DRYING OF SUBMERCHANTABLE LENGTH LUMBER

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Between the years of 1980 and 1993, the volume of timber offered for sale by the US Forest Service declined by just over 60 percent nationwide (Farnham and Mohai, 1995). Because of the inability of harvests from private land to provide enough additional stumpage, the raw material volume available to industry has been significantly impacted (Adams and Haynes, 1990). At present, the majority of private US timber stock is of a submerchantable age class. Within the next 50 years, this vast resource will be increasingly harvested as it reaches rotation age (Adams and Haynes, 1990, 1991). Efforts to utilize the existing resource more efficiently will intensify as the average age of harvested timber decreases leading to an increase in mill residue as well as the proportion of pieces containing defects and juvenile wood. This situation presents an opportunity for value-added manufacturing because finger-joined reconstitution of mill residue could potentially multiply its value ten-fold over pulp chips (Rohl, 1995). At present time, the majority of this trim-end waste is converted to pulp chips.

Young, small, fast-grown trees are being increasingly used by the lumber manufacturing industry for the production of dimension lumber. The processing of small logs presents some unique problems and opportunities related to wood and lumber quality. Small logs have a high surface area to volume ratio which leads to higher production of boards with wane that must be trimmed. The higher degree of taper present in the log also contributes to an increased incidence of wane when compared to traditional mature saw timber.

If a cost effective method could be developed to reconstitute these trim ends into dimension lumber, the proportion of high quality mature wood recovered from any given small log could increase significantly. Not only is the fiber quality of this wood excellent, these ends also tend have a smaller percentage of knots. Studies have shown that lumber produced from mature wood has significantly higher values for the modulus of elasticity and rupture than that produced from mature wood (Barrett and Kellogg 1991, Kretschmann and Bendtsen 1992, MacPeak et al. 1990, Tang and Pearson 1992, Zhou and Smith 1991).

While systems exist for gluing undried material (Garver, 1998), for a chop-stock or trim-end joining process using a conventional glue to be successful, the moisture content of the raw material must first be reduced to an acceptable level. Since much end-trim is green, especially for Douglas-fir, one must have an

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1 Currently Quality Control Field Analyst for P & M Cedar Products in Redding, CA. The authors wish to thank Swanson Superior of Noti, OR and CSI Carter Sprague for their cooperation in this study.
understanding of how piece geometry affects drying and how to configure kiln charges to fit in readily accessible, existing lumber drying equipment.

The objectives of this work were to determine the influence of piece length, width, and spacing on the drying properties of submerchantable length dimension lumber. Two methods for drying submerchantable length dimensional lumber within a common dry kiln are also presented.

Procedure

Effect of Piece Geometry on Drying Rate

Sample preparation

Two batches of 16-foot, Douglas-fir, nominal two-by-four-inch, two-by-six-inch, and two-by-eight-inch lumber were obtained, with enough lumber in each batch for two kiln charges. A 16-foot board was cut into blocks 0.5, 1.0, 1.5, 2.0, 2.5 and 3.5 feet in length. At each end of the board, 2.5 feet were discarded to reduce any influence of end drying of the lumber during transport and handling. Blocks were cut from the boards in order of sample length from left to right. On successive boards, the beginning sample length was shifted one to the right. For example, if a 0.5-foot sample was cut first from board one, then a 1.0-foot sample would be cut first from board two and a 1.5" sample cut first from board three, and so forth.

Each individual block was weighed. The percent heartwood was estimated for each block based on natural color differences on the end grain. Growth ring spacing was measured for each block at the center of its cross section. Finally, the distance of the block was from the pith in the tree was estimated based on the radius of a circle matching the ring curvature. In addition to the manufactured blocks, eight-foot long lumber in each of the three widths was used was quantified and handled like the blocks.

Charge Formation

Blocks were placed within four-by-eight foot, self-stickering, aluminum racks (FIGURE 1). These allowed the blocks to be stacked in a configuration similar to that used to dry long lumber. Two of the racks were used for each lumber width in each charge, one with the blocks butted tightly together and the second with the blocks spaced 0.375 inches apart to test the effect of moisture loss from the end grain of the blocks.

One series of samples from a sixteen-foot board in each rack received sets of shell and core resistance probes to monitor moisture content during the drying process. Core moisture content pins were installed 0.75-inch deep and the shell moisture content pin was driven 0.375 inches into the sample. Pin sets were centered within the face of each block. The shell and core moisture content values were averaged to estimate the overall moisture content of the block and the block moisture contents were averaged to estimate charge moisture content.
FIGURE 1. Diagram of rack. The racks contained twelve, eight, or six slots across their 4-foot face to accommodate 4-, 6-, or 8-inch wide lumber, respectively.

A completed charge consisted of thirteen courses orientated on the kiln cart as shown in FIGURE 2. Courses one, two, twelve and thirteen were eight-foot long green two-by-six lumber which were included as buffer layers. This was done to provide for more uniform conditions within the sample courses. Courses three and four were eight-inch-wide blocks stacked tightly and with a 0.375 inch end space, respectively. Layer five consisted of a course of eight-foot-long, eight-inch-wide lumber used as a comparison. Similarly, courses six, seven, and eight followed the same pattern but contained six-inch-wide lumber while courses nine, ten and eleven contained four-inch-wide lumber. Four separate charges were constructed in this manner.

FIGURE 2. Diagram of charge course configuration for the determination of piece geometry on drying.
Drying

The kiln employed in the research was steam heated, had a 1000-board-foot capacity, reversible fans, and a Foxboro pneumatic controller. Two charges were dried using the United States Department of Agriculture (USDA) schedule for high-grade dimension Douglas-fir while the remaining two charges were dried using the USDA schedule for low grade Douglas-fir (#291 and #294 in Boone et al., 1988). The airflow direction was reversed every six hours.

At the conclusion of each kiln run, blocks were weighed and qualitatively examined for defects. They were then placed in an oven at 217°F until the weight of several of larger blocks had become constant over a twelve-hour period. At this point the samples were again weighed in order to back calculate beginning and ending moisture contents on a dry basis.

Methods of Charge Formation

To obtain information for the second objective, the effect of drying method, actual trim ends were obtained from a local mill. This was nominal two-inch-thick by four- and six- inch-wide material. The initial weight, percent heartwood, ring count, and distance from the pith were measured for each trim end as before. In addition, the length of each was measured. Equal board footage of four- and six-inch-wide material were utilized for each charge in this phase of the study. Schedule #291 from Boone et al., (1988) was used. At the conclusion of each kiln run, the trim ends were weighed and qualitatively examined for defect. They were then oven dried and reweighed.

Aluminum Racks

Trim ends were placed in the appropriately sized aluminum rack. Thirty-two sets of moisture meter probes were randomly assigned to trim ends, eight within each rack. The order of the layers was the same as in the first set of experiments except that no courses of eight-inch wide material were utilized. Two charges were dried in this manner.

The Wire Mesh Box

A box four feet on each side constructed of plywood and 2-inch by 4-inch wire mesh was used to hold a kiln charge. The kiln air passed through the wire mesh, then through the trim ends. Plywood sides perpendicular to wire mesh sides facilitated unidirectional air flow (FIGURE 3). The wire mesh box allowed trim-ends to be randomly piled rather than stacked in racks.

The wire mesh box was loaded by alternating samples from four and six inch stock which resulted in a charge that had each width distributed throughout the load. Trim ends were randomly tossed into the bin to simulate possible mechanical loading at the manufacturing site. Thirty sets of moisture meter probes were placed in blocks which were randomly distributed within the pile.
Data Analysis

Final moisture content for each block was converted to a normalized moisture content because of board-to-board variability as well as variability in initial and final moisture content among the charges. The normalized moisture content of a block was a ratio of the mean final moisture content of its parent board expressed as

\[ N = 100 \times \frac{MC_f}{MC_{avg}} \]

Where:
- \( MC_f \) = Final moisture content of sample block
- \( MC_{avg} \) = Average final moisture content of all sample blocks from parent board
- \( N \) = Normalized final moisture content ratio

A one-way analysis of variance (ANOVA) was used to test for differences in wood characteristics among charges in each of the two phases of the experiment. The effects of length, width, and spacing of blocks in each charge were analyzed using a three-way general linear model in SAS. An ANOVA was also used to analyze final moisture content differences between the methods of charge formation. Significantly different means were determined and categorized using Tukey’s Studentized Range Test.
Results and Discussion

EFFECT OF PIECE GEOMETRY

Wood Characteristics

The overall wood characteristics for the blocks utilized to determine the effect of piece geometry on drying are shown in TABLE 1. There were differences among the charges for each property at the 95 percent confidence level.

TABLE 1. Wood properties by charge. Superscript letters indicate Tukey grouping. Averages with same letter are not significantly different.

<table>
<thead>
<tr>
<th>Shipment</th>
<th>Charge</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Pith distance, in</td>
<td>2.0^A</td>
</tr>
<tr>
<td></td>
<td>Ring count, in.^^1</td>
<td>5.9^A</td>
</tr>
<tr>
<td></td>
<td>Heartwood, %</td>
<td>47^A</td>
</tr>
<tr>
<td></td>
<td>Initial MC, %</td>
<td>59^B</td>
</tr>
</tbody>
</table>

The distance from the pith for the lumber in charge three was found to be significantly different than that in charges one and two. It is likely that the log size was larger when the wood for charges three and four was obtained. The ring count in charges one and three as well as charges two and four had similar means. The heartwood percentage in charge one was less than that in the other charges while in charge four it was greater than in charges one and three. If log size was indeed larger for the second shipment of lumber it could also explain the tendency for the third and fourth charges to have a higher mean average heartwood.

One of the most important factors affecting the final moisture content of kiln dried wood is its initial moisture content. Charges one and three were not significantly different while charges two and four stood apart from any of the other three. Charges one and three were both composed of fresh lumber which was processed on the day it was shipped from the mill. The lumber for charges two and four was stored for one week prior to processing. Though the wood was tarped and kept shaded it was not refrigerated or frozen so moisture loss was inevitable. Weather differences between storage times is the likely explanation for the lower moisture content of charge two relative to charge four.

Length Effect

The difference in final moisture content among sample lengths was statistically significant for every charge; however, the differentiated groups were those on the extremes of the length range. For example, the 0.5 foot samples were often drier than the others while the 8-foot boards were wetter. The actual
moisture contents are shown in FIGURE 4. Differences are attributable to the length effect because the wood selection method resulted in uniform properties among the lengths. For example among the block lengths, pith distance varied from 2.1 to 2.3 in., heartwood varied from 61 to 64%, and initial moisture content from 48 to 50%. Ring count was 5.3 in.\(^1\) for all block lengths. For the eight-foot boards, these properties averaged 2.8 in., 6.8 in.\(^1\), 52%, and 55%, respectively, indicating that the eight-foot boards were not as representative of the blocks as desired.

Within the above analysis the variability in moisture content from one 16-foot parent board to another tends to hide some of the moisture content variability with length. The normalized moisture contents (FIGURE 5) remove this effect and clearly indicate that pieces less than 1.5 feet in length dry faster than the longer pieces. The 0.5 and 1.0 foot pieces are each unique from the other lengths. Drying these shorter pieces separately would provide a more uniform moisture content if this was necessary for a given product. There would probably be no benefit to sorting the pieces longer than 1.5 feet.

FIGURE 4. Average final moisture content by charge and length.

It can be expected that the variation in moisture content among lengths (and pieces in general) will be reduced as the wood gets drier because the drying rate of wood decreases as it approaches the equilibrium moisture content. This can be seen in FIGURE 4 where the length affect appears to be greater at higher moisture contents. The 6-12 percent moisture content to which the experimental charges were dried could be expected to reduce observable variation due to length compared to a charge dried to, say, 15 to 18%. The lower moisture contents are, however, somewhat similar to those desired for finger-jointing so these observations should provide some practical insight.
Width Effect

Statistical differences in final moisture content were detected among the three widths for all charges. For example, the final moisture content of the six-inch-wide material was significantly greater than the four- or eight-inch-wide material for charges one and two (TABLE 2). However, the initial moisture content of this material was also higher confounding any width effect. In each charge the width with the highest initial moisture content also had the highest final moisture content. This suggests that sorting the blocks by width for drying is less important than sorting by initial moisture content.

TABLE 2. Initial and final moisture contents by width and charge. Superscript letters indicate Tukey grouping. Averages with same letter indicate no significant different in moisture content due to width.

<table>
<thead>
<tr>
<th>Shipment</th>
<th>Final Moisture Content, %</th>
<th>Initial Moisture Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Width</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>four-inch</td>
<td>8.5A 7.8A 7.8A 7.8A</td>
<td>58.6 32.8 63.3 60.9</td>
</tr>
<tr>
<td>six-inch</td>
<td>12.2B 9.0B 7.5A 7.0B</td>
<td>70.8 42.8 42.5 31.7</td>
</tr>
<tr>
<td>eight-inch</td>
<td>9.2B 8.0B 7.1B 5.7C</td>
<td>29.4 24.5 60.6 37.5</td>
</tr>
</tbody>
</table>

FIGURE 5. Normalized final moisture content by length.
Block spacing was a statistically significant effect for charges one and three (TABLE 3) resulting in moisture contents of 11.0 and 8.8% in charge one and 7.9 and 7.1% in charge three. These were subjected to different drying schedules, but both were composed of fresh lumber stacked on the day it was obtained from the mill. The predrying that occurred in charges two and four probably reduced final moisture content variability as did the lower final moisture content.

TABLE 3. Effect of spacing. Superscript letters indicate Tukey grouping. Averages with same letter indicate no significant different in moisture content due to spacing.

<table>
<thead>
<tr>
<th>Shipment</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Space</td>
<td>8.7A</td>
<td>8.1A</td>
</tr>
<tr>
<td>No space</td>
<td>11.0A</td>
<td>8.2A</td>
</tr>
</tbody>
</table>

Charge Formation

Wood Characteristics

The characteristics of the wood utilized are summarized in TABLE 4. An analysis of variance showed significant differences at the 95 percent confidence level among all class variables shown in TABLE 4. The mean trim-end length in the wire mesh box was 19.7 versus 21.7 in the racks. In each case, the distribution of length was skewed to the right (24.0 maximum). Trim saws in the source mill (as in most mills) have their drop saws set at 24.0 inch intervals. Trim decisions often result in the removal of additional two foot sections to meet a cutting order.

TABLE 4. Wood properties summary for the charge formation tests. Superscript letters indicate Tukey grouping. Averages with same letter are not significantly different.

<table>
<thead>
<tr>
<th>Charge</th>
<th>Rack 1</th>
<th>Rack 2</th>
<th>Box</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>21.9A</td>
<td>21.4A</td>
<td>19.7B</td>
<td>20.8</td>
</tr>
<tr>
<td>Initial MC, %</td>
<td>59A</td>
<td>55A</td>
<td>46B</td>
<td>58.6</td>
</tr>
<tr>
<td>Heartwood, %</td>
<td>42A</td>
<td>44A</td>
<td>57B</td>
<td>49.4</td>
</tr>
</tbody>
</table>

Scatter plots indicated no trends in initial or final moisture content with piece length and the first part of the study indicated that piece length in that range does not affect final moisture content. The percentage of heartwood was higher, 57 versus 43%, and initial moisture was lower, 46 versus 57%, for the wood in the wire mesh box compared to the rack charge, again, without any explainable cause.

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Drying

The analysis of variance showed a significant difference among all three mean final moisture contents. It's likely that the wood characteristics and drying method both influenced the final moisture content of all three charges. Of greater interest is the standard deviation of the pieces in each charge. Since standard deviation of moisture content decreases as moisture content decreases, the standard deviations among the charges should not be compared directly.

FIGURE 6 shows the standard deviation of moisture content at various moisture content ranges for both phases of this project. First, it can be seen that the standard deviation of moisture content is less for the manufactured blocks than for the actual end-trim. More importantly, however, the trend in standard deviation with moisture content is the same in both cases. This leads to the observation that the standard deviation of moisture content for the wood dried in the wire mesh box is comparable to that of the wood dried in the racks if the moisture content difference is accounted for. Thus, from a moisture content variability perspective, the wood dumped into the box dried as well as the wood in the racks.

FIGURE 6. Standard deviation versus moisture content for the manufactured blocks and the actual end trim. Drying method is indicated for the actual end trim. Manufactured end trim was rack-dried.

No visible defects, such as end checks, surface checks, or collapse were noted on the samples in the racks or the box. Douglas-fir, however, is a very easy species to dry. Hemlock, the true firs, or hardwoods may give different results.
Charge Size Analysis

A comparison of space efficiency shows that for a charge composed of equal parts four- and six-inch-wide lumber, the rack system held 9.1 nominal board feet per cubic foot of kiln space while the wire mesh box held 5.7 nominal board feet per cubic foot of kiln space. This indicated that the racks will allow 60% more material to be placed in a kiln. The wood in the box did reach a lower moisture content more quickly, however, this could be the result of airflow. The average air velocity was approximately 400 feet per minute through the sticker slots in the racks and approximately 275 feet per minute through the box. The random nature of the wood in the box, however, makes it difficult to determine the actual volume of airflow though the box for comparison to the rack. Any cost comparison between the box and rack systems should account for lower production volume through the kiln that is likely with the box system.

Conclusions

Simulated end trim created from full-length lumber results in blocks that are more uniform in properties than real end trim. This reduction in wood variability allows kiln factors to be studied with greater success.

Length affects the final moisture content of each individual piece for pieces less than 1.5 feet in length. It might be beneficial to sort these short lengths and dry them separately; however, the influence of other variables such as initial moisture content may be more significant. With a relatively large amount of exposed end grain, these pieces would be likely to rapidly gain moisture if stored with longer pieces with greater moisture contents.

Providing a space between blocks can significantly accelerate the drying rate in fresh lumber.

Choosing between a rack system and the wire mesh box for drying short pieces in a conventional kiln should be a carefully weighed decision. Although they performed comparably during the drying process, the loss of space efficiency exhibited by the wire mesh box, 38%, is great and must be factored into a cost analysis.

Bibliography


