787	689
	Lost Value	73	6	8	106

Comparing the NDP group with the DNP group, the first group saved $69/MBF, or 4.8% of its original value, in the FAS GWOD grade and $67/MBF, or 8.5% of its original value, in the No. 1C GWOD grade. This means that compared to chemical dipping treatment, the Elder Process only will save $69/MBF, and $67/MBF for FAS and No. 1C grade red oak lumber, respectively, due to less drying defects and degrade.

Obviously, the differences among the groups of lumber with different treatments depend on both the difference in degrading and price differential among grades. The drying defects and degrade for the non-Processed groups (DNP and NDNP), as documented in the literature, are fairly sensitive to air drying conditions. Therefore, the changes in the air drying conditions may affect the comparison among the treatment groups. Also, changes in dry lumber price differential among grades affects the comparison among the treatment groups.

According to the practitioners in the hardwood lumber market, it is common practice to accept a certain proportion of lumber in a grade that does not meet the standard for that grade. Such a proportion can be as large as 8-10%. For example, a pack of FAS grade lumber with 10% No. 1C grade may still be accepted as all FAS grade lumber in a transaction. One may argue that such a practice has already been factored in the prices of the dry lumber. If 10% one-grade lower grade lumber was factored into the prices of FAS, No. 1C, and No. 2AC in **Table 15**, the lost value computed in **Table 17** would have increased slightly. For example, the value loss difference between the NDP group and the DNP group for FAS GWOD grade would be $76/MBF instead of $69/MBF. The value loss difference between the same two groups for No. 1C GWOD grade would be $71/MBF instead of $67/MBF.

The Relationship between Drying Degrade and Drying Defects

To analyze the relationship between drying degrade and drying defects, a fixed effect Ordinary Least Square (OLS) regression model is specified in **Equation 2**.

$$\boxed{\begin{aligned} &DEGRADE = \alpha + \beta_1 * GSTAIN + \beta_2 * GMIN + \beta_3 * GCHECK + \\ &\beta_4 * GSTICK + \beta_5 * BSTAIN + \beta_6 * BMIN + \beta_7 * BCHECK \\ &+ \beta_8 * BSTICK + \beta_9 * DNP + \beta_{10} * DP + \beta_{11} * NDNP \end{aligned}} \qquad \textbf{Equation 2}$$

The dependent variable DEGRADE represents the level of degrading, with a minimum number of 0 for no degrading and maximum number of 3 for degrading three grades. For example, if the dry grade without defects was FAS and the dry grade with defects was No. 1C, then variable DEGRADE is recorded as 1. The α is the parameter for the constant term, and the β s are the parameters for the independent variables. Variables GSTAIN and BSTAIN indicate the percent of sap stain on the good and bad sides of the board, respectively. Variables GMIN and BMIN indicate the percent of mineral stain on the good and bad sides of the board, respectively. Variables GCHECK and BCHECK indicate the check and split in inches on the good and bad sides of the board, respectively. Variables GSTICK and BSTICK indicate the number of sticker marks on the good and bad sides of the board, respectively. Dummy variables D1, D2, and D3 represent DNP, DP, and NDNP groups, respectively. A dummy variable is 1 for true, and 0 for false. The NDP group is the default case. Its dummy variable is omitted to avoid confounding of the dummy variables.

The estimated parameters of the OLS model are displayed in **Table 18**. The adjusted R^2 statistic of the model is 0.7673, indicating a good overall fit of the model. The t statistics show that most of the individual parameters are statistically significantly different from zero at a 95% confidence level.

Table 18. Regression results for the OLS model

degrade	Coefficient	Std. Err.	t-stat	P>|t|
constant	-0.018	0.011	-1.69	0.092
GSTAIN	0.019	0.000	48.35	0.000
GMIN	0.002	0.003	0.63	0.527
GCHECK	0.003	0.001	2.04	0.041
GSTICK	-0.008	0.021	-0.39	0.699
BSTAIN	0.003	0.000	9.86	0.000
BMIN	-0.001	0.002	-0.50	0.619
BCHECK	0.003	0.001	2.71	0.007
BSTICK	-0.011	0.013	-0.88	0.380
DNP	0.059	0.018	3.23	0.001
DP	0.043	0.025	1.72	0.085
NDNP	0.179	0.030	6.06	0.000

The t statistics show that the parameters of the variables GSTAIN, BSTAIN, GCHECK, and BCHECK are statistically significantly different from zero at a 95% confidence level, indicating that sap stain and checking on both sides of the boards contributed to drying degrade in a statistically significant way. The t statistics show that the parameters of the variables GMIN, BMIN, GSTICK, and BSTICK are not statistically significantly different from zero at a 95% confidence level, indicating that mineral stain and sticker mark did not contribute to drying degrade in a statistically significant way. The t statistics also show that the parameters of the dummy variables D1 and D3 are statistically significantly different from zero at a 95% confidence level, while the parameters of the dummy variable D2 is not. The result means that the degrading between the NDP group and the DNP group, as well as the degrading difference between the NDP group and the NDNP group are statistically significant, while the degrading difference between the NDP and the DP group is not statistically significant.

The estimated parameters show that sap stain on the good side of the boards had a dominant effect on causing drying degrade. Each percent of increase in sap stain on the good side of the boards caused the lumber to degrade by an average of 1.9% of one grade. Each percent of increase in sap stain on the bad side of the boards or each inch of increase in checking on either side of the boards caused the lumber to degrade by an average of 0.3% of one grade. The parameters of the dummy variable D1 mean that by choosing chemical dipping-only over Elder Process-only, the lumber degraded by an average of 5.9% of one grade. The parameters of the dummy variable D3 mean that by choosing no treatment over Elder Process only, the lumber degraded by an average of 17.9% of one grade.

Air Drying

Air drying is dependant on climatic conditions. When the temperature is high and the relative humidity is low, air drying occurs quickly. This is because wood loses or gains moisture until the amount it contains is in balance with that in the surrounding atmosphere. The amount of moisture at this point of balance is called the equilibrium moisture content (EMC) (Simpson 91).

The EMC depends mainly on the relative humidity and temperature of the surrounding air. Thus the EMC values found in **Table 19**, **Figure 20** and **21** were approximated using the following formula:

$$\boxed{M = \frac{1{,}800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1+K_1Kh+K_1K_2K^2h^2}\right]} \qquad \textbf{Equation 3}$$

where h is relative humidity (%/100), and M is moisture content (%).

For temperature in Fahrenheit,

$W = 330 + 0.452T + 0.00415T^2$

$K = 0.791 + 0.000463T - 0.000000844T^2$

$K_1 = 6.34 + 0.000775T - 0.0000935T^2$

$K_2 = 1.09 + 0.0407T - 0.000293T^2$

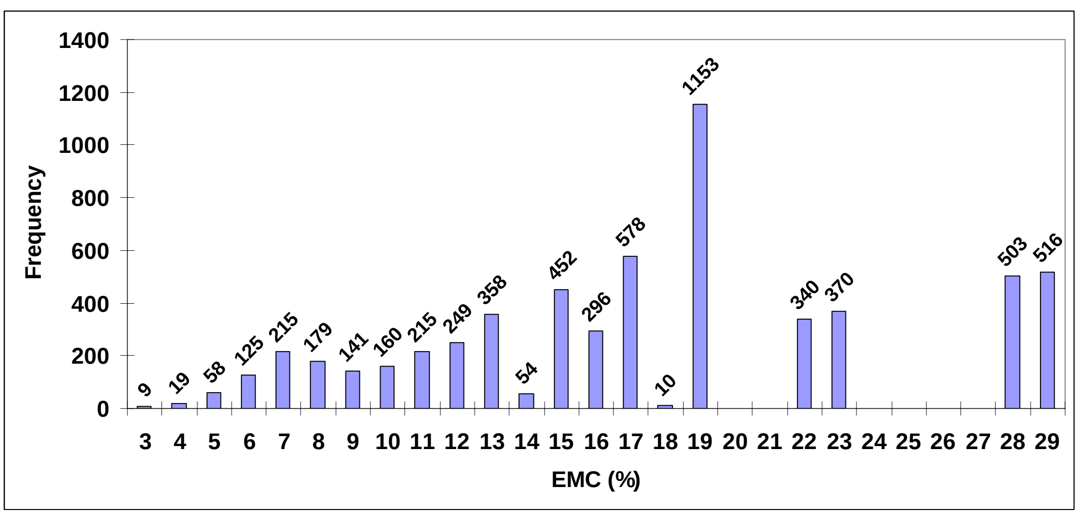

Figure 20. Distribution of equilibrium moisture content during air drying phase

The weather was cool and humid during air drying. **Figure 20** shows the EMC distribution from November 1, 2004 to January 30, 2005. One quickly notices that the EMC was higher than 18% almost half the time (47%), which would indicate poor air drying conditions.

Table 19 summarizes the temperature, relative humidity, EMC, and atmospheric pressure on a weekly basis. This data puts the effects of temperature and humidity in perspective and allows one to observe how relative humidity affects EMC.

Table 19. Weekly average weather conditions

Period	Temperature (ºF)	Humidity (%)	EMC (%)	Pressure (in)
11/01/04 - 11/07/04	60.9	77	15.2	30.09
11/08/04 - 11/14/04	60.1	73	14.1	30.22
11/15/04 - 11/21/04	66.3	83	17.2	30.16
11/22/04 - 11/28/04	59.0	75	14.6	29.97
11/29/04 - 12/05/04	54.2	78	15.6	30.14
12/06/04 - 12/07/04	58.4	72	13.8	30.00
12/13/04 - 12/19/04	44.6	71	13.7	30.40
12/20/04 - 01/07/04	42.6	79	16.1	30.17
12/27/04 - 01/02/05	58.5	89	20.2	30.31
01/03/05 - 01/09/05	57.1	90	20.8	30.24
01/10/05 - 01/16/05	56.0	88	19.7	30.24
01/17/05 - 01/23/05	47.2	75	14.8	30.35
01/24/05 - 01/30/05	49.4	84	20.6	30.14

Figure 21 shows the air drying curves for the DP group lumber, the DNP group lumber, and the EMC. Although the initial moisture content (84%) of the non-Processed lumber was higher than the Processed lumber (80%), the air drying rates for all boards were similar. There was no significant difference in drying rate between Processed and non-Processed lumber. The lumber reached a moisture content of approximately 33% after 88 days of air drying. The cool and humid weather condition explains the slow drying rates. It is interesting to note the relationship between the equilibrium moisture content and the drying rates – the drying rate slowed as EMC rose.

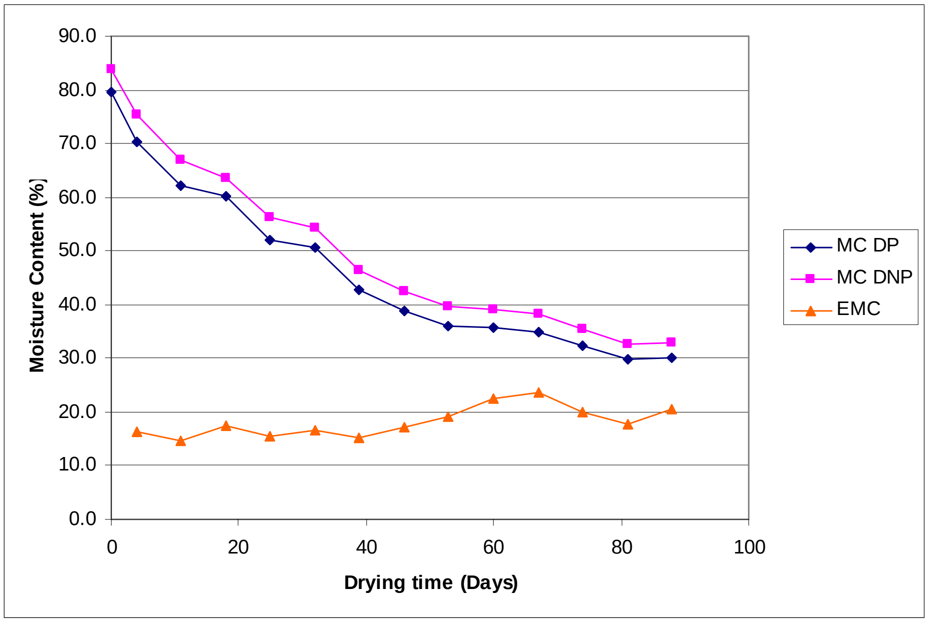

Figure 21. Air drying curves for Dipped Processed and Dipped non-Processed lumber

Figure 22 shows the drying curve for the lumber from 33% MC to 6% MC. The curve is linear, which indicates that water moved through the lumber at a constant rate.

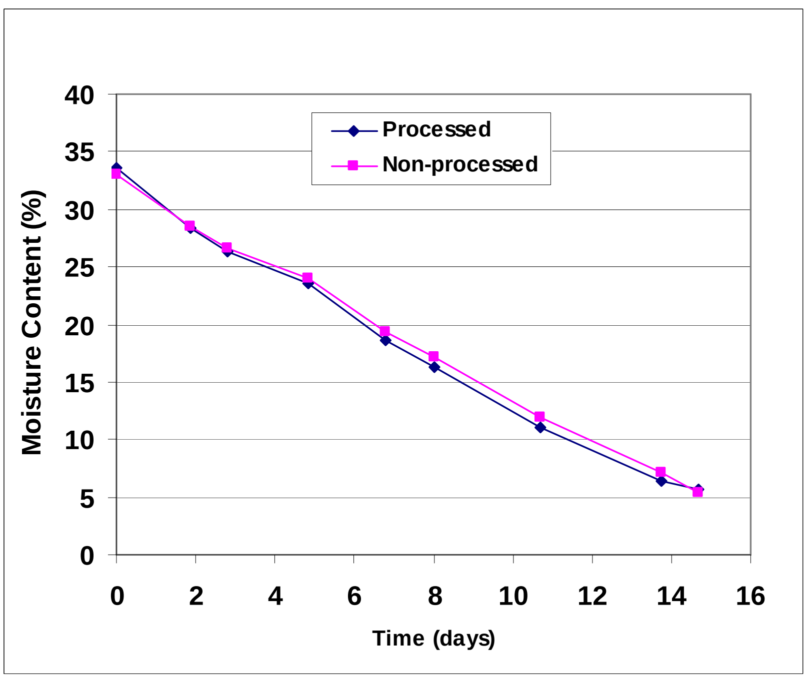

Figure 22. Drying chart for Processed and non-Processed lumber

CONCLUSION

The color readings using the CIELAB color space for the pre-drying treatments clearly showed that the Elder Processed lumber had a brighter color with an orangey tint in the sapwood. This was closer to the color of the heartwood and showed improved color consistency between the sapwood and heartwood. The ΔE2000 color values between treatment groups showed that the Elder Process had a significant effect on sapwood color changes during lumber drying while chemical dipping did not. Heartwood color was not affected by treatment. Although the Elder Process used in this study enhanced the color of sapwood to more closely resemble the color of heartwood, the colors of heartwood and sapwood remained different. A study on changing the parameters of the Elder Process to further enhance the color of the sapwood might be beneficial.

The Elder Process was very effective in minimizing enzymatic stain on sapwood and reducing drying degrade. The chemically dipped-only treatment had little effect in combating enzymatic stain on sapwood and drying defects, and the combination of chemical dipping and the Elder Process did not have significant advantage over the Elder Process-only treatment.

The ability of the Elder Process to reduce drying defects over the chemical dipping treatment translated into potential financial gains. This study clearly showed that the Elder Process minimizes enzymatic stain and reduces drying degrade. The potential financial gains from the reduced drying defects and degrade may help the southern hardwood industry compete more effectively with northern hardwood and Appalachian hardwood industries that have less enzymatic stain problem. However, the financial gains from this study were theoretically calculated based on the difference in drying degrade among treatment groups. Further study on the market acceptability of the Elder Processed lumber is necessary to better understand the real financial gain.

The air drying stage of the tests was conducted in a drying shed, which was subject to the particular weather conditions at the time. The air drying conditions were less than ideal because of insufficient airflow in the drying shed and the often-humid climate. This means that it is possible for the non-Processed groups to receive less enzymatic stain than they did in this test. On the other hand, this test showed the effectiveness of the Elder Process despite the poor air drying condition. Also, the test was conducted during a cooler winter season, a time that is more favorable to air drying than the hot, humid East Texas summer time.

The comparison of air drying rates for the two groups of lumber (DP and DNP) did not show that the Elder Process had any significant effect on air drying rate. However, since air drying is dependant on climatic conditions, this conclusion may not apply to air drying under a different climatic condition.

Finally, sweetgum is a major hardwood species in East Texas. Anecdotal evidences suggested that the Elder Process might have the potential to substantially reduce drying defects for sweetgum lumber, which is susceptible to excessive warping and cupping during the drying process, making it a more valuable product. A study to evaluate the benefits of the Elder Process on drying sweetgum lumber and thus making it a more valuable product is warranted.

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