# Forest products laboratory: Supporting the nation's armed forces with valuable wood research for 90 years

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# JOURNAL FOREST PRODUCTS

## Wood Use By Ohio's Amish Furniture Cluster

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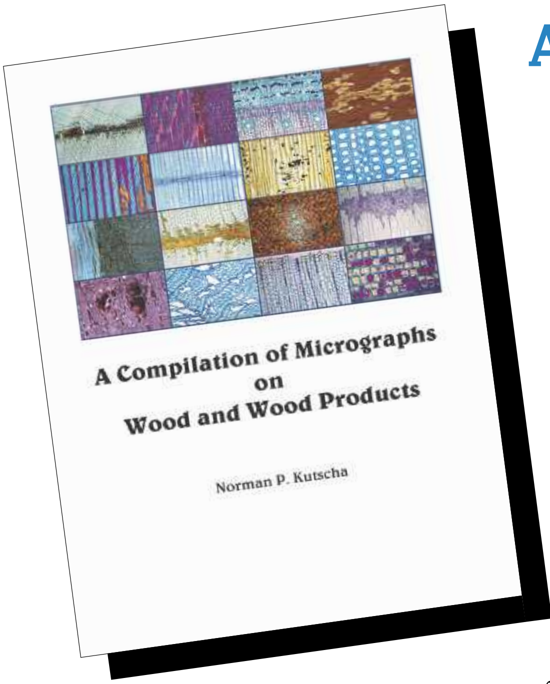


# A Compilation of Micrographs on Wood and Wood Products

by Norman P. Kutscha

Preparing a sample of wood for microscopic examination is as much an art as it is a science. Anyone who has examined a thin section of wood under a microscope realizes that the cellular structure observed can readily be referred to as "cellular architecture."

The purpose of this compilation is to illustrate some of the better or more interesting micrographs of wood and wood products the author has observed during his career as a wood scientist and wood anatomist; secondly, to illustrate a few examples of how the microscopic examination of wood and wood products can help diagnose and solve problems related to the development or manufacture of wood products; and finally, to list selected references.

This compilation will be of interest to wood products mills trying to solve process problems or dealing with customer complaints; wood products researchers trying to develop new or improved wood products; wood scientists and anatomists who have examined wood and wood products at the microscopic level; and the general public, including those who work with wood, those who do not, and those who have never seen a piece of wood under a microscope.

A CD-ROM of the images is also included. *Copyright 2007, 8-1/2 by 11 spiral bound, 98 pages, #7225*

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FOREST PRODUCTS JOURNAL





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TO FOSTER INNOVATION AND RESEARCH IN THE ENVIRONMENTALLY SOUND PROCESSING AND USE OF WOOD AND FIBER RESOURCES BY DISSEMINATING INFORMATION AND PROVIDING FORUMS FOR NETWORKING AND THE EXCHANGE OF KNOWLEDGE.

# Letter from the Editor

**Dear Reader,**

This issue marks the completion of my first year as Editor of the *Forest Products Journal*. For me, it has been a year of continuous education, learning new things and skills and relearning things and skills that have lain unused for decades. For me, the biggest surprise has been the frequency with which reviewers disagree—often strongly—about a paper's suitability for publication. In some cases, such disagreements appear to grow out of conflicting perspectives about the *Journal* and its mission. We'll work on clarifying that in months to come.

For the *Journal*, it has been a year of change aimed largely at enhancing the publication's usefulness to our readers and authors. The November issue, for example, with a guest editorial and a comprehensive report on the Northeast Section's Bio-products Conference, revives *Journal* features from years past. Such articles can create value for our readers only to the extent that members submit material.

One experiment that is proving very successful has been the switch to using e-mail to distribute papers to peer reviewers. This has greatly accelerated the peer-review process. It has also made it easier for authors; we now ask authors to submit only one hard copy along with the electronic copy of their papers. In the past we have also asked that authors for whom English is a second language have their papers edited by a native English speaker prior to submission. We still request this, but have begun to offer authors an economical, third-party academic editing service when needed.

We continue to look for articles of broad interest or that offer an unexpected perspective on some aspect of using forest biomass. Our feature article this month appears to be a narrowly focused report on the use of wood by Amish furniture makers in Holmes County, Ohio. But, beginning with the cover photo (ostensibly a typical Amish farm, but with a telltale sawdust collection system on one of the buildings), the article reveals important aspects of a business model and marketing strategy that appear to work successfully in the face of foreign competition.

Finally, we extend congratulations to long-time Forest Products Society member Ken Skog, project leader and scientist for the Economics and Statistics Research group at the USDA Forest Service's Forest Products Laboratory, who contributed significantly to two reports published by the United Nations Intergovernmental Panel on Climate Change (IPCC). The IPCC was named co-recipient, with former Vice President Al Gore, of the 2007 Nobel Peace Prize for their work related to global climate change. It is good to know that wood's role in carbon sequestration is gaining wide recognition.

With best wishes for a healthy and prosperous new year,

*George N. Couch*
Editor
george@forestprod.org

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# Wood Use By Ohio's Amish

By Matthew Bumgardner, Robert Romig, and William Luppold

Much has been reported regarding the decline of the U.S. wood furniture manufacturing industry. One segment that seems to be maintaining its competitiveness is the Amish-made furniture sector. The Amish traditionally have undertaken agriculture-related occupations (Stinner et al. 1989); however, as farmland has become increasingly scarce and expensive, and as the Amish population has grown, more are seeking opportunities in nonfarming occupations such as manufacturing (Lowery and Noble 2000, Amish.Net n.d. *b*). Amish-made furniture is an example of an emerging manufacturing sector, but like many Amish industries, one for which a dearth of information is available.

A large concentration of Amish furniture manufacturers operates in and around Holmes County, Ohio (Fig. 1). Holmes County includes the largest Amish settlement in the world; the Amish comprise nearly half of the county's total population (Lowery and Noble 2000). In 1973, only 3 percent of Amish heads of household in Holmes County were employed in the secondary wood sector; by 1997, this number had increased to 14 percent. These likely are conservative estimates as several furniture manufacturers were included in a broader manufacturing category. When combining overall manufacturing with primary and secondary wood manufacturing, nearly 35 percent of the heads of household in Holmes County were employed in these sectors in 1997, up from 16 percent in 1973. Agriculture-related occupations declined from 48 percent to 21 percent of Amish occupations in the county over the same period (Lowery and Noble 2000).

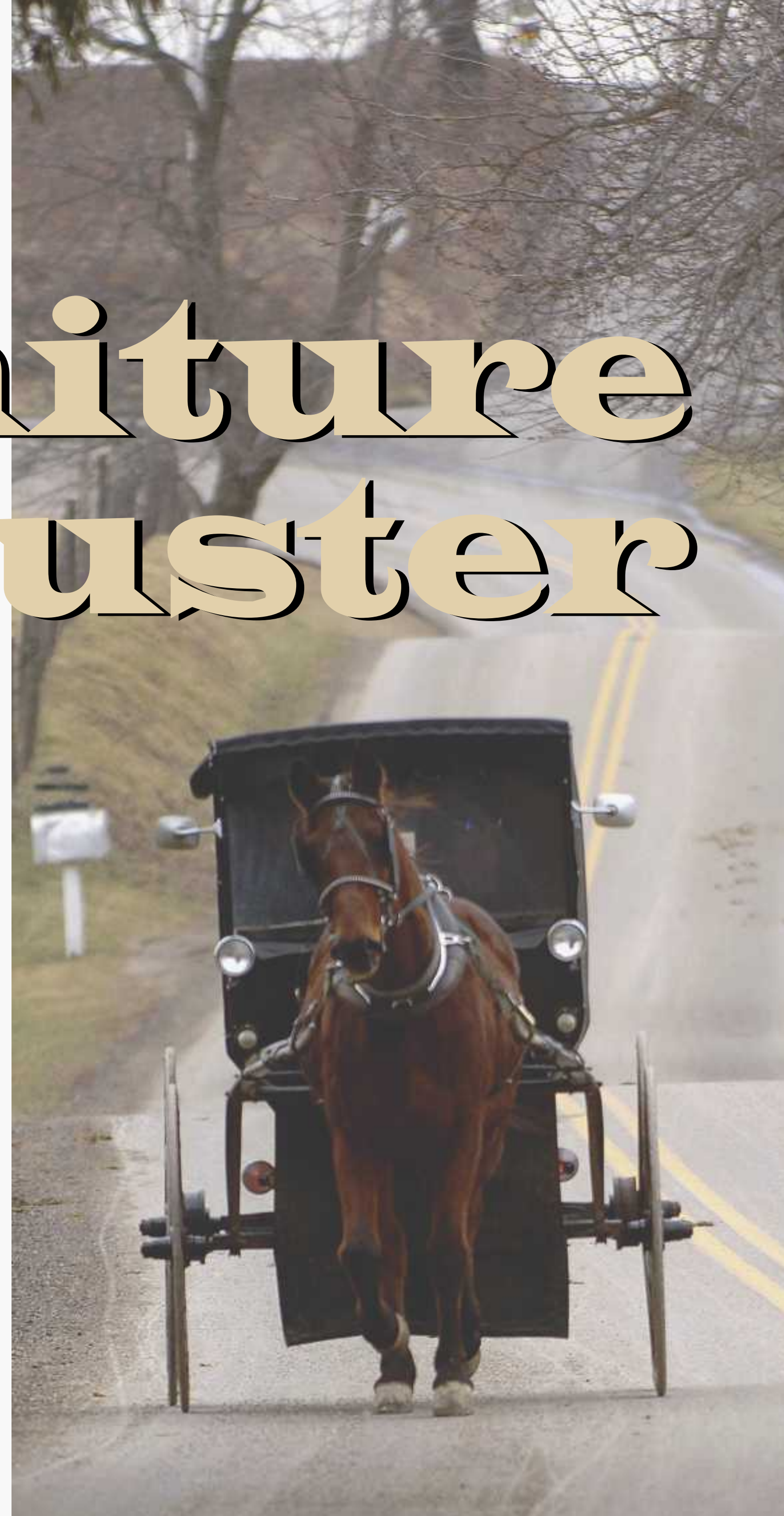
On the surface, the Amish furniture sector employs many aspects of competitiveness frequently listed as critical for the survival of domestic manufacturers (Bumgardner et al. 2004, Buehlmann et al. 2006). Amish furniture often is associated with quality craftsmanship and solid wood construction. The Amish label serves as a form of brand name with wide familiarity among consumers as a domestically made product. There also are dedicated Amish-made furniture retail stores located throughout the United States (Amish.Net n.d. *a*). In most of these stores, semi-customization is possible, allowing consumers to choose from different species (primarily oak and cherry, but also hickory, maple, pine, and walnut), finishes, and hardware for a given piece and design. The products are often locally or regionally sourced, and thus the customized requests are available with relatively short lead times.

It is evident that aspects of "clustering" are present with the concentration of Amish furniture manufacturers in Holmes County. Clusters can be defined as industries (manufacturers, suppliers, services, etc.) related to the same product existing in close proximity. But clusters are something more than mere concentrations of firms. Clusters also often include research and educational institutions, consultants, and other entities that help support the core industry. Clusters can be characterized as having well-developed supply chains, wide use of current technology, and intense competition among local firms (Schuler and Buehlmann 2003). In spite of the local competition, each cluster element reinforces the others and helps create a competitive advantage for all. For the Amish, competition is tempered by a sense of cooperation (National Hardwood Lumber Association 2007). For example, one reason Amish farms tend to be relatively small is that it makes more land available to other Amish farmers (Stinner et al. 1989). With furniture, cooperation can come from jointly designing and producing an entire furniture collection by individual manufacturers that specialize in chairs, or tables, or hutches, etc.

One example of a competitive advantage arising from furniture clustering in Holmes County is *Ohio Certified Stains*, a group of manufacturers that has worked with local suppliers to establish a collection of standardized stains. Each of the 15 colors within the system matches if bought from a participating supplier (Anonymous 2005). Thus manufacturers can offer consumers several stain options on retail floors and then conveniently source the colors selected. It also enables consumers to buy matching pieces at a later date.

Another example of clustering is found in distribution, as many of the dedicated Amish retail stores are located near the manufacturing centers in Pennsylvania, Ohio, and Indiana (Amish.Net n.d. *a*). Porter (1998) claims that cluster effects can extend downstream to channels and customers; i.e., distribution becomes part of the cluster and can generate competitive advantage. The Amish clusters of manufacturing and retail are proximate to several major population centers and, thus, potential markets. This is in contrast to other notable competitive furniture clusters (e.g., northern Italy and Denmark) where most of the production is export oriented (Schuler and Buehlmann 2003). To date, most consumption of Amish-made furniture has been domestic; conversations

# Furniture Cluster



with local manufacturers suggest distribution from the Holmes County cluster reaches nearly all 50 states.

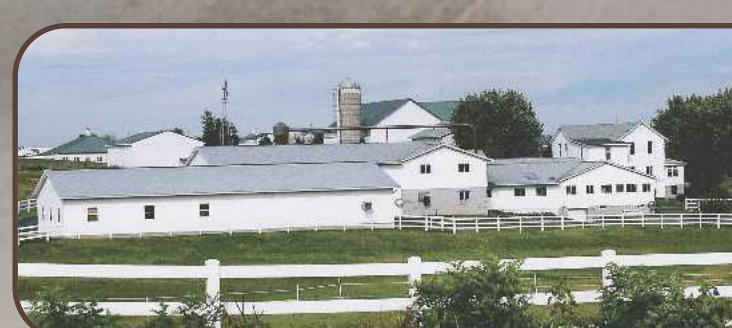
As the domestic furniture manufacturing industry continues to decline as a market for hardwood lumber, the Amish-based sector might become an increasingly important component. The question arises as to what influence this segment has on regional and national hardwood use. Little is known about the size of this industry segment or its impact on hardwood lumber demand. This study is a preliminary assessment of wood use by Ohio's Amish furniture industry in Holmes and surrounding counties.

## Methods

Data were collected from several secondary sources, including the 2005-2006 edition of *The Furniture Book: A Complete Guide to the Furniture Manufacturers and Wholesalers in Ohio's Amish Country* (Anonymous 2005). This guide (referred to hereafter as *The Furniture Book*) covers all known Amish establishments in Holmes County and portions of five surrounding counties. Data of primary interest included number of employees, year of establishment, and product descriptions. A meeting with four representatives from three Amish furniture manufacturers in Holmes County also was held to discuss the project and the assumptions made in determining wood use estimates; these manufacturers were larger in size and older in establishment age than the average Holmes County Amish furniture firm.

### Determining the number of firms

Each of the nearly 600 entries in *The Furniture Book* was analyzed. A total of 153 entries were removed because they were finishing and distribution firms, or manufacturers of lawn/outdoor furniture, bedding, upholstery, and crafts. Thus, 429 establishments were identified as manufacturers of household furniture, components, and related products such as grandfather clocks and jewelry cabinets. There also were some millwork and cabinet products included, but these were only occasionally listed compared to household furniture products. Discussion with local manufacturers indicated that a few firms listed in *The Furniture Book* had gone out of business; conversely, a few existing firms were not listed.



*Amish furniture shop & homestead near Mt. Hope, Holmes County, Ohio*


*Figure 1. — Location of Holmes County, Ohio.*

Consequently, the figures reported above reflect adjustments for unlisted firms and those no longer in business.

As a cross-reference to the listings in *The Furniture Book*, the *Secondary Directory of Ohio Wood Manufacturing Companies, 2002* (Romig et al. 2002), a directory compiled by Ohio State University and the Ohio Department of Natural Resources, was analyzed (referred to hereafter as the *Directory*). For Holmes County, 80 firms were listed that produced household furniture and related products. Of those, 67 firms, or 84 percent, also were listed in *The Furniture Book*. This suggests general agreement between the sources, although it is apparent that the number of listings in *The Furniture Book* was much larger than those in the *Directory*. It also can be noted that across a 3-year differential in reporting years, 63 percent of the firms with employment figures reported in both *The Furniture Book* and the *Directory* were within five employees (the average size from the *Directory* of the 19 firms with employment figures reported in both sources was 25.7).

## Development of employment figures

Employment data were available from *The Furniture Book* for 271 of the firms. For the 158 firms not reporting number of employees (including a small number added through discussion with local manufacturers but with unknown employment information), data were imputed. It was noted that many firms advertised in *The Furniture Book*. For firms with one, two, or three employees, the advertisement rate was about 25 percent. For firms with four employees, this figure jumped to near 50 percent, and was over 80 percent for firms with five employees. Very few of the firms with missing employment data were advertisers (n=1), so it was assumed that these firms tended to be small based on the advertising rates just described. These firms therefore were assigned employment values of one, two, or three employees in proportion to the prevalence of these figures among reporting firms. Given that the overall employment mean for reporting firms was 7.3 and the median was 4.0 (discussed more in the results section), these estimates seemed reasonable.

The cross-reference with the *Directory* provided employment figures for six nonreporting firms in *The Furniture Book*. For these firms, assigned employment (as described above) was replaced with the figure reported in the *Directory*. The range in reported employment for these firms was 8-65, somewhat higher than the assigned values (range 1-3). While it was believed that most nonreporting firms were small, obviously some were larger companies; thus, the overall employment figure might be slightly conservative. Also, discussion with local manufacturers provided estimates for 26 additional *Furniture Book* entries with missing employment data; and again these tended to be higher than the imputed values.

## Development of wood use ratios

Once a total number of employees was established, this figure was multiplied by an estimate of hardwood lumber use per employee as found in other furniture industry data sources. Employment in the wood household furniture industry, according to U.S. Department of Labor (2006) data, was divided by hardwood lumber use by the furniture industry, according to the Hardwood Market Report (2004, 2005, 2006) for the 5-year period of 2000-2004 (the latest year for which hardwood lumber use data were available). Using this method, the average wood use per employee per year over the period was 17,433 board feet (BF). The range was a maximum of 19,275 BF per employee in 2000 to a minimum of 15,012 BF per employee in 2004. The average figure (17,433 BF) was used in subsequent analysis; discussion with local manufacturers suggested this was a reasonable estimate. In considering the appropriateness of this ratio, the generally small and sometimes less mechanized nature of Amish firms (which might seem to make this ratio too large) must be balanced with the fact that most Amish furniture is constructed of nearly all solid wood, which is uncommon in the broader domestic furniture industry, where veneered surfaces and composite materials are frequently used and reduce lumber use per employee.

To generate a second ratio from a different source, data from a recent study of wood use in the furniture industry (for the year 2000) conducted at Mississippi State University (Seale et al. undated) was utilized. By estimating an average firm size (386 employees) from the reported distribution of responding firms and determining average lumber use per employee by combining reported average lumber use per firm (5,114 thousand board feet or MBF) and a conversion of average dimension use per firm (1,787 MBF) to lumber volume (2 x 1,787 MBF = 3,574 MBF, assuming a 50 percent conversion rate from lumber to dimension parts), a total of 22,508 BF per employee was derived. While slightly larger than the estimate reported above, the study was based predominately on larger furniture manufacturers and included both softwood and hardwood lumber and dimension. This second ratio thus was viewed as lending credence to the first.

# Results and Discussion

## Firm size and establishment

Ohio Amish furniture manufacturing firms employed an average 7.2 employees in 2005, (n=271, median=4.0) (Table 1). The average year of establishment was 1994.1 (n=278, median=1996.0). These figures suggest that the typical Amish furniture manufacturer in Ohio is small and relatively new. An illustration of the small nature of firms is found by observing advertising behavior. The average size of firms running full-page color ads in *The Furniture Book* was only 11.6 employees (n=27, median=8.5). The number of employees ranged from 1 to 105. Figure 2 shows the distribution of firm size, with an obvious skew to the right. The difference in the mean and median values for employment (median being smaller) also suggests a concentration of firms in the smaller employment categories. As described later, the small size of the typical Amish firm is offset by the shear number of establishments: 429 firms in an approximately 1000 sq. mile area, or roughly the size of two counties in Ohio.

The 1990s generally were favorable times for the overall U.S. wood household furniture industry, as shipments increased in real terms (constant 1982 dollars) from $6.3 billion in 1990 to $7.7 billion in 1999 (Luppold and Bumgardner, in press). Many Amish producers in Ohio entered the market around this time, based on the median establishment year of 1996. As shown in Figure 3, a plurality of the Amish firms present in 2005 were established in 1999, which also was the peak year for value of domestic furniture shipments. Since 1999, furniture imports have increasingly captured market share from domestic manufacturers; it seems this rise in imports negatively influenced the establishment rate of Amish furniture firms as well. On the other hand, 27 percent of the Amish furniture manufacturers operating in Ohio in 2005 were established since 2000. Porter (1998) claims that it takes about a decade for a cluster to establish depth and to realize a competitive advantage; from Figure 3 it appears that the majority of firms were established between 1989 and 1999; the cumulative distribution curve by establishment date also suggests a maturing cluster (Fig. 4). In sum, the Amish furniture cluster in Holmes County arose from an economic transition away from locally oriented agricultural occupations, due in part to an increasing population and decreasing land base for farming. As such, it increasingly operates within the parameters of the broader U.S. economy.

## Employment, wood use, and value of shipments

The total number of employees of reporting firms was 1,959; the total number of employees including imputed employment was 2,723 (Table 1). However, these figures included some known component manufacturers that supplied local furniture manufacturers. Their inclusion would inflate wood use estimates since the same wood would be double-counted — once for the employee at the component firm and once for the employee at the furniture firm. Discussion with local manufacturers identified several such firms, which were removed for generation of wood use estimates. The adjusted figures were 1,911 employees for reporting firms and 2,497 employees including assigned estimates. The latter figure, multiplied by the average consumption per employee for the overall furniture industry (17,433 BF) results in hardwood lumber use of 43,530,201 BF annually by the Amish furniture industry in Holmes and surrounding counties in Ohio.

As Ohio was listed by the USDC Census Bureau (2006) as producing 401 million BF (MMBF) of hardwood lumber in 2005, these results suggest that the Amish furniture industry consumes the equivalent of about 11 percent of the hardwood lumber produced in Ohio. Including only appearance-based uses (58 percent of total production excluding pallets

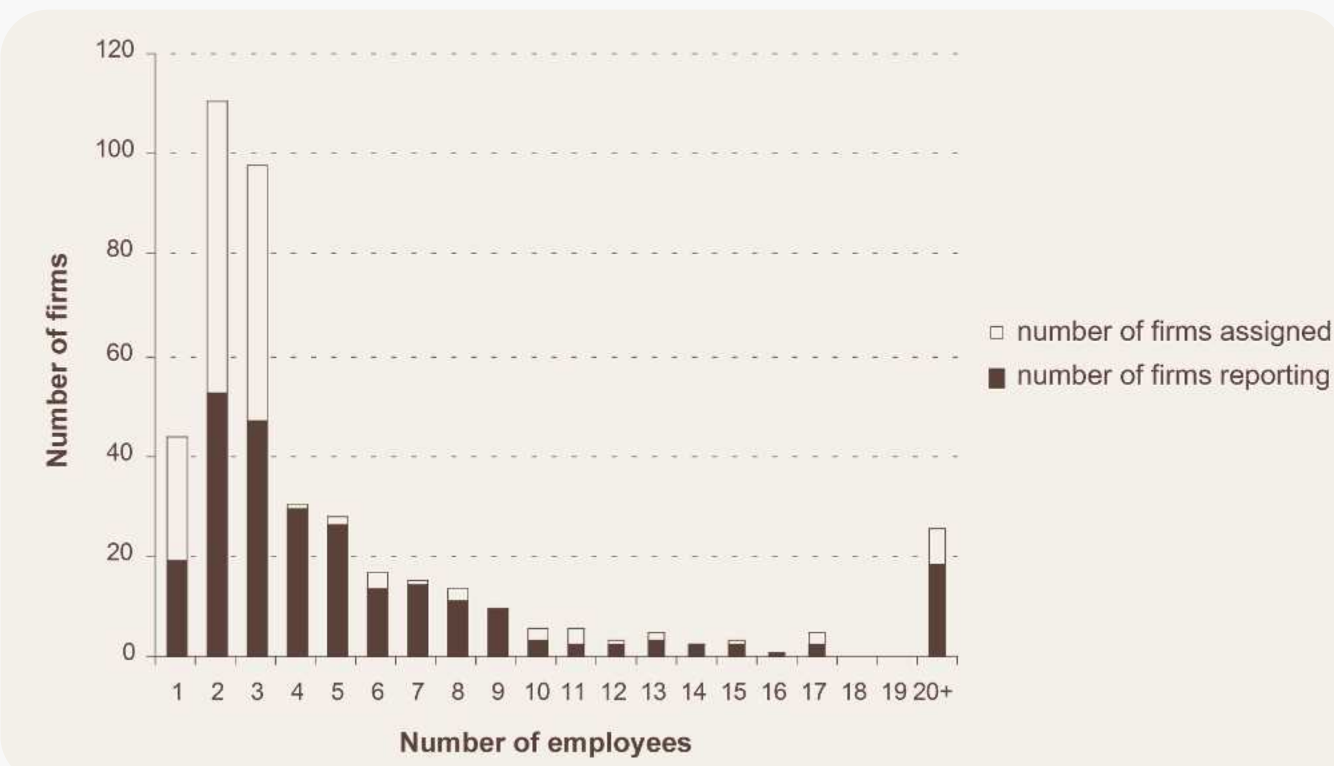



*Figure 2. — Distribution of establishment size for Amish furniture manufacturers in Ohio's Holmes County cluster. Solid bars represent reported employment figures (various sources); clear bars represent assigned employment.*

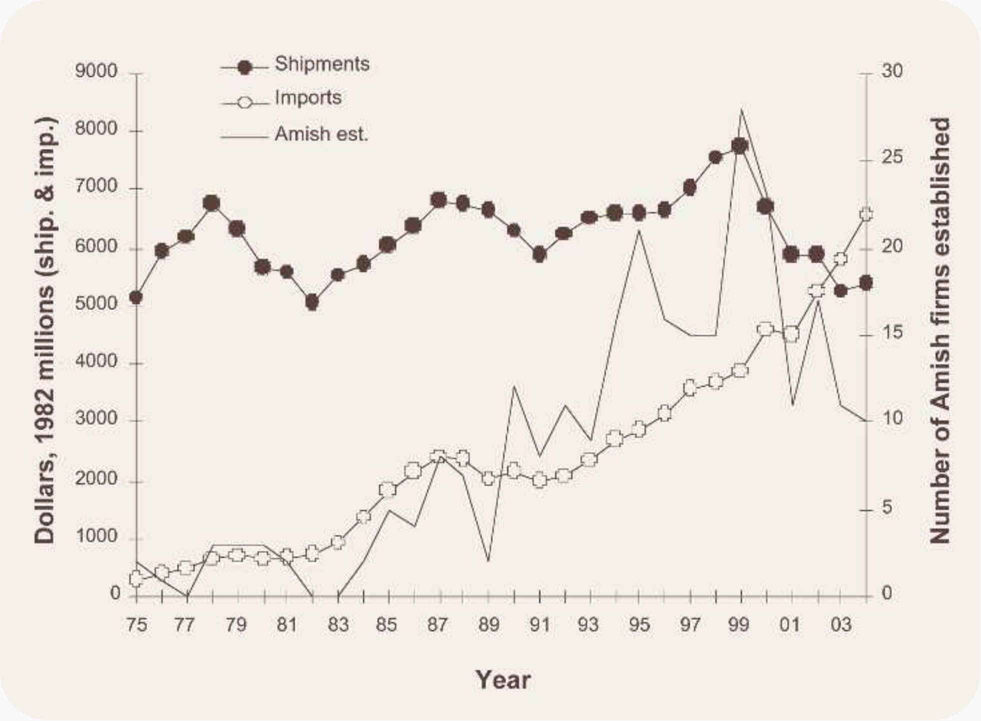



*Figure 3. — Value of overall U.S. wood household furniture shipments and imports by year (Luppold and Bumgardner, in press), and year of establishment for Ohio Amish furniture manufacturers in operation in 2005 (Anonymous 2005).*

and railway ties) (Hardwood Market Report 2006) results in consumption of the equivalent of nearly 19 percent of Ohio's grade lumber production. According to Census figures, Ohio ranked 13th nationally in hardwood lumber production in 2005, falling just behind Wisconsin, Michigan, and New York.

Value can be considered as another measure of impact. According to U.S. Department of Commerce data (Akers 2006), the value of shipments of wood household furniture in the United States in 2004 was $9,736.3 million. According to U.S. Department of Labor data (USDL Bureau of Labor Statistics 2006) employment in the wood household furniture industry was 86,600 in 2004, for a ratio of $112,428 per employee (a figure supported as reasonable based on discussion with local manufacturers). Multiplying this ratio by the employment estimate generated in this paper (2,497) results in shipment value of $280,732,716 from the Holmes County Amish furniture cluster, or nearly 3 percent of the national total. These estimates of the wood use and value of shipments generated by the cluster are summarized in Table 2.

Donnermeyer (2004) suggests that Ohio is home to 30 percent of all known Amish; extrapolating the wood use estimate for Ohio's Amish furniture sector from this figure would result in total hardwood lumber consumption of approximately 147 MMBF by Amish furniture manufacturers in the United States, or 1.3 percent of the national production total based on Census figures. This estimate would be higher (about 2.3 percent) if considering only lumber used for appearance-based products by excluding pallets and railway ties; and about 11 percent if including only the hardwood lumber used by the furniture industry (Hardwood Market Report 2006). Similar extrapolation for value suggests that nationally, Amish-made furniture accounts for about 10 percent of the value of all domestic furniture shipments. However, these extrapolations beyond the two-county area comprising the cluster should be viewed with caution, as it is not known if Amish furniture manufacturing density in Ohio is similar to other areas.

### Formation and size of associated businesses in the cluster

Data also were available in *The Furniture Book* for two prominent service sectors for Amish furniture: finishing and wholesale distribution.

Fifty finishing establishments were listed. Both the average and median number of employees per firm was 4.0 (n=31). Average year of establishment was 1996.9 (n=32, median = 2000.0) (Table 1). These results suggest that the finishing portion of the cluster was established later than (i.e., as a result of) the manufacturing portion, and that they are of a similar size as the manufacturers. New business formation is a characteristic of successful clusters and increases the collective pool of competitive resources that gives companies in the cluster competitive advantage over firms in other locations (Porter 1998). The total of employees by reporting firms was 124; by assigning to those with missing employment data the mean/median of 4.0 (very few finishers advertised, so there was no basis for assigning employment as was done with manufacturers; the range in reported employment was 1 to 10 and the standard deviation was 1.8), there were a total of 197 employees in wholesale finishing in Ohio's Amish furniture cluster.

For wholesale distributors, 13 establishments were listed. Of these, 10 provided employment and year of establishment data. The average number of employees per firm was 6.2 (median = 5.5). Average year of establishment was 1996.6 (median = 1997.0) (Table 1). Similar to finishing firms, these results suggest that the distribution portion of the cluster was established slightly later than the manufacturing firms (e.g., new business formation), and they are similar in size to the manufacturers and finishers. The sum of employees by reporting firms was 62. To assign employment figures to firms with missing values, it was noted that the rate of advertising went up substantially for firms with greater than three employees; since none of the firms with missing values advertised, an employment number of 3 was assigned to the four missing values. As the range in employment among the distribution firms with known values was 3 to 14, this seemed like a suitable estimate. As a result, there is an estimated 71 employees in wholesale distribution in Ohio's Amish furniture cluster, although a majority of distribution employment is non-Amish as indicated through discussion with local manufacturers.

## Conclusion

When combining wood household furniture manufacturers, finishers, and distributors, there are approximately 2,991

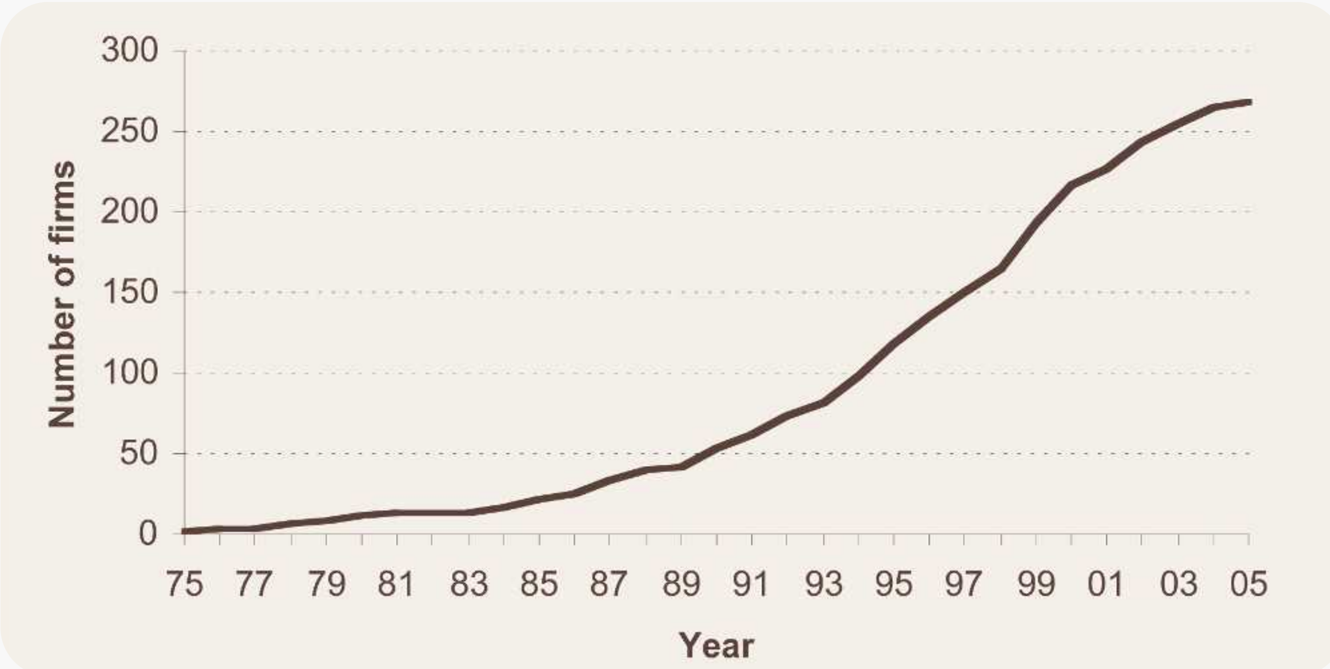



*Figure 4. — Cumulative distribution of Amish furniture firms in the Holmes County, Ohio cluster, based on firms reporting an establishment year (Anonymous 2005).*

persons estimated to be employed in Ohio's Amish furniture cluster. This represents nearly 6 percent of Ohio's entire Amish population of 52,000 persons (Donnermeyer 2004), and excludes a small number of lawn/outdoor furniture, bedding, upholstery, and crafts manufacturers, as well as other suppliers and service providers in the cluster. This employment corresponds to nearly 500 establishments in an approximately 1000 sq. mile area, or roughly the size of two Ohio counties. In sum, it is a concentrated cluster of many small firms. This cluster reasonably could be consuming nearly 44 MMBF of hardwood lumber per year, or the equivalent of about 11 percent of Ohio's total hardwood lumber output and 19 percent of the hardwood lumber used in appearance-based applications in Ohio. As the Amish manufacturing and distribution model employs many of the competitiveness factors discussed in the literature, and has fared relatively well during a very volatile time in domestic furniture manufacturing, this segment likely will continue to be an important regional market for hardwood lumber. Perhaps similar conditions exist in other areas with Amish concentrations (e.g., portions of Pennsylvania and Indiana). Collectively, Amish furniture manufacturing could be making a measurable impact on U.S. hardwood lumber demand.

Can the Amish model work elsewhere in the United States? Portions seemingly could be implemented (e.g., development of supply chains that can offer semi-customized pieces, more emphasis on brand image); however, other features might be more difficult to replicate, such as the cooperative aspects of the society and the commitment to furniture manufacturing as a way of life as farming becomes less viable. Firms operating within the Amish cluster are positioned to take advantage of niche opportunities by cooperating with others to source components and services not easily produced in-house, especially given their typically small size. The clustering dynamic thus seems paramount to the success of the Amish model, even as firms seek to be individually profitable. More research is needed to confirm and expand upon this preliminary assessment of the wood use and competitive attributes of Amish furniture manufacturing.

*Table 1. — Number of firms and employees, median firm size, and median year of establishment for furniture manufacturers, finishers, and wholesale distributors in Ohio's Amish furniture cluster.*

| Firm category | Number of firms | Total employment[1] | Employees per firm (median)[2] | Year established (median)[2] |
|---|---|---|---|---|
| Manufacturers | 429 | 2,723 | 4.0 | 1996.0 |
| Finishers | 50 | 197 | 4.0 | 2000.0 |
| Wholesale Distributors | 13 | 71 | 5.5 | 1997.0 |

[1] Based on the sum of reported (various sources) and assigned employment figures.
[2] Based on reporting firms only (Anonymous 2005).

*Table 2. — Estimates of hardwood lumber use and value of shipments for the Holmes County furniture manufacturing cluster.*

| | |
|---|---|
| Hardwood lumber use: | 43.5 MMBF |
| as a % of Ohio's total production: | 11% |
| as a % of Ohio's total grade production: | 19% |
| Value of shipments: | $280.7 million |

## Limitations

The majority of firms and associated data used in this analysis came from *The Furniture Book*. However, the figures used in this paper include both reported and assigned employment numbers, and other secondary data sources were utilized. The procedures also were discussed with local manufacturers, which resulted in changes to some employment assignments and firms included in the analysis. The firms included in the wood use analysis likely included some that produce components supplied to local furniture manufacturers; where this may have occurred, estimates of wood use might be slightly inflated. Although all known components firms that supplied local firms *exclusively* were removed from the analysis, some could have been missed and some supplied a combination of local and nonlocal secondary manufacturers. Lastly, although the terminology used throughout the report used the name "Amish" to describe all firms, some were non-Amish owned but located within the cluster. Discussion with local manufacturers suggested the non-Amish proportion was about 15 percent, but even among these firms most employees were Amish. It also should be noted that the "furniture" terminology used throughout the paper included some cabinet and millwork firms, but this proportion was small.


## About the authors

The authors are, respectively, Research Forest Products Technologist, Northern Research Station, USDA Forest Service (mbumgardner@fs.fed.us); Executive Director, Ohio Forestry Association (bobr@ohioforest.org); and Economist, Northern Research Station, USDA Forest Service (wluppold@fs.fed.us).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*Bending oak chair backs, Amish furniture maker*

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# 2007 International Convention

Highlights of Section, Chapter, Division/TIG, and Executive Board Meetings

## Section/Chapter Officers Meeting

The FPS 2007 Section & Chapter Officers Meeting was held on Wednesday, June 13 in Room 200E at the Knoxville Convention Center. The meeting was called to order by FPS President Bob Little.

### Roundtable Discussion with Industry Focus Day Speakers

Little welcomed all in attendance and extended a special welcome to Industry Focus Day Speakers. He opened the floor for discussion in regard to Corporate Memberships in the Society. Many of the industry representatives present stated that they felt Membership in the Society is beneficial. It was also noted that with the huge number of organizations/associations competing for membership in today's world and dealing with what are often reduced budgets, memberships are sometimes viewed as cost prohibitive.

### Proposal to Merge FPS Sections

Fran Wagner, FPS Northwest Regional Board Member, facilitated a discussion regarding a proposal to merge FPS Sections. Specific elements as defined in the proposal are as follows:

1. Merge the **Pacific Northwest** and **Inland Empire Sections** to form the **Northwest Section**.
2. Merge the **Pacific Southwest** and **Rocky Mountain Sections** to form the **Southwest Section**.
3. Merge the **Upper Mississippi Valley** and **Midwest Sections** to form the **Mississippi/Missouri Valley Section**.
4. Merge the **Ohio Valley** and **Great Lakes Sections** to form the **Great Lakes/Ohio Valley Section.**
5. Merge the **Southeast** and **Carolinas-Chesapeake Sections** to form the **Southeast Section;** move East Tennessee into the newly formed **Southeast Section**.
6. Move Alabama into the **Mid-South Section.**
7. Merge the **Northeast** and **Eastern Canadian Sections** to form the **Northeast Section**.

Dave Damery, FPS Northeast Regional Board Member shared information on behalf of the FPS Eastern Canadian Section, submitted in a letter from Paul Cooper, EC Section Chair, indicating that the Eastern Canadian Section is not in favor of the proposed merger with the Northeast Section. The group discussed pros and cons that might result from the adoption of this proposal. In light of the significance of this decision, it was the consensus of all in attendance that further evaluation is needed prior to a final decision being made.

### Section/Chapter Activity Reports

Annual Activity Reports were provided by the Section/Chapter representatives in attendance. FPS Executive Vice President Carol Lewis expressed appreciation to everyone for their support of and participation in Society activities during the past year. FPS Special Publications Director Susan Stamm reminded everyone that the International Office Staff is happy to provide assistance to Sections in a variety of areas: promotion of Section Meetings, providing materials regarding Member Benefits in the Society, posting PowerPoint presentations from Section meetings to the FPS website, etc.

Outgoing President Bob Little (right) presented the presidential gavel to incoming President Mike Barnes during the Official Luncheon.

## Division Coordinator and Technical Interest Group Officers Meeting

The 2007 Division Coordinator and Technical Interest Group Officers Meeting was held on Sunday, June 10 in Room 301E at the Knoxville Convention Center. The meeting was called to order by FPS Vice President and Technical Program Chair Anthony Weatherspoon. Weatherspoon asked for discussion regarding the minutes from the 2006 meeting. Upon review of the information distributed prior to the beginning of the meeting, it was noted that a copy of the 2006 minutes was not included. In light of this, no formal motion to approve these minutes was made. It was also noted that the name of the Structural Panel TIG was listed incorrectly in the TIG Officers Directory. This should be changed to Structural Composites, per approval by the FPS Executive Board at the 2006 IC. (Note: Although copies of the minutes from the 2006 meeting were included when materials were shipped to Knoxville, they were unable to be located during the meeting. Copies of the 2006 meeting minutes were distributed for review with the minutes from the 2007 meeting.)

### Guidelines for TIG Reports

John Shelly stated that guidelines are being developed for the establishment of a standard format for the annual TIG Business Meeting Reports that are forwarded to the International Headquarters. A draft of the guidelines will be forwarded to TIG Officers for review.

### Review of 2007 IC Technical Program

Weatherspoon asked for feedback from the group in regard to the 2007 Technical Program schedule. Many in attendance expressed concern with the high number of concurrent sessions. Considerable discussion followed regarding changing the amount of time allotted for each Technical Session presentation at future FPS IC's from the current policy of offering presenters a choice between 15- or 30-minute timeslots to requiring all presentations to be 20 minutes in length. Upon conclusion of the discussion, Weatherspoon asked for a show-of-hands vote regarding the approval of this revision. The majority of those present voted in favor of the revision. Weatherspoon stated that this information would be shared with the FPS Executive Board during their upcoming meeting on Thursday. He reviewed the schedule for TIG Business Meetings to be held during the 2007 IC and thanked all in attendance for their time and valuable feedback.

## Executive Board Meetings

The FPS Executive Board met on Sunday, June 10 (meeting chaired by outgoing President Bob Little) and Thursday, June 14 (chaired by incoming President Mike Barnes) at the Hilton Knoxville, Knoxville, TN. Items discussed by the Board during these meetings included the following:

### Progress To-date – Ad-Hoc Membership Committee

Dave Damery, Chair of the Ad-Hoc Membership Committee, reported that the Members of this Committee met for several hours during their time in Knoxville. He stated that the Committee is reviewing historic information in regard to Membership issues and a full report will be provided to the Board at the 2007 Fall Board Meeting.

### Past Presidents Meeting

Little gave the report from the Past Presidents Meeting. He stated that Lewis' attendance at the meeting was very beneficial in regard to the provision of updated financial information. He reported that concern was expressed by the Past Presidents regarding the fact that the amount of annual interest earned from the Markwardt investment funds does not cover the cost of the honorarium presented for this award. He stated that it was the consensus of the Past Presidents that their future meetings be held on Tuesday afternoon, to follow the Society's Annual Business Meeting. The final request presented on behalf of the Past Presidents for consideration by the Board was in relation to potential revisions in the awards presented during the Society's Official Luncheon. After discussion, the Board approved the following changes:

1. The lengthy presentation program traditionally held during the Official Luncheon will be shortened.
2. In lieu of individual award plaques for Sections and Chapters, perpetual-style plaques will be created with small nameplates to be displayed at the International Headquarters in Madison.
3. Individual certificates recognizing Section and Chapter achievements will continue to be created – to be mailed to recipients.
4. An Official Luncheon Program recognizing all award winners will be created for distribution onsite to all attendees.
5. Member Recognition Certificates will continue to be created – to be mailed to recipients.
6. Winners of the Markwardt, Gottschalk, Wood and Wood Engineering Achievement Awards will continue to receive award plaques and be recognized during the Official Luncheon.

## Proposal to Merge FPS Sections

There was a brief discussion regarding this proposal originally presented by Fran Wagner at the 2006 Fall Board Meeting. It was the consensus of all present that more time should be devoted to the evaluation of this proposal prior to a final decision being made. John Shelly and Niels de Hoop were appointed to join the original members of the Ad-Hoc Committee (Wagner, Little and Todd Shupe) formed to research and evaluate the potential benefits to the Society in regards to a final decision being made. A report will be provided to the Board regarding further direction prior to the 2007 Fall Board Meeting.

## 2008 FPS IC

Steve Winistorfer, General Chair of the Planning Committee for the 2008 IC in St. Louis, Missouri, reported on progress to-date. There was considerable discussion regarding potential format changes for the meeting. Shelly reported that the majority in attendance at the 2007 Division Coordinator and TIG Officers Meeting voted in favor of having all of the TIG Sessions be 20 minutes in length. The group also discussed the decision made by SWST to participate in future FPS IC's only in odd numbered years, and the majority of Board Members in attendance agreed that the Industry Focus Day does not seem to be accomplishing the goal for which it was established i.e. increasing attendance from industry representatives. A motion was made and passed unanimously that "All TIG Sessions at the 2008 IC will be twenty minutes in length and that each session will conclude with a 5 minute Q and A period." Lewis stated that in light of the fact that the contract for meeting space in St. Louis was signed in the fall of 2006, she would need to negotiate any changes with a representative from the Hyatt Union Station It was the consensus of the group that Winistorfer and Lewis work together on the creation of a revised format for the 2008 FPS IC, with revisions to be based upon the feedback that had been shared by the group.

## Recognition of Incoming and Outgoing FPS Executive Board Members

Little recognized outgoing Regional Board Members Steve Bratkovich, West Central Region, Dave Patterson, South Central Region, Ron Ames, Eastern Canadian Region, and Immediate Past President Ramsay Smith. He expressed sincere appreciation on behalf of the Society for their time and commitment during their service on the Board. He extended a warm welcome to incoming Regional Board Members Steve Winistorfer, West Central Region, David Thompson, Eastern Canadian Region, and Niels de Hoop, South Central Region. He also welcomed and congratulated John Shelly on being elected Vice President of the Society.

# Awards for Excellence in Research, Leadership, and Service Presented at the Official Luncheon

**2007 Forest Products Society Award Winners were recognized during an Awards Ceremony at the Official Luncheon. President Bob Little presided over the ceremony.**

## Gottschalk Award

The Fred W. Gottschalk Memorial Award recognizes exceptional service to the Forest Products Society on behalf of an individual Member. The Award is presented annually in memory of Fred W. Gottschalk, the first President of the Society, who died in a plane crash in Salt Lake City in 1965. In order to be eligible for this prestigious award, the candidate must have been an active member of the Society for a minimum of 10 years with a demonstrable history of service to the organization. The candidate must not have held the office of President, President-Elect, or Vice-President or currently be a nominee for Vice-President. The 2007 Gottschalk Award was presented to George Woodson by Mike Barnes, Chair of the 2007 Gottschalk Award Committee. George has been a Member of the Society since 1962. He served as the Co-Chair for the Annual Meeting in 1991, and was a Member of the 1998 – 99 International Nominating Committee. He served as Vice-Chair for the Hardboard Technical Interest Group from 1987 – 90 and again in 1992 – 93. He served as the Chair for this TIG from 1990 – 92. He was Vice-Chair for the Particle Board TIG from 1997 – 2000. He served as one of the Members of the Award Committee for the Wood Award in 1980-81, the Markwardt Award Committee from 1993 – 95, and served as the Chair for this Committee in 1995. He was a Program Chair Speaker in 1990 and again in 1992. George is currently the Business Technical Manager for Flakeboard Company, Louisiana Particleboard Plant, Simsboro, Louisiana.

George Woodson (right) was selected as the 2007 recipient of the prestigious Gottschalk Award, honoring exceptional service to the Society on behalf of an individual Member. The award was presented by Mike Barnes, Chair of the Gottschalk Award Committee.

The second place Wood Award was presented to Jinwu Wang (left), Research Assistant at Washington State University for his paper titled *Kinetic Analysis and Modeling of Mechanical and Chemical Cure Development for Wood-PF Bonds.* The award was presented by Dynea representative Bruce Broline, Research Manager - North America.

# Wood Award

The Wood Award recognizes outstanding graduate research in the field of wood science and forest products. The award is sponsored by Dynea, in cooperation with the Forest Products Society. The 2007 Wood Awards were presented by Dynea representative Bruce Broline, Research Manager - North America, Springfield, Oregon.

### First Place

First place winner Natalie Vadeboncoeur received a check for $1,000 and an engraved plaque for her award-winning paper *"Separate-Sided Surface Measurement Using a Handheld Profiling Device."* Natalie was born in San Antonio, Texas. She received her Bachelors Degree in Mechanical Engineering from the University of Illinois at Urbana-Champaign. She is currently an M.A.Sc. student and a Research Assistant at the University of British Columbia, Canada, in the Renewable Resources Laboratory working on Lumber Manufacturing Process Control. Professor Gary Schajer, University of British Columbia, Vancouver, BC, serves as Natalie's advisor.

### Second Place

The second place winner, Jinwu Wang, received a $500 check and an engraved plaque for his paper *"Kinetic Analysis and Modeling of Mechanical and Chemical Cure Development for Wood-PF Bonds."* Jinwu received a Bachelors Degree in Wood Processing and Technology from Nanjing Forestry University, Nanjing, China in 1986. He received a Masters Degree in Wood Science and Technology from Nanjing Forestry University, Nanjing, China in 1989, and a second Masters Degree in Wood Science and Technology from the University of California, Berkeley, California in 2003. He completed his PhD in Civil Engineering – Structural Engineering and Materials at Washington State University, Pullman Washington in 2007. He is currently working as a Research Assistant at Washington State University. Jinwu's advisors at Washington State University are Assistant Professor Marie-Pierre Laborie and Professor Mike Wolcott.

# Markwardt Wood Engineering Award

The L. J. Markwardt Wood Engineering Award is intended to encourage research and promote knowledge of wood in the engineering field as a means of enhancing the efficient utilization of wood. The award is presented annually to the author or authors of a technical paper, published in either the *Forest Products Journal* or *Wood and Fiber Science* during the two prior calendar years, which is judged to be the most outstanding research paper in the area of wood as an engineering material. The award alternates between two categories – engineering science (basic research) and engineering practice (applied research). Founded in 1969 by the late L. J. Markwardt, a Charter Member of the Society, the award consists of an engraved plaque, a certificate and an honorarium of $1,000, supported in part by an Award Fund comprised of personal contributions by Mr. Markwardt. The 2007 L. J. Markwardt Engineering Award was presented by Rado Gazo, Associate Professor, Department of Forestry & Natural Resources, Purdue University and Chair of the 2007 Awards Committee, to the authors of the most outstanding paper in the field of engineering practice. This year, the award was presented for a pair of papers – *"Torsional Rigidity of Rectangular Wood Composite Materials"* and *"Torsional Rigidity of Wood Composite I-joists"* both published in *Wood and Fiber Science*, Volume 37, Number 2 (2005). The papers were authored by Daniel Hindman, Assistant Professor, Dept. of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, John Janowiak, Professor, Penn State University, University Park, Pennsylvania, and Harvey Manbeck, Professor Emeritus, Penn State University,

This year's Wood Engineering Achievement Award in the category of Lifetime Achievement was presented to Roy Pellerin, Professor Emeritus, Washington State University. The award was presented by Buddy Showalter on behalf of the AF&PA American Wood Council, sponsor of the award.

University Park, Pennsylvania. Gazo presented Senior Author Daniel Hindman with an engraved plaque and a check for $1,000. Coauthors were presented engraved plaques.

## Wood Engineering Achievement Award

This award was established in 1996 by the Wood Engineering Division of the Society to recognize outstanding contributions to the discipline of wood engineering through innovations in engineered structures, components, design methods, codes, standards, or education. The award, consisting of an engraved plaque and a $500 honorarium, is sponsored by the American Forest & Paper Association's American Wood Council. The 2007 award was presented in the category of Lifetime Achievement, honoring an individual for cumulative contributions to the discipline of wood engineering. This year's award was presented to Roy Pellerin, Professor Emeritus, Washington State University, Ocean Park, Washington. The award was presented by John "Buddy" Showalter, Director – Technical Media, AF&PA's American Wood Council.

Natalie Vadeboncoeur, M.A.Sc. student and Research Assistant at the University of British Columbia, was awarded first place in the 2007 Wood Award competition for her paper titled *Separate-Sided Surface Measurement Using a Handheld Profiling Device.* The award was presented by Bruce Broline.

## Section/Chapter and Student Chapter Awards

FPS Sections and Student Chapters were recognized for their achievements and their contributions to the Society. The Section/Chapter/Student Chapter award system is based on 10 criteria that are deemed important to the continued growth of the organization. Each Section/Chapter/Student Chapter rates itself on the number of criteria met during the year. Completing 5 – 7 of the criteria constitutes a Commendable Rating; completion of 8 – 9 constitutes an Excellent Rating; successfully completing the requirements for all 10 criteria constitutes an Outstanding Rating. Outstanding Awards were presented to the Rocky Mountain Section, Midwest Section, Mid-South Section, and the Northeast Section. Excellent Awards were presented to the Pacific Southwest Section and the Eastern Canadian Section. The Great Lakes and Upper Mississippi Valley Sections were recognized for their Commendable performance. Outstanding Awards were presented to FPS Student Chapters at Oregon State University, Purdue University, and the University of Arkansas at Little Rock. The University of Massachusetts Student Chapter received an Excellent Award. Student Chapters at Iowa State University, Mississippi State University, and the University of Idaho were recognized for their Commendable performance.

Rado Gazo presented the L. J. Markwardt Award to (right to left) Senior Author Daniel Hindman, Assistant Professor, Virginia Tech, John Janowiak, Professor, Penn State University, and Harvey Manbeck, Professor Emeritus, Penn State University for a pair of papers titled *Torsional Rigidity of Rectangular Wood Composite Materials* and *Torsional Rigidity of Wood Composite I-joists.*

## 2007 Membership Recruitment Contest

Final results of the 2007 Membership Recruitment Contest were announced. Leonard Smith, Associate Professor, SUNY-ESF, Syracuse, New York took top honors in the Individual Member Category with five new Members recruited. Warren Rowan, Alcorn State University, Lorman, Mississippi, won first place in the Student Member Category with 12 new Student Members. Leonard received a Certificate of Recognition, a complimentary registration to the 2008 IC in St. Louis, Missouri, and a $25 Certificate redeemable for FPS logo apparel or publications. Warren received a Certificate of Recognition, a complimentary registration to the 2008 IC, and a check for $100. The Mid-South Section received a plaque for the highest number of Members recruited by Section Members with a total of 18 new Members and two reinstated Members.

### Student Activities Fund Contributors

Bill Boehner; Delmhorst Instrument Company; Frank Lumber Company, Inc.; Osmose, Inc.; Swift Lumber Inc. Western Wood Products Assn.

# New Members

*The Forest Products Society welcomes the following new members who joined during October 2007:*

## Voting Members under Sustaining Memberships

| | | |
|---|---|---|
| Phil Line | American Forest & Paper Assoc | Carolinas-Chesapeake Section |
| Robert Taylor | American Forest & Paper Assoc | Carolinas-Chesapeake Section |

## Voting Members

| | | |
|---|---|---|
| Larry G. Avant | Roy O Martin Lumber Company LP | Mid-South Section |

## Student Members

| | | |
|---|---|---|
| Natalia A. Barreto | North Carolina State University | Carolinas-Chesapeake Section |
| John C. Bouldin, Jr. | Virginia Tech | Carolinas-Chesapeake Section |
| Ryan Cox | Colorado State University | Rocky Mountain Section |
| Fredrick D. Fleischman | Colorado State University | Rocky Mountain Section |
| Ashley Garrison | Colorado State University | Rocky Mountain Section |
| Amy D. Jahnke | Virginia Tech | Carolinas-Chesapeake Section |
| Steven A. Kelly | Pennsylvania State University | Northeast Section |
| Qingqing Li | Virginia Tech | Carolinas-Chesapeake Section |
| Matthew C. Moldenhauer | Clemson University | Carolinas-Chesapeake Section |
| Jesse S. Mowry | Pennsylvania State University | Northeast Section |
| Nathan Pierce | Colorado State University | Rocky Mountain Section |
| Benjamin Ralston | Virginia Tech | Carolinas-Chesapeake Section |
| Lauren A. Rega | Pennsylvania State University | Northeast Section |
| Brian Schroeder | Colorado State University | Rocky Mountain Section |
| William Youngblood | Virginia Tech | Carolinas-Chesapeake Section |

## CALL FOR NOMINATIONS FOR THE 2008 FRED W. GOTTSCHALK MEMORIAL AWARD

Members are urged to submit nominations for the 2008 Fred W. Gottschalk Memorial Award. This prestigious Award is intended to recognize and honor exceptional service to the Forest Products Society by an individual member. The Award is presented in memory of Fred W. Gottschalk, the first President of the Society who died in a plane crash in 1965.

### ELIGIBILITY

A candidate for the Fred W. Gottschalk Memorial Award must:

1. have been an active member of the Society for a minimum of 10 years;
2. not have held the office of President, President-Elect, or Vice President;
3. not be a nominee for Vice President;
4. have a long history of active service to the Society, including involvement in permanent working committees, assigned committees, and/or elected offices such as Division, Technical Interest Group, Section/Chapter, or Regional Officer. Significant involvement in Society affairs on the part of the nominee should be ongoing or at least recent at the time of nomination;
5. have demonstrated conscientious efforts to carry out assigned or elected responsibilities of the Society as set forth in its Constitution.

Each nomination must be submitted on a nomination form supplied by the International Office of the Society and must be accompanied by a synopsis (not to exceed 200 words) outlining the candidate's service to the Society and the reasons why he or she should be given consideration for the Award. Members who are unsure of the history of a particular member and whether they may qualify are encouraged to send in the nomination request coupon below; if the nominee does not qualify, the International office will notify the nominator.

To obtain a nomination form, fill out and mail or fax the coupon below IMMEDIATELY. You may also e-mail your request to vbruce@forestprod.org. **ALL FINAL NOMINATIONS FOR QUALIFIED CANDIDATES ARE DUE AT THE SOCIETY'S INTERNATIONAL OFFICE PRIOR TO MARCH 1, 2008**.

I would like to nominate the following Society member for the 2008 Fred W. Gottschalk Award (please print nominee's name)____________________________________.

If this individual qualifies, please send a nomination form to:
Name ____________________________________
Address ____________________________________
City/State/Postal Code/Country ________________________
Phone __________________ Fax__________________
E-mail Address:________________________________

Return to Vickie Bruce, Forest Products Society, 2801 Marshall Court, Madison, WI 53705-2295 USA, Fax: 608-231-2152, E-mail: vbruce@forestprod.org.

# Practicalities and Possibilities

**The *Forest Products Journal* is well respected for publishing high quality peer-reviewed technical research that reflects the current state of wood science and technology. In an effort to emphasize the practical importance of the research in the following section, this department provides concise statements of why the research is useful or where it might lead.**

### A mold resistance test on adhesives used in wood composite products

This research demonstrates that adhesives used in engineered wood products are no more susceptible to mold than the wood itself, and the incorporation of adhesives should not increase the mold susceptibility of the products.

**Article begins on page 25.**

### Preliminary study of thermal treatment effects on mold growth of selected Quebec wood species

Thermally treated wood is a new material in North America and the properties of heat-treated North American species are not known. These properties change depending on the technology and the treatment conditions used. In this study the mold resistance of five species heat-treated using Thermowood technology was studied and the treatment conditions affecting the mold growth were identified. The results of this study will help the industry to choose the optimum treatment conditions in order to have a product which has good resistance to mold growth.

**Article begins on page 30.**

### A method to assess lumber grade recovery improvement potential for black spruce logs based on branchiness

This study demonstrated that consideration of both knot size and location around and along a stem is critical to determination of log orientation prior to processing.

**Article begins on page 34.**

### Structural lumber from suppressed-growth ponderosa pine from northern Arizona

This paper shows that structural lumber can be recovered from 2 by 4's cut from suppressed growth ponderosa pine with properties that meet, or exceed, those given in the National Design Specification. Good grade recovery can be obtained in the Light Framing and Structural Light Framing grading systems. While some lumber will meet popular mechanical grades, such grading is not generally recommended because of lower yields and a lack of established markets. Higher value can be obtained if this lumber is graded for appearance grades, rather than structural grades.

**Article begins on page 42.**

### Properties of wood from ice-storm damaged loblolly pine trees

The results of this study will aid pine timberland managers in making harvest decisions after catastrophic events such as ice storms or hurricanes.

**Article begins on page 48.**

### Migration of boron from Douglas-fir lumber subjected to simulated rainfall

This study demonstrated the feasibility of storing DOT-treated lumber in a rainy environment for a limited time without the loss of residual boron in the lumber.

**Article begins on page 52.**

### Control of discoloration in pitch pine

This study has demonstrated a reducing temperature drying schedule which can produce pitch pine boards of excellent color. It is anticipated that the ability to dry pitch pine at high temperatures without excessive darkening stain, while also reducing resin exudation and twist, will add value to this species.

**Article begins on page 58.**

### Relationship between bending and tensile stress distribution in veneer plywood

The study results suggest the possibility of optimizing the relationship between bending and tensile strength in plywood. It is possible to produce plywood with the same thickness and same bending strength, but with varying tensile strength, i.e., plywood with a varying ratio of bending to tensile strength. Such varying plywood would provide designers with adequate selection in the design of structural constructions.

**Article begins on page 65.**

### Wood density in *Pinus taeda* × *Pinus rigida* and response 10 years after thinning in Virginia

The results of this study expand the knowledge about pine hybrids, their density, and their response to thinning, thus allowing for a better understanding of the management and use of hybrid pine.

**Article begins on page 70.**

### Antioxidative activity of water extracts from leaf, male flower, raw cortex and fruit of *Eucommia ulmoides* Oliv.

The study showed that water extracts from the male flower and the leaf of *Eucommia ulmoides* Oliv. could be possibly promoted as a natural antioxidant.

**Article begins on page 74.**

### Evaluating selected demographic factors related to consumer preferences for furniture from commercial and from underutilized species

Consumer preferences in two Pacific Northwest markets were explored for six domestic wood species that were evaluated across four furniture pieces. Age and income were statistically significant, while gender was not significant. Results of this study indicate the important role that species choice plays in developing a customized domestic furniture industry.

Article begins on page 79.

### Effect of post-treatment steaming on the bending properties of southern pine treated with copper naphthenate

This study shows that post-treatment steaming of copper naphthenate-treated southern pine for 30 minutes produces no deleterious effects on bending properties other than the recognized treatment effect found with all waterborne preservative systems.

Article begins on page 83.

### The standardization puzzle: An issue management approach to understand corporate responsibility standards for the forest products industry

This research shows that societal expectations from the forest products industry vary by region. The results indicate that corporate social responsibility (CSR) in the forest sector is not a context-free phenomenon and any global CSR standard must be based on the local context. These results could lead to further investigation of the possible forms of CSR standards for the global forest products industry.

Article begins on page 86.

## *Forest Products Journal* Publication Style Sheet

The *Forest Products Journal* is published by the Forest Products Society. The *Journal*'s primary purposes include communicating research findings at the applied or practical level, communicating news and items of current interest to the membership, and describing Society programs and activities. Technical manuscripts submitted for publication are reviewed by referees selected by the editor; however, final evaluation of the material rests with the editor. Authors speaking English as a second language should have their manuscripts edited by a native English speaker prior to original submission.

The *Journal* relies on the U.S. Government Printing Office Style Manual for questions of punctuation, abbreviation, etc. The manual is available on the internet.

### Form of Manuscripts

The original submission of a manuscript for review must be printed on a letter-quality printer with double spacing throughout on nonerasable 8-½- by 11-inch paper. Mail one hard copy and one floppy disk or CD that contains the manuscript in a Microsoft Word file. All pages, except the title page, should be numbered consecutively. The sequence of material in the manuscript as submitted should be: title page, abstract, text, literature cited, captions page, tables, and figures (i.e., drawings and photographs). Do not incorporate tables or figures in the text.

**A)** The title page should include the manuscript title, authors' names, titles, affiliations, complete addresses of the affiliations, and e-mail addresses. The title should be as concise as possible. If acknowledgments are necessary, they should be made as a footnote on the title page.

**B)** The abstract should contain, in very condensed form (250 words for an article, 75 for a note), the essence of the whole work. It should summarize why the work was done, what was done and how, and results and conclusions, perhaps with a mention of the significance.

**C)** In the text, make certain all figures, tables, and references are mentioned. If fewer than six references are mentioned, they should be typed as footnotes at the bottom of the page. If six or more references are mentioned, they should be cited in parentheses at the appropriate location in the text using the author-date style, in chronological order. For example: . . . (Brown and Banks 1990, Adams 1995, Evans et al. 1997).

**D)** References should be listed at the end of the manuscript in a section called "Literature cited." They should be listed alphabetically (if an author is repeated, the sequence is single author first, then two authors etc.). Use lowercase for periodical titles and uppercase for main words in book titles. Translate foreign titles, then indicate what language and if an English abstract is available.

Examples:
Adams, R 1997. Wood is good. Forest Prod. J. 47(1):68-70.
Adams, R. and T. Banks. 1995. Drying Wood. Prentice Hall, Englewood Cliffs, NJ. 550 pp.
Adams,W., P. Abner, and H. Collins. 1998. Drying hickory. *In*: Proc. Drying Various Woods. Proc. No. 7432. Forest Prod. Soc., Madison, WI. pp. 43-52.

Banks, T. 1991. Drying Wood for Fun and Profit. Van Nostrand Reinhold, New York. 485 pp.

**E)** All tables should be prepared using MS Word on separate pages and numbered consecutively in Arabic numerals. Tables should be kept simple and used for summary data, rather than raw data, if possible. Captions should be listed on the tables and on a separate sheet.

**F)** Detailed instructions for submitting figures are given in Preparing Figures for Publication in the *Forest Products Journal* at www.forestprod.org/FPJfigures. html.

Technical manuscripts published in the *Forest Products Journal* are subject to a page charge of $135 per printed page ($155 per page if none of the first three authors are members of the Forest Products Society). Mail submissions to the Editor, *Forest Products Journal*, 2801 Marshall Court, Madison, WI 53705.

### Final Format Guidelines

Revised manuscripts must be provided on an IBM-compatible, high-density floppy disk or a CD that contains the manuscript, tables, and captions in an MS Word file, and the figures in separate files.

# A mold resistance test on adhesives used in wood composite products

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D. Minchin
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**Abstract**

There are increasing expectations for products to be resistant to mold growth even when subjected to moisture conditions for which they were not originally intended. Products may be subjected to wetting during shipment, storage, or from exposure to leaks while in use. Although the susceptibility to mold growth of many wood composite products in the marketplace has been investigated, the ability of the adhesives used in the manufacture of the products to support mold growth is unknown. APA–*The Engineered Wood Association* approached Forintek Canada Corp. (now FPInnovations–Forintek Div.) to investigate the potential for mold growth to occur on surfaces of samples of six selected adhesives commonly used to manufacture wood composite products. The American Wood-Preservers' Association (AWPA) E 24 *Standard Method of Evaluating the Resistance of Wood Product Surfaces to Mold Growth* was used to determine susceptibility of adhesive samples to mold growth. The test evaluates susceptibility to growth of a broad range of molds from both natural and artificial inocula for up to 8 weeks on sample surfaces. In addition, a repeat test was performed on two adhesives, phenol formaldehyde (PF), with filler and extender used in plywood (PF-ply) and phenol resorcinol formaldehyde (PRF), with filler, after the first test indicated incomplete curing of samples. Test results show that wood controls, southern pine sapwood and aspen sapwood were susceptible to mold growth. PF-ply and PRF were also susceptible to mold growth on both incompletely cured and cured samples, although little growth occurred during the first 2 weeks on PF-ply. Melamine urea formaldehyde (MUF) was not susceptible to mold growth for the first 4 weeks, and supported very little growth up to 8 weeks. PF-OSB (phenol formaldehyde used in oriented strand board), P-methylenediphenyldiisocyanate (PMDI), and urea formaldehyde (UF) were not susceptible to mold growth for the duration of the 8-week test. None of the adhesives was significantly more susceptible to mold growth than southern pine or aspen sapwood. Moisture contents (MC) of southern pine sapwood and aspen samples approximated the expected equilibrium MC of solid wood for the conditions in the chamber.

Concerns of possible risks to human health from exposure to molds are prompting markets to scrutinize building materials for susceptibility to mold growth (Uzunovic et al. 2003). As a result of these concerns, it is desirable to mitigate the risk of mold growth on building products even when subjected to moisture conditions for which they were not originally intended. Products may be subject to wetting during shipment, storage, or from exposure to leaks or condensation while in end use (Hazleden and Morris 1999, Morris 2006). Recognizing the reality of marketplace conditions and demands, some producers are designing mold resistance into their products through the use of moldicides or protective barriers, and improving handling and storage procedures to reduce potential exposure to conditions that may cause mold growth. Although the susceptibility to mold growth of many wood composite products in the marketplace has been investigated (Pasanen 1994, Wang 1994, Morris et al. 1999, Ritschkoff 2000, Fogel and Lloyd 2002, Laks et al. 2002), the susceptibility to mold growth of the adhesives used in manufacture of the products is unknown. APA–*The Engineered Wood Association* approached Forintek Canada Corp. to investigate the resistance to mold growth on surfaces of samples of adhesives commonly used to manufacture wood composite products.

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*Forest Products Society Member.

Forest Prod. J. 57(12):25-29.

The new American Wood Protection Association (AWPA) E24 *Standard Method of Evaluating the Resistance of Wood Product Surfaces to Mold Growth* (AWPA 2006), was used to determine susceptibility of samples of six selected adhesives to mold growth. Comparisons were made to mold growth on three reference materials: fibreglass cloth (on which the test adhesives were cured), southern pine sapwood, and aspen sapwood. This method uses controlled temperature and humidity in a small environment chamber to maintain ideal conditions for mold growth. The test evaluates susceptibility for up to 8 weeks on sample surfaces to colonization and growth of a broad range of molds from both natural and artificial inocula. In the initial testing, a problem rapidly became apparent with the samples of phenol formaldehyde (PF), with filler and extender used in plywood (PF-ply) and phenol resorcinol formaldehyde (PRF) with filler. The samples absorbed excessive moisture and a brown liquid residue dripped from the samples. It was later determined the samples were incompletely cured. Additional samples, properly cured, were prepared and the test repeated for these adhesives and the three reference materials. This paper presents the initial and repeat test results from the investigation of the susceptibility of cured adhesives to surface colonization by molds.

## Materials and methods

APA acquired ready-to-use adhesives representing commonly available commercial products for inclusion in the test. Adhesive products tested were:

- phenol formaldehyde used in plywood (PF-ply) with filler and extender, also used in laminated veneer lumber (LVL),
- PF used in oriented strand board (PF-OSB), also used in hardboard,
- P-methylenediphenyldiisocyanate (PMDI) used in OSB,
- phenol resorcinol formaldehyde (PRF) with filler, used in glue-laminated beams,
- melamine urea formaldehyde (MUF) used in particleboard and medium density fiberboard (MDF), and
- urea formaldehyde (UF) used in particleboard, MDF, and decorative plywood.

APA fabricated the adhesive test specimens on fiberglass cloth and provided Forintek with test-ready, 76- by 152-mm (3- by 6-inch) samples of cured adhesives ready for installation in the test chambers. Fiberglass was used as the substrate for the adhesives in an attempt to isolate mold growth solely due to the adhesive. Samples of fiberglass cloth with no adhesive were also provided as controls.

Six replicates of each of the six adhesives types and controls were tested. For the initial test, adhesive types were grouped for testing in one of two chambers based on potential off-gassing of formaldehyde. Adhesives considered to have little or no potential for emission of formaldehyde were exposed in chamber "A" and adhesives considered to have greater potential for emission of formaldehyde were exposed in chamber "B." The objective of using separate chambers was to eliminate any potential influence of formaldehyde emission. For the repeat test, adhesive types with different potential for off-gassing were mixed in one chamber, chamber "C", since there was no significant difference in mold growth on reference samples in the two chambers (A and B) in the initial test. If off-gassing had occurred it would have been expected to suppress mold growth on the reference materials. The types of adhesives grouped in each chamber of the initial and repeat tests are shown in **Table 1**. Six replicates of fiberglass cloth controls were included in each of the test chambers.

*Table 1. — Grouping of adhesives in chambers for initial and repeat tests.*

| Chamber "A" – Initial test | Chamber "B" – Initial test | Chamber "C" – Repeat test |
|---|---|---|
| Controls and expected low-formaldehyde emitting adhesives: | Controls and potential formaldehyde emitting adhesives: | Controls and mix of expected low-formaldehyde emitting and potential formaldehyde emitting: |
| Cloth only | Cloth only | Cloth only |
| Southern pine | Southern pine | Southern pine |
| Aspen | Aspen | Aspen |
| PF-ply (filler and extender) | PRF (filler) | PF-ply (filler and extender) |
| PF-OSB | MUF | PRF (filler) |
| PMDI | UF | |

APA also sourced untreated, dried southern pine sapwood, and, together with aspen sapwood provided by Forintek, six replicate 3- by 6- by 3/8-inch samples of each species were prepared at Forintek for inclusion in each of the two chambers of the initial test, and in the repeat test, as solid wood positive controls. Since there were only three of the original aspen controls available, three additional aspen sapwood control samples were produced from new source material to provide a full set of six replicates for the repeat test. Due to narrow sapwood bands, some of the aspen samples included some heartwood. Only the sapwood portions of samples were considered when rating samples for mold growth.

For the initial and repeat test, immediately prior to installation in the environment chambers, the southern pine and aspen samples were weighed. Upon completion of the 8-week tests, the solid wood samples were removed from the chambers rated and then weighed, ovendried, and reweighed to enable calculation of moisture content (MC) of the samples before and after exposure in the chambers. As a result of excessive moisture uptake of some adhesive samples in the initial test, all samples in the repeat test, including fiberglass controls, were weighed before and after exposure to determine change in MC.

Each environment chamber (**Fig. 1**) used in the tests consisted of a rectangular (61 by 46 by 46 cm) heavy-duty polyethylene tank fitted with a pitched-roof cover made of clear acrylic sheet. The pitch was sufficient to allow condensation to run down the inside surface of the cover instead of dripping onto the samples suspended inside the tank.

The bottom of the tank contained about 8 cm of water. A tray with a bottom of stainless steel coarse wire mesh covered with plastic sunscreen fabric was supported about 3 cm above the surface of the water. It contained an 8-cm-thick layer of nonsterilized commercial potting soil. Approximately 5 cm was left between the side of the tray and the tank wall to permit air movement within the tank. A 10-cm-diameter fan positioned at one end of the soil tray circulated air within the chamber over the surface of the soil to aid in the distribution of spores.

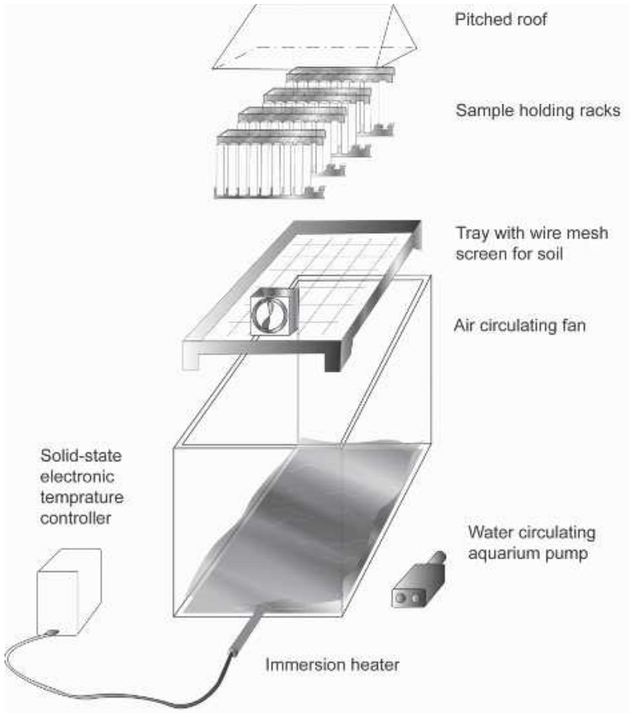


*Figure 1. — Controlled environment mold growth chamber.*

Samples were placed in one of four acrylic plastic sample holders spanning the width of the tank. The samples were held with the long dimension vertical and parallel to each other so that the faces were perpendicular to the fan airflow. The lower ends of the samples were about 13 cm above the soil surface.

Heat was applied to the chamber by an immersion heater installed horizontally in the water through one end of the chamber. The heater was controlled by a solid-state electronic temperature controller to maintain a temperature of 25 °C in proximity to the samples, as measured by a thermocouple located amongst the samples. To aid in even heat distribution, water within the tank was constantly stirred by an aquarium circulating pump. Lack of chamber ventilation resulted in a constant relative humidity at, or near, 100 percent inside the chamber. This was confirmed by the constant formation of condensate on the pitched cover.

The artificial inoculum contained four organisms known to colonize wood. The following cultures were first grown on 1.5 percent malt extract, 2 percent agar (Difco) Petri plates (one plate prepared for each culture) and incubated for 14 days at 25 °C to produce inoculum for the test chamber:

| | |
|---|---|
| *Alternaria tenuissima* group (Kunze) Wiltshire | Ftk 691B |
| *Aspergillus niger* v. Tiegh. | ATCC 6275 |
| *Aureobasidium pullulans* (de Bary) Arnaud | ATCC 9348 |
| *Penicillium citrinum* Thom | ATCC 9849 |

An inoculation suspension was prepared by scraping spores and mycelium from the surface of the incubated plates and mixing them all together in a blender with water for 15 seconds. The suspension volume was adjusted with water to about 500 mL. A large volume pipette was used to distribute the inoculum evenly over the soil surfaces in the chambers. The chambers used in these tests had been operating at test conditions for about 12 weeks for the initial test and 2 weeks for the repeat test after soil inoculation, which was ample time for the fungi to become established in the soil and to produce spores for dispersal to the sample surfaces during the test. Viability of molds within the chamber was confirmed prior to introduction of the samples by exposing clean agar plates inside the chambers for 30 minutes and observing subsequent growth of mold colonies over several days.

For each test, a second set of plates (one of each culture) was prepared for inoculation of the sample surfaces. About 500 mL of inoculation suspension was prepared as before. Upon placement of the samples in the chambers, the inoculum was evenly applied to the sample surfaces as a fine mist using a trigger sprayer so as to wet the surfaces, but not to the point of runoff. In addition to this artificial inoculum, natural inoculum was present in the form of natural airspora and unsterile soil.

Following 2, 4, 6, and 8 weeks of exposure within the environment chamber, samples were rated for the extent and intensity of mold growth on a scale of 0 to 5, where 0 represents no growth and 5 represents extensive and intense fungal growth, as described below:

| Rating | Description |
|---|---|
| 0 | No visible growth |
| 1 | Mold covering up to 10 percent of surfaces providing growth is not so intense or colored as to obscure the sample color on more than 5 percent of surfaces. |
| 2 | Mold covering between 10 percent and 30 percent of surfaces providing growth is not so intense or colored as to obscure the sample color on more than 10 percent of surfaces. |
| 3 | Mold covering between 30 percent and 70 percent of surfaces providing growth is not so intense or colored as to obscure the sample color on more than 30 percent of surfaces. |
| 4 | Mold covering greater than 70 percent of surfaces providing growth is not so intense or colored as to obscure the sample color on more than 70 percent of surfaces. |
| 5 | Mold covering 100 percent of surfaces or with less than 100 percent coverage and with intense or colored growth obscuring greater than 70 percent of the sample color. |

## Results and discussion

Ratings of mold growth on samples at 2-week intervals during the 8-week tests are summarized in **Table 2** as averages of six replicates of each sample type. Generally, similar resistance to mold growth was observed on comparable sample types in the initial and repeat tests.

For sample types weighed before and after exposure in the initial or repeat test, the average oven dry MC determinations after 8 weeks in the chambers are shown in **Table 3.** The theoretical EMC calculated for solid wood at the chamber conditions (25 °C and 100 percent RH) would be 27 percent. The EMC results confirm the consistency of conditions in all chambers. Increases in MC for adhesive samples indicate affinity for moisture.

PF-ply was resistant to mold growth for the first 2 weeks in both the initial and repeat tests. Between 2 and 6 weeks, mold growth progressed at a consistent rate in both the initial and repeat tests. In the initial test, mold growth reached a maximum by week 8 (average rating of 5.0). In the repeat test, the average rating at 8 weeks reached 3.3, with no indication the growth rate was slowing. The growth rate was less aggressive in the repeat test, perhaps due to better curing and reduced

*Table 2. — Average mold growth ratings of adhesives and controls during 8 weeks in an environment chamber.*

| | | Average rating at 2 weeks | | Average rating at 4 weeks | | Average rating at 6 weeks | | Average rating at 8 weeks | |
|---|---|---|---|---|---|---|---|---|---|
| Sample type | Chamber | (ave) | (sd)* | (ave) | (sd)* | (ave) | (sd)* | (ave) | (sd)* |
| PF-ply | A | 0.0 | (0.0) | 2.2 | (0.8) | 4.3 | (0.5) | 5.0 | (0.0) |
| PF-ply | C | 0.2 | (0.4) | 1.5 | (0.5) | 2.3 | (0.5) | 3.3 | (0.8) |
| PF-OSB | A | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| PMDI | A | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| PRF | B | 2.3 | (0.5) | 3.3 | (0.5) | 3.7 | (0.5) | 3.8 | (0.4) |
| PRF | C | 2.3 | (0.8) | 2.8 | (0.4) | 3.8 | (0.4) | 4.0 | (0.0) |
| MUF | B | 0.0 | (0.0) | 0.0 | (0.0) | 0.2 | (0.4) | 0.7 | (0.8) |
| UF | B | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| Cloth controls | A | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| Cloth controls | B | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| Cloth controls | C | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) | 0.0 | (0.0) |
| Southern pine | A | 3.3 | (0.5) | 4.3 | (0.5) | 4.5 | (0.5) | 4.5 | (0.5) |
| Southern pine | B | 3.2 | (0.8) | 4.3 | (0.5) | 4.5 | (0.5) | 4.8 | (0.4) |
| Southern pine | C | 3.3 | (0.8) | 3.8 | (0.4) | 4.5 | (0.5) | 4.7 | (0.5) |
| Aspen | A | 2.0 | (0.6) | 3.0 | (0.9) | 3.3 | (1.2) | 4.2 | (1.2) |
| Aspen | B | 1.5 | (1.2) | 2.5 | (1.4) | 2.5 | (1.9) | 2.5 | (1.9) |
| Aspen | C | 2.3 | (0.5) | 3.2 | (0.4) | 3.8 | (0.4) | 4.0 | (0.0) |

*sd is the standard deviation.

*Table 3. — Average MC of samples at 8 weeks.*

| | | Initial MC | | Eight week MC | |
|---|---|---|---|---|---|
| Sample type | Chamber | (percent) | (sd)* | (percent) | (sd)* |
| PF-ply | C | 4.1 | (0.5) | 25.1 | (4.9) |
| PRF | C | 10.3 | (0.9) | 13.3 | (1.3) |
| Cloth controls | C | 1.8 | (0.8) | 0.3 | (0.5) |
| Southern pine | A | 15.5 | (5.4) | 25.1 | (2.2) |
| Southern pine | B | 15.5 | (5.2) | 25.9 | (1.5) |
| Southern pine | C | 12.3 | (2.8) | 25.1 | (1.6) |
| Aspen | A | 11.1 | (0.6) | 29.0 | (2.1) |
| Aspen | B | 11.0 | (0.5) | 30.8 | (1.9) |
| Aspen | C | 9.4 | (0.1) | 27.4 | (1.1) |

*sd is the standard deviation.

moisture absorption of the adhesive. Both tests indicate susceptibility of this adhesive to mold growth.

General observations indicated that a single species of mold, not included in the artificial inoculum, colonized samples of PF-ply. In the initial test, the samples seemed to absorb moisture, which led to a release of brown liquid from the lower end of the samples between week 4 and the end of the test. The samples appeared swollen and were soft and flexible. With slight surface drying, while out of the humid chamber during rating, specks of white residue became visible, which became less visible when reintroduced into the humid chamber as surfaces rewetted. The same species of mold growing on the samples colonized the brown liquid pooled on the sample holder below the samples. In the repeat test, the properly cured samples did not swell or exude liquid, although the MC at 8 weeks was determined to be higher than other adhesives at 25 percent, indicating affinity for moisture.

After 8 weeks, PF-OSB samples were not susceptible to mold growth; there was no visual evidence of mold. Small droplets were observed on surfaces of these samples after 2 weeks, indicating an affinity to moisture. Later in the test, small quantities of brown liquid were observed on the sample holder beneath some samples. No mold growth was observed associated with this liquid. The samples remained rigid with a hard surface.

After 8 weeks, PMDI samples were not susceptible to mold growth; there was no visual evidence of mold. There was no evidence of affinity to moisture for these samples and no visual or physical changes in sample characteristics were observed during the test.

In both the initial and repeat tests, the PRF adhesive was susceptible to mold growth, having similar mold growth rates to those on southern pine and aspen controls during the 8-week tests. After 2 weeks, PRF samples in the initial and repeat tests both had average ratings of 2.3. After 4 weeks, mold growth continued to progress on PRF samples (average ratings of 3.3 and 2.8, in initial and repeat test, respectively), and continued through 6 weeks (average ratings of 3.7 and 3.8, in the initial and the repeat tests, respectively). At the end of the 8-week test, there was little additional growth since the 6 week rating (average rating of 3.8 and 4.0, in initial and repeat tests, respectively). After 2 weeks, samples in the initial test appeared to be absorbing moisture, evidenced by sample deformation (curling or collapsing). In the repeat test there was no observable change in sample characteristics, although determination of MC at 8 weeks (13%) indicated some affinity for moisture.

There was no visible growth of molds on the MUF samples until week 6, when very light growth was evident on one sample (average rating of 0.2). Some additional growth was evident at week 8 (average rating of 0.7), although growth was still very limited. MUF is therefore only slightly susceptible to mold growth. There was no evidence of affinity for moisture in these samples and no visual or physical changes in sample characteristics were observed during the test.

After 8 weeks, UF samples were not susceptible to mold growth; there was no visual evidence of mold. After 2 weeks, samples appeared to be absorbing moisture, evidenced by slight sample flexibility and formation of whitish droplets on the sample surfaces.

The fiberglass cloth control was not susceptible to mold growth and remained mold-free for the 8-week duration of the tests.

The southern pine sapwood in both chambers of the initial test and in the repeat test was susceptible to mold growth, with the most rapid progression occurring during the first 4 weeks, reaching an average rating of 4.3 in each chamber of the initial test and average rating of 3.8 in the repeat test. There was some additional growth between week 4 and week 8, reaching average ratings of 4.5 and 4.8 in chambers of the initial test and 4.7 in the repeat test. The growth of molds on southern pine sapwood was consistent on samples in both chambers of the initial test, indicating there was no impediment to mold growth from potential off-gassing of formaldehyde in the second chamber.

Aspen sapwood was susceptible to mold growth in the initial and repeat tests (average ratings at week 2 of 2.0 and 1.5 for chambers in the initial test, and 2.3 in the repeat test), although the growth rate and extent of growth was slightly less than on southern pine sapwood. By week 8, average ratings were 4.2 and 2.5 for the two chambers in the initial test, and 4.0 in the repeat test. The lower average rating for one chamber may be due to the variable growth on some aspen sapwood. In the initial test, in both chambers, the growth of mold was less consistent between samples than for southern pine. Due to this variability, there was no clear indication of possible impediment to mold growth from off-gassing of formaldehyde.

## Conclusions

None of the adhesives was significantly more susceptible to mold growth than southern pine or aspen sapwood and some were substantially less susceptible.

PRF and PF-ply were both susceptible to mold growth, although PF-ply was resistant to growth of mold for the first 2 weeks. Properly cured PF-ply was slightly less susceptible than improperly cured PF-ply samples after 8 weeks. PF-ply showed considerable affinity for moisture. PRF showed some affinity for moisture.

PF-OSB, PMDI and UF were resistant to mold growth for the duration of the 8-week test while MUF was resistant to mold growth for the first 4 weeks, with very little mold growth up to 8 weeks.

The differences observed between the PF-OSB and PF-ply adhesives were presumably an indication that the fillers/extenders believed to be incorporated in the latter may be mold susceptible.

Southern pine sapwood and aspen sapwood were susceptible to mold growth, with growth on aspen generally less extensive and more variable than growth on southern pine sapwood.

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# Preliminary study of thermal treatment effects on mold growth of selected Quebec wood species

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Dian-Qing Yang*
Jilei Zhang*

**Abstract**

ThermoWood® is a Finnish process used for heat treatment of wood at a temperature range of 180 to 260 °C. This process was introduced to Québec, Canada, by Ohlin Thermo Tech. During the initial start-up period, five types of Québec wood (spruce (*Pices* spp.), pine (*Pinus* spp.), fir (*Abies* spp.), aspen (*Populus* spp.), and birch (*Betula* spp.)) were thermally treated in Ohlin Thermo Tech laboratory furnace using ThermoWood® technology. The resistance of the treated wood against mold fungi was examined. Preliminary experimental results indicated that mold resistance of spruce, pine, fir, aspen, and birch can be improved through the thermal modification. The significance of mold resistance improvement was governed by heat treatment schedule in terms of maximum temperature level and heat treatment processing time, which were affected by initial MC and thickness of the boards to be treated.

## Molds and wood

Molds are a specific group of fungi that are often colorful and appear as spots or fuzzy masses (Zabel and Morrell 1992). Mold fungi thrive in high humidity and warm temperatures. Molds are often found on the exposed surfaces of wood structures and ceilings, joints, walls, and surfaces subjected to high humidity. Molds growing on wood surfaces can produce a dark discoloration that can persist even after the mold is cleaned up, but molds are not decay fungi, and do not damage the wood. However, the presence of mold fungi on wood can indicate that decay fungi are present as well. Molds are of increasing concern since some of them can cause respiratory problem in sensitive people. Up to date, it is not well known how molds affect human health (Robbins and Morrell 2002).

Moisture content (MC) of the material and relative humidity and temperature of the environment are critical factors influencing mold growth. Wood, which contains cellulose, lignin, hemicellulose, sugars, starches, proteins, lipids, and fatty acids, can provide the necessary nutrients for mold growth. The key element is moisture. Heat treatment of wood decreases the mold formation because heat-treated wood becomes less hygroscopic as explained in the following section.

## Thermal wood modification

Wood modification is a term applied to treatments that modify the physical and chemical properties of cell wall material in wood. Available methods of wood modification can be divided into: thermal, chemical, biological, and enzymatic treatments. Heating wood to a temperature of 180 °C or above

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is a thermal modification method that changes the chemical structure of wood without introducing chemicals. This method improves the dimensional stability and biological durability of wood (Dirol and Guyonnet 1993). There are several processes for heat treatment of wood, e.g., Plato-Process (The Netherlands), Retification Process (France), Bois Perdure (France), OHT-Process (Germany), and ThermoWood® Process (Finland) (Rapp and Sailer 2000, Syrjänen et al. 2000, Vernois 2001, Militz 2002, Chanrion and Schreiber 2002).

During heat treatment, chemical changes occurring in wood components such as hemicellulose and lignin result in a material that is less hygroscopic compared to untreated wood (Feist and Sell 1987, Tjeerdsma et al. 1998, Alén et al. 2002, Tjeerdsma and Militz 2005). Equilibrium MC (EMC) of thermally modified wood becomes three to four times lower than that of untreated wood (Jämsä and Viitaniemi 2001). Therefore, thermal modification of wood is an environmentally friendly approach to modify the chemical structure of wood cell walls so that its dimensional stability and bio-durability are improved. However, mechanical properties, especially bending strength are decreased in thermally modified wood (Santos 2000, Bengtsson et al. 2002, Chanrion and Schreiber 2002, Yildiz et al. 2002).

## Background

ThermoWood® is a wood heat-treatment process developed at VTT, Finland. Ohlin Thermo Tech., a company in Québec, Canada, and a member of the Finnish ThermoWood® Association, has a pilot-scale furnace for research purposes. During the start-up period of this furnace, some Quebec species were thermally treated using different heat treatment schedules. A typical treatment diagram is shown in **Figure 1**, which can be found in ThermoWood® Handbook (Finnish ThermoWood® Assoc. 2003). As shown, the treatment has three major phases. The first phase is the heating and high-temperature drying phase. During this phase, the wood is heated quickly to 100 °C, then the temperature is increased up to 130 °C and maintained at this temperature until the MC of wood is nearly zero. The second phase is the heat-treatment phase, which takes place at 215 °C. This temperature is kept constant for a predetermined time depending on the species used. The third phase covers the cooling and conditioning periods. The temperature of heat-treated wood is lowered to 80 to 90 °C and the wood MC is brought up to new equilibrium levels, which are much lower than the EMC of the untreated species.

The mold growth resistances of thermally treated and untreated different types of Quebec wood were investigated with the main objective of assessing the improvement in mold resistance of several wood species as they were heat-treated using different process schedules. This study provides data on the resistance of thermally modified wood to mold fungi colonization.

## Material and methods

Five types of wood from Québec, namely, spruce (*Pices* spp.), pine (*Pinus* spp.), fir (*Abies* spp.), aspen (*Populus* spp.), and birch (*Betula* spp.), were thermally treated at Ohlin Thermo Tech. laboratory. **Table 1** summarizes the conditions for the heat-treatment trials. The duration of maximum temperature was 3 hours for all trials. All boards had been previously kiln-dried. The initial MC of the boards ranged from 13.3 percent to 19.2 percent. MC of the thermally modified boards was measured as 2 to 3 percent. After the heat treatment, the boards were visually evaluated for cracks, twists, and deformations. Boards that were free of defects were used for mold growth scale measurements. The untreated boards of the five species were used as reference samples.

Ten replicates were evaluated for each combination of wood types and trials. Observation of mold growth was carried out on specimens with dimensions of 50 mm by 50 mm × 10 mm. All specimens were ovendried at 103 ± 2 °C before the mold test. Then, the specimens were placed in a chamber at a temperature of 25 °C and a relative humidity of 100 percent for mold incubation. The methods and procedures given in ASTM D 3273–94 (1994) were followed. After 8 weeks of incubation, the specimens were visually rated for mold growth scale, and the method can be found in **Table 2**. A 16× magnifying lens was used for the observation. Experimental trials were carried out in each series. Duncan's multiple-range test was performed to examine the difference in mold growth scales among the different trials within each wood type at 0.05 significance level using Statistical Analysis Software® (SAS Inst., Inc.1990).

## Results and discussion

**Table 3** presents the average mold growth scales (average of 10 measurements), standard deviations, as well as the percentage change in each average mold scale compared

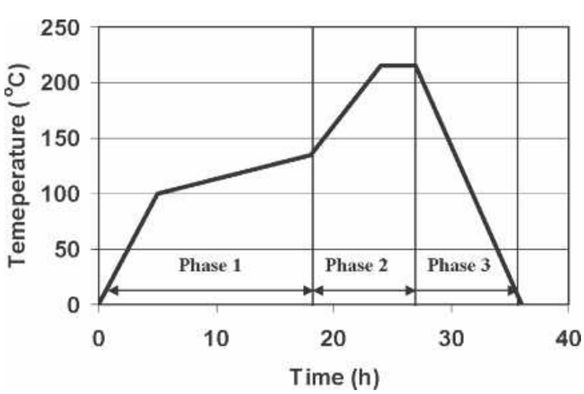


*Figure 1. — Diagram of ThermoWood® heat treatment process cycle. (Finnish ThermoWood® Association 2003)*

*Table 1. — Summary of heat treatment trials.*

| Species | Trial no. | Initial average MC | Board dimension | Maximum temperature | Total processing time |
|---|---|---|---|---|---|
| | | (%) | (mm) | (°C) | (h) |
| | 1 | 19.2 | 39 × 140 × 2000 | 212 | 40.5 |
| Spruce | 2 | 16.4 | 39 × 140 × 2000 | 212 | 44 |
| | 4 | 13.3 | 23 × 140 × 2000 | 202 | 25 |
| Pine | 7 | 18.7 | 32 × 140 × 2000 | 200 | 34 |
| | 6 | 19.1 | 45 × 145 × 2000 | 202 | 46 |
| | 8 | 15.5 | 32 × 140 × 2000 | 202 | 34 |
| Fir | 9 | 18.2 | 32 × 140 × 2000 | 212 | 30 |
| Aspen | 3 | 19.1 | 44 × 140 × 2000 | 200 | 46 |
| Birch | 5 | 14.3 | 23 × 120 × 2000 | 200 | 31 |

*Table 2. — Rating method for visual examination of mold growth scale on the specimens.*

| Scale | Severity of mold growth |
|---|---|
| 0 | no mold growth |
| 1 | <5 percent mold coverage |
| 2 | 6% < 25 percent mold coverage |
| 3 | 26% < 50 percent mold coverage |
| 4 | 51% < 75 percent mold coverage |
| 5 | >76 percent mold coverage |

*Table 3. — Mold growth scale of heat-treated spruce, pine, fir, aspen, and birch.*

| | | Mold growth scale | | |
|---|---|---|---|---|
| Species | Treatment | Value* | SD | Change in percentage (%) |
| Spruce | Untreated | 3.13*a* | 1.25 | -- |
| | Trial no. 1 | 1.39*b* | 1.08 | −56 |
| | Trial no. 2 | 1.41*b* | 0.27 | −55 |
| Pine | Untreated | 1.35*a* | 0.52 | -- |
| | Trial no. 4 | 1.28*a* | 0.80 | −5 |
| | Trial no. 7 | 1.37*a* | 0.50 | +1 |
| Fir | Untreated | 2.97*a* | 1.20 | -- |
| | Trial no. 6 | 0.82*b* | 0.44 | −72 |
| | Trial no. 8 | 0.80*b* | 0.50 | −73 |
| | Trial no. 9 | 0.78*b* | 0.51 | −74 |
| Aspen | Untreated | 2.44*a* | 0.58 | -- |
| | Trial no. 3 | 2.12*a* | 0.53 | −13 |
| Birch | Untreated | 4.23*a* | 0.06 | |
| | Trial no. 5 | 3.50*b* | 0.17 | −17 |

* Values with the same letter within a species were not significantly different at the 5 percent significance level.

to that of untreated wood. The percentage change in mold growth scale of each trial compared to untreated one within each species was calculated. The differences were expressed as percentage of the scale for untreated wood as shown in column 5 of **Table 3**.

Mold growth scale values of thermally modified spruce specimens were significantly reduced compared with untreated specimens. This implies that the heat treatment of spruce at 212 °C for 3 hours with a total processing time of 40.5 hours can effectively improve the mold resistance of spruce. No significant difference in mold growth between trials no. 1 and 2 were observed.

There was no significant difference in mold growth among thermally modified and untreated pine specimens. This might be due to the synchronous effects of initial MC, process maximum temperature, and total processing time, especially for the lower maximum temperature and shorter heat processing time compared to heat treatment conditions for spruce. The heat treatment parameters of trial no. 4 (25 hours and 202 °C) and trial no. 7 (34 hours and 200 °C) were not sufficient to improve the mold resistance of pine.

The thermally treated fir specimens showed significantly reduced mold growth compared with untreated specimens. The percentage differences between treated and untreated were 72 percent, 73 percent, and 74 percent for trials 6, 8, and 9, respectively. These results further indicated that the maximum temperature and processing time for heat treatment should be determined with consideration of initial MC of the board to be treated. For higher MC such as 18.2 and 19.1 percent, if higher temperature 212 °C is selected, then the shorter processing time of 30 hours is sufficient, or if lower temperature 202 °C is used, then the longer treatment hours are needed. There was no significant difference in mold growth among the treated fir specimens.

Mold growth of the treated aspen was reduced by 13 percent (**Table 3**), but this change is not significant. This result showed that the 46-hour treatment at 200 °C for 3 hours is not sufficient to significantly reduce the mold growth of aspen specimens with the board initial MC of 19.1 percent. This observation seems to be consistent with the result of pine treated through trial no. 7. These results might imply that for the board with higher MC a higher temperature and longer processing hours are required, which was supported by the results from the trials no. 6 and 9.

The mold growth of heat-treated birch was reduced by 17 percent compared with untreated birch, and this reduction is significant. This result indicated that the mold resistance of birch specimens with an initial MC of 14.3 percent can be improved through treating the board at 200 °C for 3 hours with a total processing time of 31 hours. This indicates that the total processing time is a significant factor, i.e., the shorter interval may result in insignificant reduction in mold growth. Insignificant reduction in mold growth of trial no. 4 for pine specimens seems to support the observation that longer total processing time is suitable for lower temperature.

## Summary and conclusions

Five wood types, three softwood, and two hardwood, from Québec were thermally modified using Finnish ThermoWood® technology with various heat treatment schedules. Mold growth of the thermally modified wood specimens was visually rated after 8 weeks of incubation and compared with untreated specimens. Experimental results indicated that, in general, the magnitude of mold growth reduction was affected by initial MC of the boards to be treated, maximum temperature, total processing time, and thickness of the boards. Maximum temperature and total processing time should be determined according to the initial MC and thickness of the boards to be treated.

For softwood specimens with initial MC values ranging from 18.2 percent to 19.1 percent, a total processing time of 34 hours with a maximum temperature of 200 °C and duration of 3 hours was not sufficient to significantly improve mold resistance. Spruce specimens 29-mm thick can be significantly improved (56%) with a treatment schedule of total 40.5 to 44 hours with 3 hours at 212 °C. Under the same conditions, 32-mm-thick fir needed 30 hours for the processing time. A lower temperature of 202 °C with a total 46-hour processing time also can yield a significant improvement of 72 percent in mold resistance for fir specimens with 45-mm thickness.

For softwood specimens with initial MC values ranging from 13.3 to 16.4 percent, a total processing time of 25 hours with a maximum temperature of 202 °C maintained for 3 hours was not sufficient to significantly improve mold resistance. At a maximum temperature 202 °C, it seems longer processing hours are needed. A 34-hour processing time yielded 73 percent improvement in mold resistance. A higher maximum temperature 212 °C for 44 hours yielded a significant improvement (55%) in mold resistance compared to that of untreated wood.

For aspen specimens with an initial MC of 19.1 percent, a higher maximum temperature might be needed in order to improve mold resistance significantly. A higher maximum temperature or longer processing time should improve mold resistance for birch boards with an initial MC of 14.3 percent.

Experimental results of this preliminary study show the benefits of heat treatment for improving mold resistance. Further studies with more trials need to be carried out with desired species in order to develop the most favorable heat treatment schedules for each wood species by considering different board thickness levels and with different initial MC values. Beside the consideration of mold resistance improvement, other material properties such as mechanical properties may also need to be considered when developing such optimum heat treatment schedules for various wood species.

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# A method to assess lumber grade recovery improvement potential for black spruce logs based on branchiness

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**Abstract**

A log-level lumber grade assessment method based on branchiness was developed to bring lumber grade considerations into forest management planning. Existing methods focus primarily on mean or maximum knot size per log. The method developed in this study is based on branch size and location on log surface, internal knot shape, and log size. Assuming a cylindrical log shape with a central pith, a log transformed linear regression model was developed to predict minimum horizontal branch angle (branch azimuth) between successive knots, with respect to log size, that would produce at least one piece of lumber at a desired grade, by product, from the center cant using either an edge or centerline knot pattern. The minimum difference in horizontal branch angle between successive branches decreased with increasing log size if product specifications were held constant and increased with increasing product width if log size remained constant. The above method was demonstrated using a sample of logs from three initial spacings (1.8 m, 2.7 m, and 3.6 m). Although lumber grade recovery improvement potential varied from 0 percent to 40 percent across spacings, no clear trend was evident for improvement potential by spacing at the product and grade level based on a chi-square analysis using a 2×3 contingency table ($\chi^2_{0.05,3} = 7.815$, $\chi^2_{edge} = 3.979$, and $\chi^2_{centerline} = 2.392$).

The forest industry in North America has billions of dollars invested in wood-processing facilities, harvesting equipment, and reforestation programs. Management of this resource is without question critical to each company's financial success. Forest growth models provide overall estimates of tree growth and stand volume needed for long-term resource planning. Technological advances on harvesting equipment provide detailed log product specifications for sawmill delivery schedules. Sophisticated log shape scanners and sawing equipment are used to maximize lumber volume recovery based on log geometry. In general, however, there is far less information available on wood quality prior to processing.

Log scanning technology and lumber conversion simulation programs make it relatively easy for sawmills to predict lumber recovery. Many high production mills have log scanners located on in-feed lines, which use log shape information to optimize sawing patterns. There are several wood product simulation software packages available in the research community (Todoroki 1990, Grondin and Drouin 1998). In each case the user has control over sawmill configurations and product specifications (e.g., dimensions and price). Logs are represented as a series of circular cross sections or by true shape determined from laser scanned images. Not to oversimplify this process, but in essence this is an exercise in geometry. These programs cut rectangles from circles. Realistic estimates can also be made manually or in simple spreadsheet programs. At the most basic level, all that is required are data pertaining to tree height and diameter. As planning tools, these programs provide estimates of product volume from a given stand or harvest block, but it is more difficult to include product quality considerations.

Knots (or branches) are the most prominent wood quality defect visible on both standing trees and solid wood products.

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*Table 1. — Maximum knot sizes by product and grade (NLGA 2003).*

| Product | Grade | Maximum knot size Edge | Center |
|---|---|---|---|
| | | --------------- cm (in)------------- | |
| 2 × 3 | SS | 1.27 (½) | 1.27 (½) |
| | No. 2 | 2.22 (⅞) | 2.22 (⅞) |
| 2 by 4 | SS | 1.90 (¾) | 2.22 (⅞) |
| | No. 2 | 3.18 (1 ¼) | 5.08 (2) |
| 2 by 6 | SS | 2.86 (1 ⅛) | 4.76 (1 ⅞) |
| | No. 2 | 4.76 (1 ⅞) | 7.30 (2 ⅞) |

Both knot size and position within the piece of lumber is an important consideration in determination of lumber grade. In general, larger knots are allowed at the centerline of the piece, as opposed to knots that have the potential to be in a face and exposed to tension or compression stress (ASTM 245–05). Basic knot characteristics (size by position) for selected grades of dimension lumber are presented in **Table 1**. Given this fact, any system that allows *a priori* evaluation of the log to produce pieces with maximum strength values has the potential to increase profitability.

The significance of knots to lumber quality is highlighted by many log quality measures. Knot indices for logs include maximum or average knot sizes (Grah 1961, Ballard and Long 1988, Mitchell 1988, Johansson 1992, Di Lucca 1999, Zhang et al. 2002), number of clear faces (Wagner and Taylor 1975), and average knot size per quadrant (Inglis and Cleland 1982, Briggs and Fight 1992). The underlying assumption for the above knot indices is that they can be related to final product quality from each log. Mitchell (1988) developed a deterministic relationship between average knot size per log and lumber grade yield for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Johansson (1992) went one step further in his Norway spruce (*Picea abies* (L.) Karst) stem quality assessment by adding number of branches per whorl and height to lowest live branch to the relationship between maximum branch diameter and lumber grade recovery (visual and machine stress rated). None of these measures can be used to determine the "best" log orientation.

Improvements in lumber grade can be achieved if knot location is considered during primary log breakdown. It has been illustrated using southern pine logs that simulated grade yields with respect to knots vary with changes in log position during processing (Wagner and Taylor 1975). Samson (1993) conducted a theoretical study to determine effect of three separate knot patterns (one knot, two knots 180 degrees apart, and three knots 120 degrees apart) on two log breakdown patterns (live and cant sawing). Results showed that variations in grade yield of 6 to 25 percent existed between each case. Although this study does outline a methodology for assessing log orientation with respect to knots during primary processing, the assumption of having only one to three knots per log makes it difficult to apply results in a practical manner. Knot shape was also oversimplified in this study: a circular cone, positioned normal to log axis with a 20-degree vertex. Black spruce lumber strength can be improved if knot location is considered during primary log breakdown. Lemieux et al. (2002) showed that a difference of 15 percent for modulus of elasticity (MOE) and 25 percent for modulus of rupture

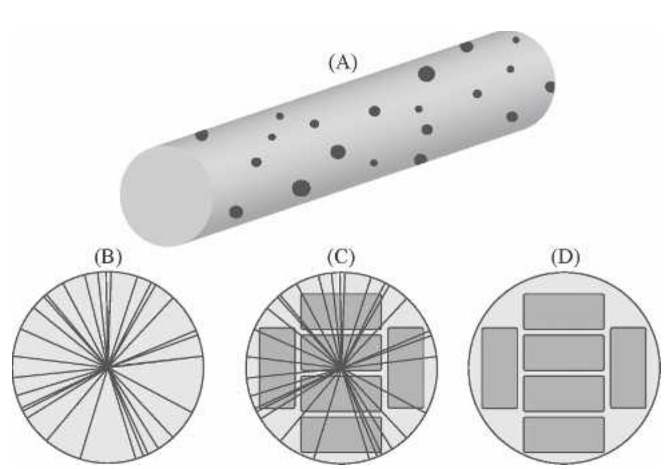


*Figure 1. — Log quality assessment example for 2 by 4 dimension lumber assuming 2.5 m log length and 22 cm top diameter (A). Knot centerlines are projected onto top log cross sections for all knots (B), for all knots overlaid with 2 by 4 cant saw pattern (C), and for all knots greater than or equal to grade No. 2 or better minimum knot size limits for 2 by 4 dimension lumber (D).*

(MOR) was observed between the best and worst sawing patterns. Although lumber properties improved significantly, lumber volume recovery was reduced to 32 percent. The same study (Lemieux et al. 2002) also determined that with respect to visual grade recovery, downgrade according to knots in black spruce from natural stands is quite low. To obtain an accurate assessment of these results for the sawmilling industry, quantity and quality of final product must be compared.

There is a maximum value associated with every log as defined by product volume recovery and product quality. Depending on knot size and location, and log shape, there may be multiple combinations of log orientation and sawing pattern that achieve maximum value for a given log. Since a log can only be sawn once, only *one* of the possible combinations of log orientation and sawing pattern needs to be identified. In some instances, log orientation may have no effect on lumber grade yield. Therefore, a sawmill needs to first determine if a log even has *potential* to improve lumber grade by considering knot location prior to processing.

The objectives of this study were: 1) to develop a method to assess lumber grade recovery improvement potential at the log level using branch size and location on log surface, internal knot shape, log top diameter, and visual grading rules for dimension lumber, and 2) to demonstrate how this method could be applied using a sample of 2.5 m black spruce logs selected from a spacing trial near Thunder Bay, Ontario.

## Assessment method

Following the approach of Grah (1961), the most basic log level assessment of lumber grade recovery is based on a comparison between the largest knot per log and the minimum product and grade knot size limits as listed in **Table 1**. Consider a log 2.5 m in length and 22 cm in diameter at the top end. Thirty knots are identified on the log surface; three knots are between 23 and 30 mm and the remaining 27 knots are less than 22 mm (**Fig. 1a**). The centerlines for all knots on the log can be projected onto a single cross section based on top log diameter (**Fig. 1b**). This assumes that knots are oriented perpendicular to the pith and does not account for log taper or

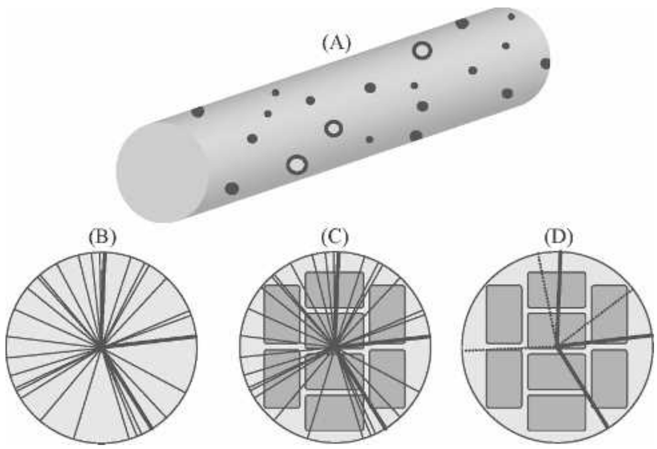


*Figure 2. — Log quality assessment example for 2 by 3 dimension lumber assuming 2.5 m log length and 22 cm top diameter. (A) Knot centerlines are projected onto top log cross sections for all knots, (B) for all knots overlaid with 2 by 3 cant saw pattern, and (C) for all knots greater than or equal to grade No. 2 or better minimum knot size limits for 2 by 3 dimension lumber (D). Open filled knots (A) and heavy knot centerlines (B to D) denote knots greater than 22 mm (7⁄8 in). Dashed lines (D) represent location of knots greater than 22 mm (7⁄8 in) after the log is rotated approximately 90 degrees.*

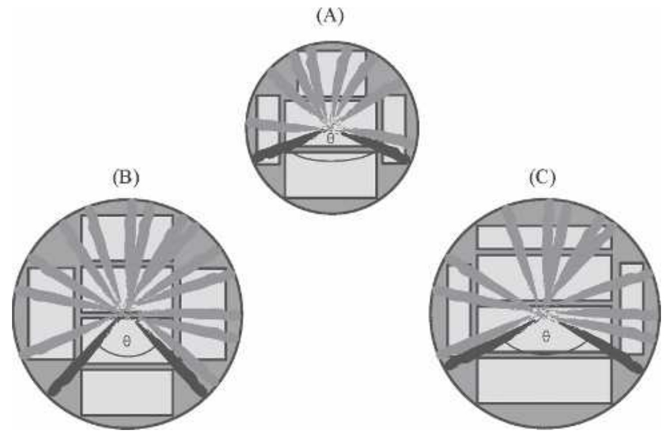


*Figure 3. — Sample sawing patterns illustrating effect of log size (A to B) and product (B to C) on angle difference, Θ, between successive edge knots.*

sweep. If a 2 by 4 cant sawing pattern is overlaid onto the cross section from **Figure 1b**, it is obvious that no piece of lumber will be clear of knots (**Fig. 1c**). If one considers that the knot size limit for grade No. 2 or better 2 by 4 dimension lumber is less than or equal to 31.8 mm, then all processed 2 by 4 lumber from that log will be grade No. 2 or better (**Fig. 1d**).

Limitations of this assessment become evident as knot size limits change based on grade or product. Knots greater than 23 mm and less than 30 mm from the above example are highlighted in **Figures 2a** and **2b** as open filled circles with heavy lines. As was the case for 2 by 4 lumber, if a 2 by 3 cant sawing pattern is overlaid onto the cross section from **Figure 2b**, no piece of lumber will be clear of knots (**Fig. 2c**). If one considers that knot size limits for grade No. 2 or better 2 by 3 dimension lumber is less than or equal to 22.2 mm, it becomes evident that not all 2 by 3's would meet grade No. 2 or better specifications (**Fig. 2d**). As shown with dashed lines in **Figure 2d**, it is clear that rotating the log approximately 90 degrees counterclockwise would improve grade recovery with respect to knots. It is important to note that some products, those processed closest to the pith, may still meet minimum grade requirements due to knot taper, but grade recovery can still be underestimated if only knot size is considered prior to processing.

Knot size must be considered with difference in horizontal angle between successive knots and log diameter to determine lumber grade recovery improvement potential. As shown in **Figure 3**, the difference in horizontal knot angle, θ, decreases with increasing log size if product specifications are held constant (A to B) and increases with increasing product width if log size remains constant (B to C). These observations hold true when considering knots located at or near the edge of lumber (edge knot pattern) and lumber grading rules for edge knots apply accordingly (**Table 1**). It should be noted that examples shown in **Figure 3** assume a perfect cylinder for log shape with a central pith. Knots displayed on each cross section represent all knots along log length, which was fixed at 2.5 m.

The minimum horizontal knot angle between successive knots that would produce at least one piece of lumber at a desired grade from the center cant was estimated for each grade and product class at log diameter intervals of 2 cm based on edge knot size limits (NLGA 2003). Angle estimates were made using a spreadsheet based sawing simulation program called CantSIM (Benjamin 2006). For this study, sawkerf was assumed to be 6.35 mm (1/4 inch) and cant widths considered were for unseasoned dimension lumber. The center cant in CantSIM is offset from log center to allow for a smaller size of lumber or board to fit above it (**Fig. 3c**), so the minimum angle between successive knots can be over 180°.

Using simulated data from above, a log transformed linear regression model was developed to predict the minimum angle between successive knots (MINHKA) with respect to log size (LOGSIZE) that would produce at least one piece of lumber at a desired grade, by product (prod), from the center cant. The equation fitted was:

$$\log(\text{MINHKA})_{\text{prod}} = b_0 + b_1 \cdot \log(\text{LOGSIZE}) \qquad [\mathbf{1}]$$

Visual grading rules for lumber also provide allowances for centerline knots (NLGA 2003). Although location of three knots must be considered for a centerline knot pattern (**Fig. 4**), Equation [**1**] can still be used to determine the minimum angle difference required between edge knots. **Figure 4a** shows the ideal case where $\theta c1 = \theta c2$ and the center knot is located along the product centerline. A second scenario is more likely to arise where $\theta c1 + \theta c2 > \text{MINKHA}$, but as long as both θc1 and θc2 are > 1/2 MINKHA, the center knot can still be positioned along the product centerline (**Fig. 4b**). Given that a centerline knot can be located anywhere within the middle third of the wide product face (NLGA 2003), a third and final scenario exists for centerline knot patterns (**Fig. 4c**). As long as $\theta c1 + \theta c2 > \text{MINKHA}$, θc1 is the determining factor in classifying the middle knot as a centerline knot. Using simple trigonometric relationships, the minimum value for θc1 (**Fig. 4c**) was found to be:

$$\theta c1 = (\text{MINHKA}/2) - \tan\left(\frac{\tan^{-1}(\text{MINHKA}/2)}{3}\right) \qquad [\mathbf{2}]$$

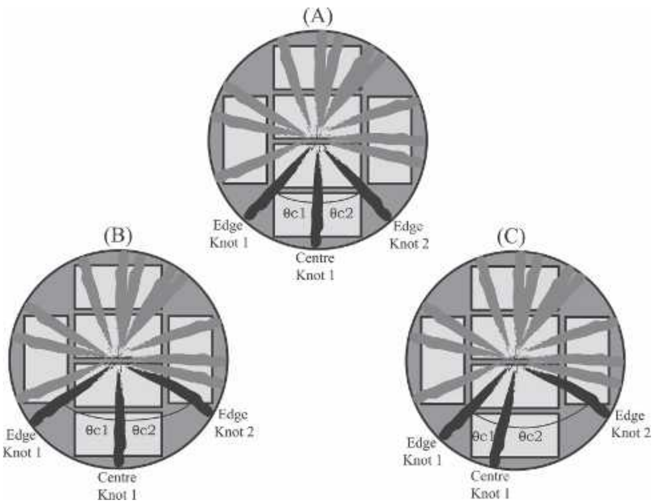


Figure 4. — Sample sawing patterns illustrating three options for centerline knots.

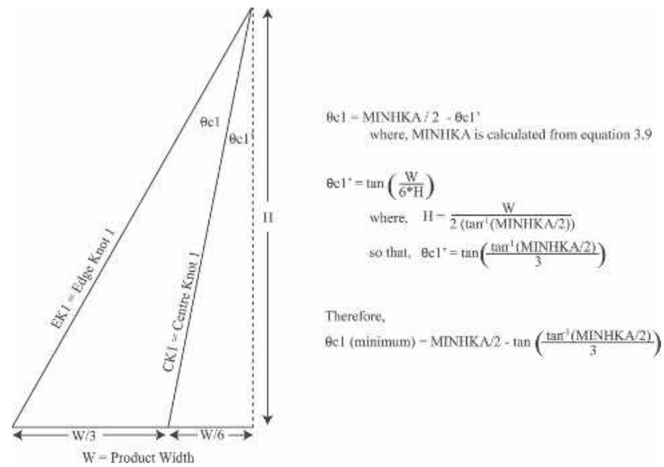


Figure 5. — Determination of minimum angle, θc1, required for centerline knot pattern as shown in Figure 4.

*Table 2. — Regression statistics, parameter estimates and approximate standard errors for minimum difference in horizontal knot angle (radians) model (Eq. [1]).*

| | | | | $\log(\text{MINHKA})_{\text{prod}} = b_0 + b_1 \cdot \log(\text{LOGSIZE})$ | | | |
|---|---|---|---|---|---|---|---|
| Model | Product | Grade | $R^2$ | $B_0$ | SE | $b_1$ | SE |
| Equation [1a] | 2 by 3 | SS | 0.997 | 4.761 | 0.0690 | −1.503 | 0.0225 |
| Equation [1b] | 2 by 3 | No. 2 | 0.998 | 4.765 | 0.0669 | −1.474 | 0.0218 |
| Equation [1c] | 2 by 4 | SS | 0.999 | 4.759 | 0.0511 | −1.400 | 0.0164 |
| Equation [1 days] | 2 by 4 | No. 2 | 0.999 | 4.801 | 0.0395 | −1.388 | 0.0127 |
| Equation [1e] | 2 by 6 | SS | 0.998 | 5.144 | 0.0601 | −1.382 | 0.0187 |
| Equation [1f] | 2 by 6 | No. 2 | 0.996 | 5.144 | 0.0938 | −1.357 | 0.0291 |

An illustration and derivation of Equation [**2**] is provided in **Figure 5**.

Parameter estimates and associated regression statistics for minimum difference in horizontal knot angle model, Equation [**1**], are shown in **Table 2**. Given the theoretical nature of this exercise (i.e., using simulated data) it is not surprising that each model performed well. It is interesting to note however, that knot size, as defined by each grade, does not influence minimum difference in horizontal angle as much as log diameter or product width (**Fig. 6**).

In summary, potential to improve lumber grade can be assessed at the log level if consideration is given to branch size and location around the stem prior to processing. The edge knot pattern assessment is determined by comparing the largest difference between successive knots with minimum knot angle from Equation [**1**]. The centerline knot pattern assessment also considers angle difference between the centerline knot and its closest edge knot from Equation [**2**].

## Application

### Study site description and measurements

The Ontario Ministry of Natural Resources (OMNR) established two spacing trials near Thunder Bay, Ontario in 1950. Each trial contained white spruce (*Picea glauca* ((Moench) Voss)), red pine (*Pinus resinosa* (Ait.)), and black spruce. The projects are known as the Thunder Bay and Stanley spacing trials. These are the oldest black spruce spacing trials in Canada. The objective of the trials was to determine effect of initial spacing on tree growth and stand yield over time. Blocks were established at spacings of 1.8 m, 2.7 m, and 3.6 m for all species.

In 2003, 18 trees were harvested from the Stanley trial for a detailed black spruce branchiness study. A description of selected trees is shown in **Table 3**. To facilitate measurement of branch azimuth, a line was painted on each tree from breast height to ground indicating north and south facing sides prior to harvest. Once trees were felled branches were pruned with loppers leaving 5 to 10 cm stubs and each branch was identified as either live or dead. Painted direction lines were continued along stem length. Trees were bucked into approximately 2.5 m (8 ft) sections to facilitate measurement of external knot (branch stub) characteristics.

Distance to each knot from base of log was measured to the nearest 1 cm and used to calculate knot height (KH). Vertical knot diameter (VD) was measured parallel to the stem and horizontal knot diameter (HD) was measured perpendicular to the stem using a digital micrometer to the nearest 0.1 mm. Knot size (KSZ) was calculated as the arithmetic average of VD and HD. Horizontal knot angle (HKA) was measured using a 360-degree protractor and string system. A protractor was fastened to the base of each log and oriented with respect to painted direction lines along the tree stem. A string was placed over each branch stub and run down the stem to intersect with the protractor (Lemieux et al. 2001). Knots were pruned flush with the tree stem before final log measurements (top and bottom diameters, and length) were made. A summary of branch size from selected trees by initial spacing is shown in **Table 4**.

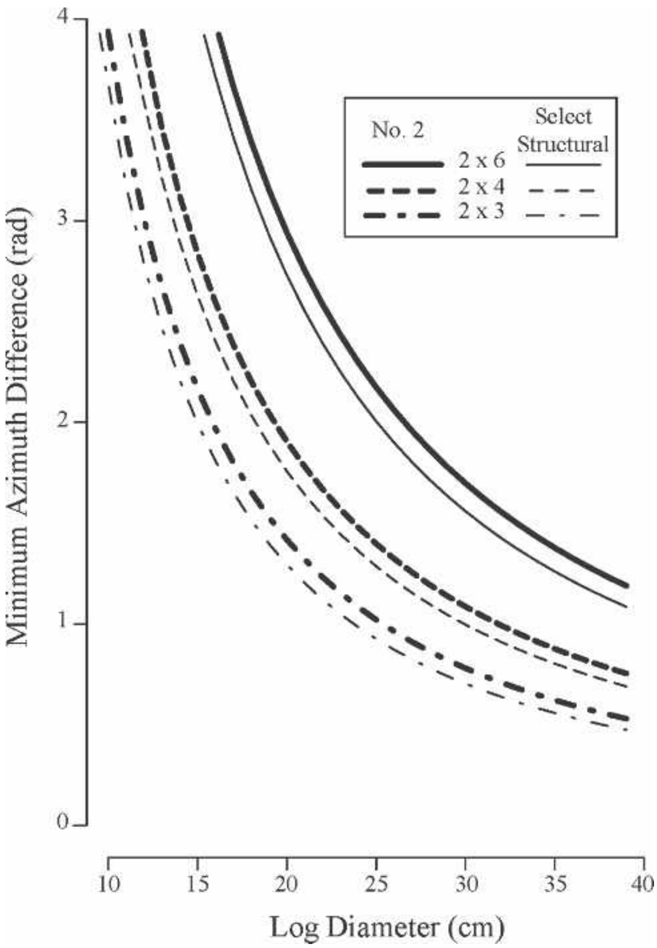


*Figure 6. — Minimum angle difference (radians) between successive knots by log diameter for product and grade.*

## Results

An assessment of lumber grade improvement potential was performed on logs from the Stanley site. **Figures 7** and **8** illustrate how the assessment was conducted using the log of maximum top diameter. Knot size limits changed with each grade of product (**Table 1**), so the number of knots per log that impacted lumber grade and resulting distribution of knots around the log also changed. Solid lines originating from log center on **Figures 7** and **8** represent location of knots greater than minimum grade limits. Each sawing pattern produced 32 BF of lumber, but the only option to improve grade recovery for both edge and centerline knot assessments was for No. 2 2 by 4's (**Figs. 7d** and **8d**). All 2 by 6's also met grade No. 2 requirements (**Figs. 7f** and **8f**) but there was no improvement potential for either situation because the log did not contain any knots greater than minimum grade requirements.

Lumber quality assessment results are shown in **Table 5**. The number of logs assessed from each spacing decreased with increasing product size due to minimum top diameter limits for each product. Lumber grade improvement potential varied from 0 percent to 40 percent across spacings when considering edge and centerline knot patterns (**Table 5**). As stated earlier, log orientation will have no effect on lumber grade yield, with respect to knots, if there are too many knots greater than minimum grade requirements. The same is true if there are *no knots* greater than a given size limit. These scenarios explain why several spacing-product-grade classes in **Table 5** have a zero percent improvement potential.

There is no clear trend in improvement potential across spacings for each product and grade (**Table 5**). With increasing spacing lumber grade recovery improvement potential decreased for select structural 2 by 3's and increased for No. 2 2 by 3's for both edge and centerline knot pattern assessments. An increase in improvement potential exists for No. 2 2 by 4's with increasing spacing, but only for the edge knot pattern assessment; there is a zero percent chance of improvement for the centerline knot pattern assessment. Even the magnitude of improvement potential varies widely across spacings for each product and grade (7 to 22 percent for 1.8 m spacing, 13 to 35 percent for 2.7 m spacing, and 14 to 40 percent for 3.6 m spacing).

A chi-square analysis using a 2 × 3 contingency table ($\chi^2_{0.05,3} = 7.815$) did not show a difference in lumber grade recovery improvement potential across spacings with either knot pattern assessment for select structural grade ($\chi^2_{edge} = 0.185$, $\chi^2_{centerline} = 0.225$). A difference was found for No. 2 lumber ($\chi^2_{edge} = 8.646$, $\chi^2_{centerline} = 13.615$), but given industry practice of marketing lumber under a grouped classification of "No. 2 and Better," it is more relevant to consider results for all products and grades. There was no difference in lumber grade recovery improvement potential across spacings for all products and grades ($\chi^2_{edge} = 3.979$, $\chi^2_{centerline} = 2.392$).

## Discussion

The above log assessment confirms conclusions by other studies (Wagner and Taylor 1975, Samson 1993, Steele et al. 1994, Lemieux et al. 2002, Todoroki et al. 2005) which indicate opportunities exist to improve grade recovery if consideration is given to knot location prior to processing. None of the other studies, with the exception of Todoroki et al. (2005) who indicated that changes in horizontal knot angle of up to 2.5 degrees influenced grade yield in simulations, attempted to explain why improvements are expected nor how they can be achieved. This study shows that log orientation influences lumber grade recovery, by consideration of knot size and horizontal knot angle, and provides a method to assess log-level lumber grade recovery improvement potential. This does not mean that current sawmilling practices never find the "best" sawing pattern and log orientation. As noted earlier, there may be many ways to saw a particular log and achieve the same result. As the number of sawing solutions increases, so does the likelihood that the "best" solution would be found by chance.

Knot size is usually not a limiting factor for visually graded black spruce lumber. It has been shown that less than 10 percent of black spruce lumber is downgraded due to knots (Zhang et al. 2002). The above method and results may not be important for black spruce, but the methodology proposed is not species specific. Equations [**1**] and [**2**] were developed using visual grading rules for softwood dimension lumber in Canada. Additional products (e.g., 2 by 8 or 2 by 10) can be added to the models if necessary and new equations can be developed for other species-product combinations or grading rules. This method could also be adapted to visual quality level restrictions placed on edge knots from machine-stress-rated (MSR) lumber (Courchene and Lam 1998). Since the

Table 3. — Mean tree size and SD (in parentheses) by initial spacing for destructively sampled black spruce trees at the Stanley Spacing Trial.

| Initial spacing | No. of trees | No. of logs | DBH | Total height | Crown Width | Crown Length |
|---|---|---|---|---|---|---|
| (m) | | | (cm) | (m) | (m) | (m) |
| 1.8 | 8 | 30 | 17.1 (2.2) | 16.8 (1.0) | 1.5 (0.5) | 5.4 (1.1) |
| 2.7 | 7 | 30 | 22.6 (1.5) | 19.0 (0.7) | 3.1 (0.4) | 9.2 (1.4) |
| 3.6 | 3 | 7 | 25.5 (3.7) | 16.7 (0.2) | 4.7 (1.0) | 14.5 (0.3) |

Table 4. — Sample size and summary statistics for branch size of selected trees by initial tree spacing.

| Initial tree spacing | No. of knots | Summary statistics Minimum | Maximum | Mean | Std. dev. |
|---|---|---|---|---|---|
| (m) | | (mm) | (mm) | (mm) | (mm) |
| 1.8 | 1219 | 5 | 27.7 | 9.1 | 3.6 |
| 2.7 | 1873 | 5 | 35.6 | 10.6 | 4.9 |
| 3.6 | 1523 | 5 | 43.0 | 12.9 | 7.1 |

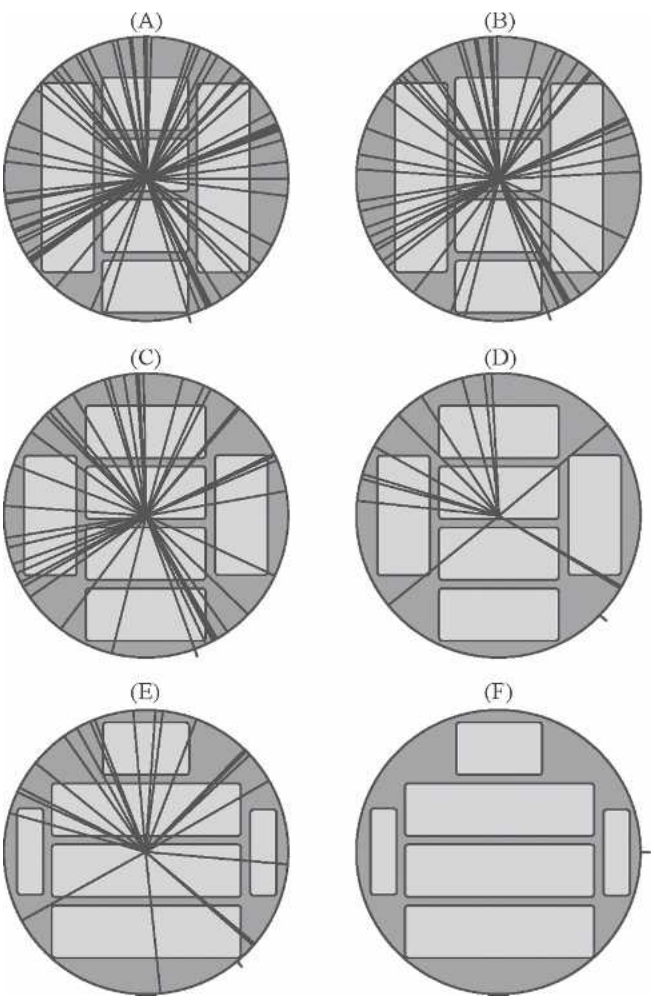


Figure 7. — Edge knot lumber quality assessment on Stanley log of maximum top diameter (21.35 cm). (A) 2 by 3 SS; (B) 2 by 3 No. 2; (C) 2 by 4 SS; (D) 2 by 4 No. 2; (E) 2 by 6 SS; (F) 2 by 6 No. 2.

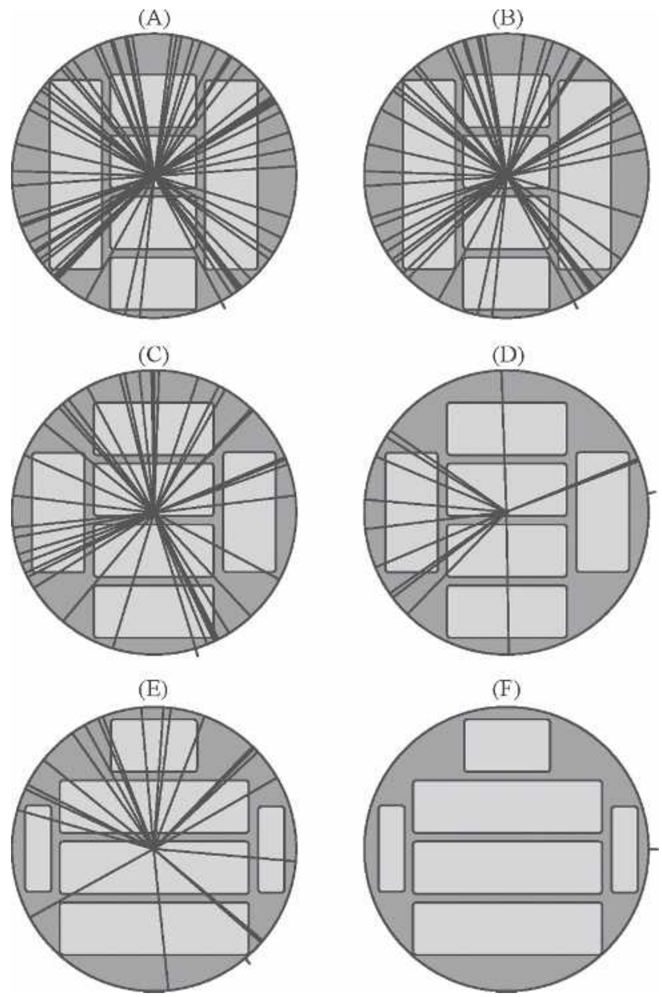


Figure 8. — Centerline knot lumber quality assessment on Stanley log of maximum top diameter (21.35 cm). (A) 2 by 3 SS; (B) 2 by 3 No. 2; (C) 2 by 4 SS; (D) 2 by 4 No. 2; (E) 2 by 6 SS; (F) 2 by 6 No. 2.

method is theoretical and based on geometric and trigonometric relationships, extensive sampling and destructive testing are not required to expand the models and methodology.

It should be stressed once again that log shape has been oversimplified for the assessment method and demonstration described in this chapter. Only log top diameter was used in the assessment and knots along entire log length (approximately 2.5 m) were projected onto a single cross section while maintaining their respective circular locations. This was necessary to develop the equations (**Table 2**) and relationships (**Figs. 3** to **6**) between product size and grade, knot size and

*Table 5. — Percentage of logs with grade improvement potential by spacing.*

| Spacing | Product | Grade | No. of logs | Percentage of logs (%) Edge knot pattern | Centerline knot pattern |
|---|---|---|---|---|---|
| (m) | | | | | |
| 1.8 | 2 by 3 | SS | 30 | 17 | 17 |
| | | No. 2 | 30 | 7 | 0 |
| | 2 by 4 | SS | 23 | 22 | 0 |
| | | No. 2 | 23 | 0 | 0 |
| | 2 by 6 | SS | 5 | 0 | 0 |
| | | No. 2 | 5 | 0 | 0 |
| 2.7 | 2 by 3 | SS | 30 | 17 | 13 |
| | | No. 2 | 30 | 33 | 13 |
| | 2 by 4 | SS | 26 | 35 | 15 |
| | | No. 2 | 26 | 8 | 0 |
| | 2 by 6 | SS | 16 | 0 | 0 |
| | | No. 2 | 16 | 0 | 0 |
| 3.6 | 2 by 3 | SS | 7 | 0 | 14 |
| | | No. 2 | 7 | 43 | 29 |
| | 2 by 4 | SS | 7 | 14 | 14 |
| | | No. 2 | 7 | 29 | 0 |
| | 2 by 6 | SS | 5 | 40 | 0 |
| | | No. 2 | 5 | 0 | 0 |

location, and log diameter. Sample logs in this study were not significantly tapered at 2.5 m to adversely affect lumber recovery, so the assumption of cylindrical shape based on top diameter is valid. Influence of log sweep would be greatly reduced in practice providing curve sawing techniques were used.

Initial tree spacing positively influences knot size through increased crown dimensions and DBH. Therefore, from a forest management perspective, it is expected that lumber grade recovery would be greater at closer spacings. In fact, many studies have demonstrated this assumption. Using material from the same site as this study, Zhang et al. (2002) found that lumber grade recovery and lumber strength and stiffness increased with increasing stand densities and Lei et al. (2005) used stand density and other tree characteristics to predict bending strength and stiffness of lumber. Increased lumber grade recovery with decreasing initial spacing was also found in loblolly pine (Clark et al. 1994). None of these studies first determined the "best" log orientation prior to processing, so it is impossible to determine if grade recovery could have been improved further. When all knots larger than minimum grade specifications are considered with respect to position along and around the stem, no trend exists between improved lumber grade recovery potential and spacing as shown for both the edge and centerline knot pattern assessments (**Table 5**). Lack of a spacing trend simply highlights the need to assess grade recovery at the log level prior to processing.

The method developed in this study has practical applications. If external knot size and location can be determined while scanning for log shape, a log quality assessment can be completed at the sawmill infeed with limited impact on production. Since many logs will not have grade improvement potential, only a small percentage of logs would have to be processed with special attention given to log orientation. This may require rescanning and either a separate line or at the very least a separate log category.

## Conclusion

This paper has described a method to assess lumber grade recovery improvement potential at the log level based on horizontal knot angle, external knot size, knot size limit by grade, and top log diameter. Although based on a simplified log shape, the method illustrates that both knot size and horizontal knot angle must be considered to determine the "best" sawing pattern. Horizontal knot angle, often ignored in studies of sawing strategy and log orientation, was found to influence lumber grade recovery improvement potential. Application of this method using real data shows that improvements to grade recovery are possible for black spruce logs, although the overall method is not species specific. There should be even greater opportunities for lumber grade improvement for species with larger knots and /or fewer knots per whorl.

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# Structural lumber from suppressed-growth ponderosa pine from northern Arizona

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**Abstract**

Lumber was sawn from 150 suppressed-growth ponderosa pine trees, 6 to 16 inches in diameter, harvested near Flagstaff, Arizona. This paper presents grade recover and properties for dry 2 by 4's sawn from the logs and graded by a variety of structural grading systems. Flexural properties met or exceeded those listed in the National Design Specification. When graded as Light Framing 43 percent of the 2 by 4's made Standard and Better and as Structural Light Framing, 34 percent made No. 2 and better. Warp was the biggest factor limiting grade yield. About 7 percent of the lumber would make a machine stress-rated (MSR) lumber grade of 1450f, but with no established market such production is not recommended. If graded as laminating stock, about 8 percent of the lumber qualified as L3 or better. A comparison of the results from this study with those from a companion study indicates that appearance grades offer the highest value alternative for lumber produced from this resource.

Ponderosa pine (*Pinus ponderosa,* L.) is one of the most important softwood species in western North America. It is found in commercial quantities in every state west of the Great Plains. Wood from mature trees is relatively lightweight, nondurable, nearly white, and has straight grain and a medium texture. It is easy to work with hand tools, glues well, and is average in paint- and fastener-holding abilities. It is a principal millwork species, being used for window framing, sashes, doors, moulding, shelving, and paneling. In roundwood form, it is used for posts, poles, and house logs (Lowery 1984). As structural lumber, it is sold as part of the Western Woods species grouping (NDS 2005).

Natural regeneration of ponderosa pine is sporadic over much of its range, with successful germination thought to be the result of the chance combination of a heavy seed crop and favorable weather during the following growing season (Burns and Honkala 1990). Historically, the ponderosa pine forests were primarily open stands of mature trees interspersed with pockets of younger trees and grassland. Prior to the early 1900s, frequent low-intensity fires killed off competing vegetation, including ponderosa pine seedlings, and help maintained open stands of large, fire-resistant trees (Fiedler et al. 1997). Fire suppression, along with livestock grazing and timber harvest, has promoted the conversion of

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Forest Prod. J. 57(12):42-47.

the historical forest to dense stands containing a preponderance of small-diameter trees. Under these conditions, tree growth is often suppressed. Because ponderosa pine is intolerant of shade, rapid growth of seedlings prior to crown closure will produce a relatively large core of juvenile wood, generally defined as the first 20-years of growth (Shuler et al. 1989, Voorhies and Groman 1982). Juvenile wood tends to have higher than normal longitudinal shrinkage and may warp excessively. This has been identified as a primary problem in the utilization of small-diameter ponderosa pine (Fahey et al. 1986).

Management goals for ponderosa pine forests include reducing stand density to increase resistance to insect and disease attack, reduce the risk of catastrophic wildfires, provide diverse mosaics of wildlife habitat, and provide economic benefit to local communities (Willits et al. 1997). Increasing product utilization, along with reducing harvesting and processing costs, is critical for restoring ecological processes in ponderosa pine forests (Fiedler et al. 1997, Larson and Mirth 1998, Rummer et al. 2003). Several studies have shown that old growth trees (generally defined as more than 150 years old) produce a larger proportion of high value "shop and select" grades of lumber than do younger ("blackjack") trees (Ernst and Pong 1985, Fahey and Sachet 1993, Fahey et al. 1986). Fahey and Sachet (1993) concluded that lumber from second growth ponderosa pine logs is primarily in the Dimension grades. These older studies, however, were not specific to suppressed stands and often were limited in the lumber grading options investigated, especially for engineered product applications. Recent studies have shown that small-diameter trees growing in dense stands may have higher annual ring density and smaller knots than more open-grown trees and can be used as an input raw material for higher value products ranging from visually and mechanically graded lumber to veneer for structural composite lumber (Willits et al. 1997, Erickson et al. 2000, Green et al. 2005).

In a previous paper we compared volume and value recovery from 6- to 16-inch (152- to 406-mm) diameter breast height (DBH) suppressed-growth ponderosa pine harvested near Flagstaff, Arizona (Lowell and Green 2001), which was manufactured into structural and nonstructural lumber. In that paper, the structural dimension lumber was limited to the Structural Light Framing grading system (WWPA 1998). The objective of this paper is to further investigate the yield of structural lumber graded under a wider range of structural grading systems.

## Procedures

### Log selection and processing

Trees were selected from the Fort Valley Research and Demonstration Forest, Flagstaff, Arizona, and harvested in summer 2006. The demonstration project contained three experimental blocks with four treatment plots each. The experimental blocks represented different initial stand conditions: blackjack (young growth), yellow pine (old growth), and a mixture of the two age groups. The treatments within blocks were different thinning prescriptions designed to return stands to presettlement conditions. This involved thinning from below in which the larger, older trees were retained. Trees to be left had been marked, but no thinning treatment had been applied prior to sample selection for this study. Sample trees came from three of the four treatment plots in the mixed age block.

A sample of 150 trees ranging in DBH from 6 to 16 inches (152 to 406 mm) was selected. A matrix of five 2-inch (51-mm) diameter classes was used, and the trees selected represented those that would have been removed under the silvicultural prescription. The trees had an average age of 88 years. The sample was randomly divided into two subsamples, one to be sawn for dimension lumber and the other for appearance-grade lumber. Only the 2 by 4's from the dimension lumber sample are discussed in this report. The logs were sawn and the lumber kiln-dried by the Fremont Lumber Company, Lakeview, Oregon, owned by the Collins Companies. A more detailed discussion on selection and processing procedures and the overall results for both subsamples are presented in Lowell and Green (2001). Simpson and Green (2001) give additional information on kiln-drying procedures in the Fremont Lumber Company sample.

### Grading and testing

The dry and surfaced 2 by 4's were shipped from the sawmill to the University of Idaho where they were graded as structural products by a lumber inspector of the Western Wood Products Association (WWPA). Each 2 by 4 was graded under several structural grading systems including Structural Light Framing, Light Framing, and the visual requirements for machine stress-rated (MSR) lumber and laminating grades (AITC 1993, WWPA 1998). If the grade of the lumber could be increased by trimming 2 to 4 feet (0.6 to 1.2 m) from the end, the trimmed length and trimmed grade were recorded. The lumber was conditioned for several months at approximately 70 °F (21 °C) and 55 percent relative humidity.

Modulus of elasticity (MOE) was determined by transverse vibration (Etv) using a E-Computer (Metriguard, Inc., Pullman, Washington) with specimens supported at the ends and vibrated in the flatwise orientation. Specimens were then tested to failure on edge in static bending using third-point loading and a span-to-depth ratio of 21:1 following the procedures of ASTM D 198 (ASTM 2005). The rate of loading was approximately 2 inches (51 mm) per minute. In accordance with ASTM Standards D 2395 and D 4442–92, ovendry moisture content (MC) and specific gravity (SG) based on ovendry weight and ovendry volume were determined from sections taken near the failure region after testing (ASTM 2005).

### MSR simulation

Simulations of MSR grades were conducted for a range of potential grades having static edgewise MOE values ranging from 1.0 to 2.4 × $10^6$ psi (6.9 to 16.5 GPa). Individual pieces in the simulation of MSR grades had to meet four criteria to qualify for a specified grade: (1) fifth percentile (minimum) MOE, (2) fifth percentile (minimum) modulus of rupture (MOR), (3) grade average MOE, and (4) visual grading requirements for edge knots. Traditionally, for mechanically graded lumber, the fifth percentile non-parametric point estimate must equal 82 percent of the target average MOE value (i.e., 0.82 × average grade MOE). This limits the variability of the lower half of the MOE distribution of the grade to a coefficient of variation (COV) of 11 percent. Thus, the minimum MOE for a 1.3E grade would be $0.82 \times 1.3 = 1.07 \times 10^6$ psi (7.4 GPa). The minimum MOR value would be 2.1 times the allowable bending strength (Fb) for the specified grade. In addition to the MOE and MOR requirements, knot size is limited by grade category. More information on MSR lumber may be found in Galligan and McDonald (2000) and the Summer 1997 issue of *Wood Design Focus* (FPS 1997). A more comprehensive discussion of our MSR simulation procedures, along with several grading alternatives, is given in Green et al. (2005).

### Laminating grades

Traditional ponderosa pine lumber used in glulam is referenced in glulam standards as part of a species grouping called Western Species. As part of this grouping, only visual grading of the lumber was conducted. The rules for visual rating are based entirely on the characteristics that are readily apparent to the human eye, such as knot size, slope of grain, and wane. The following tabulation is an example of the knot size limitations for visual glulam grades:

| Grade | Maximum knot size |
|---|---|
| L1 | 1/4 width |
| L2 | 1/3 width |
| L3 | 1/2 width |

Laminating lumber assigned to the Softwood Species grouping has relatively low values for mechanical properties. Thus ponderosa pine in this species grouping was historically restricted to homogeneous L3 combinations. Other species, such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and southern pine (*Pinus* spp.), employ measurement of MOE (E-rating) of the outer laminations to make efficient use of the timber resource. Recent research has demonstrated that it is possible to produce glulam beams with only ponderosa pine lumber using a combination of E-rated lumber and visual characteristics (Hernandez et al. 2005). These grades are expressed in terms of MOE followed by the limiting knot size. Thus, a 2.0E-1/6 grade has a MOE of $2.0 \times 10^6$ psi (13.8 GPa) and a maximum edge knot size of 1/6 the lumber width. The L-grades for our lumber were determined by the WWPA lumber inspector.

## Results

### Visual grading

*Grade yield.* — In this paper, grade yield is based on the total volume of 2 by 4's produced from all the logs, rather than being relative to the volume of wood in each individual log as was done in our previous paper (Lowell and Green 2001). This was necessary because only the 2 by 4 lumber was evaluated for structural products. This decision also removes the sawing efficiency of a given sawmill as a limitation and makes the results more applicable to other mills that might have different equipment configurations to process the logs.

Under the Structural Light Framing system, most of the 2 by 4's were either grades No. 2 or No. 3, with only a little more than 7 percent making the higher grades of Select Structural No. 1 (**Table 1**). These results are similar to those we previously found for lumber cut from small-diameter ponderosa pine from Grangeville, Idaho (**Table 2**). Here the lumber that did not make at least No. 3 grade is termed "No. 4", to avoid confusion with the lumber that did not make at least Utility grade in the Light Framing grading system, which is called "Economy." The primary characteristics that limited grade were warp (43%), wane (17%), and knots (7%). Likewise, when graded as Light Framing (Table 1), only about 13 percent of the lumber made Construction grade. Grade limiting

*Table 1. — Grade yield for visually graded 2 by 4's from suppressed ponderosa pine from Flagstaff, Arizona.*

| Grade | No. of pieces | Volume | Yield |
|---|---|---|---|
| | | (BF) | (%) |
| | Structural light framing | | |
| Select structural | 21 | 141 | 2.4 |
| No. 1 | 39 | 287 | 4.9 |
| No. 2 | 200 | 1555 | 26.7 |
| No. 3 | 224 | 1883 | 32.3 |
| No. 4 | 223 | 1961 | 33.7 |
| Total | 707 | 5827 | 100 |
| | Light framing | | |
| Construction | 104 | 763 | 13.1 |
| Standard | 219 | 1739 | 29.8 |
| Utility | 179 | 1517 | 26.0 |
| Economy | 205 | 1815 | 31.1 |
| Total | 707 | 5834 | 100 |

characteristics were essentially the same as those for Structural Light Framing. Thus, as has been shown in previous studies, warp is the primary grade limiting problem. Prevention of warp could significantly increase utilization of lumber from small-diameter ponderosa pine trees (Simpson and Green 2001, Simpson 2004).

*Mechanical properties.* — To reduce the amount of lumber that was tested, only the 2 by 4's that were broken in this study had potential for mechanical grading and glulam. Generally, these were at least a No. 3 visual grade and met other required visual characteristics, as determined by the WWPA lumber inspector. Only a small proportion (< 10%) of the No. 3 visual grade qualified for MSR and was tested, and only a few pieces (< 5%) of the No. 2 grade were not tested. In the Light Framing system, only one piece of Utility grade lumber qualified for MSR, whereas only a few pieces of Standard grade did not qualify.

**Table 3** shows the flexural properties when the lumber is graded as Structural Light Framing. The lumber had a MC of about 10 percent. The SG of all the lumber averaged about 0.41 based on ovendry weight and volume. This is slightly lower than the value of 0.43 given in the National Design Specifications (NDS 2005). When adjusted to 15 percent MC as per ASTM Standard D1990 (ASTM 2005, Evans et al. 1989), the allowable bending strength, Fb, and MOEs of the Structural Light Framing and Light Framing grades were at least as high as those specified in the NDS (**Table 4**). Property values are not shown for the No. 3 and Utility grades because too many pieces in these grades were not tested. Light framing grades for ponderosa pine were not tested in the in-grade program (Green and Evans 1987).

### Mechanical grading

There is a good relationship between MOE and Etv and between MOR and MOE (**Table 5**, **Fig. 1**). Although the $r^2$ values are a little lower than expected, our previous studies on ponderosa pine from small-diameter trees found higher $r^2$ values; thus, there is no reason to expect a problem with mechanically grading this lumber. The lower 90 percent confidence interval on the MOE-MOR relationship is shown in **Figure 1**. Five percent of the data would be expected to be below this

*Table 2. — Grade yield of Structural Light Framing for 2 by 4's cut from small-diameter ponderosa pine trees from interior west locations.*

| Location | Situation | Sample size | Grade yield, %[a] | | | | | Reference[c] |
|---|---|---|---|---|---|---|---|---|
| | | | S.S. | No.1 | No.2 | No.3 | Econ. | |
| Emmit, ID | Plantation[b] | 200 | 0 | 1.6 | 11.4 | 31.9 | 55.1 | 1 |
| Grangeville, ID | Plantation[b] | 388 | 0.2 | 14.0 | 33.2 | 3.2 | 49.4 | 2 |
| Flagstaff, AZ | Suppressed | 707 | 2.4 | 4.9 | 26.7 | 32.3 | 33.7 | 3 |

[a]Percent of the BD FT volume of 2 by 4's in a grade relative to the total volume of 2 by 4's.
[b]Planted initially at a given spacing, not a commercial plantation.
[c]1, Erickson et al. 2000; 2, Gorman and Green 2000; 3, current study.

*Table 3. — Mechanical properties of visually graded ponderosa pine 2 by 4's.*

| Grade | N | MC (%) | SG (OD/OD) | MOE[a] ($10^6$ psi) | | MOR ($10^3$ psi) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Mean | SD | fifth |
| | | | Structural light framing | | | | | |
| SS | 17 | 9.8 | 0.431 | 1.374 | 0.173 | 7.841 | 2.553 | 4.258 |
| No. 1 | 35 | 9.8 | 0.409 | 1.248 | 0.189 | 5.511 | 1.605 | 2.874 |
| No. 2 | 181 | 9.7 | 0.407 | 1.106 | 0.181 | 4.418 | 1.814 | 2.062 |
| | | | Light framing | | | | | |
| Construction | 94 | 9.7 | 0.409 | 1.193 | 0.205 | 5.257 | 2.290 | 2.300 |
| Standard | 192 | 9.7 | 0.407 | 1.079 | 0.190 | 4.198 | 1.791 | 1.880 |

[a]$10^3$ psi × 6.894 = MPa, $10^6$ psi × 6.894 = GPa.

*Table 4. — Flexural properties of ponderosa pine 2 by 4's adjusted to 15 percent MC.*

| Grade | Current study | | NDS - 2 by 4's[a] | | In-grade program[b] | |
|---|---|---|---|---|---|---|
| | MOE[c] | $R_{05}/2.1$ | E | Fb | MOE | $R_{05}/2.1$[d] |
| | Structural light framing | | | | | |
| S.S. | 1.270 | -- | 1.2 | 1.350 | 1.078 | 2.056 |
| No. 1 | 1.153 | 1.331 | 1.1 | 1.012 | -- | -- |
| No. 2 | 1.021 | 0.982 | 1.0 | 1.012 | 0.932 | 1.260 |
| | Light framing | | | | | |
| Construction | 1.101 | 1.095 | 1.0 | 0.775 | -- | -- |
| Standard | 0.996 | 0.895 | 0.9 | 0.425 | -- | -- |

[a]Western Woods species group, NDS, 2005.
[b]Green and Evans 1987.
[c]MOE has units of $10^6$ psi, $R_{05/2.1}$ has units of $10^3$ psi, $10^3$ psi × 6.894 = MPa, $10^6$ psi × 6.894 = GPa.
[d]$R_{05}$ is the non-parametric fifth percentile.

*Table 5. — Property relationships for 2 by 4's cut from suppressed-growth ponderosa pine.*

| Property[a] | X | Sample size | Property = A + BX | | | |
|---|---|---|---|---|---|---|
| | | | A | B | $r^2$ | RMSE[b] |
| MOE | Etv | 293 | 0.179 | 0.777 | 0.63 | 0.124 |
| MOR | MOE | 293 | −3.346 | 7.093 | 0.49 | 1.476 |

[a]MOE, Etv has units of $10^6$ psi, MOR has units of $10^3$ psi, $10^3$ psi × 6.894 = MPa, $10^6$ psi × 6.894 = GPa.
[b]Root mean square error, in $10^3$ psi.

line and is the basis for establishing mechanical grades. The equation that we used for the lower confidence interval is:

$$MOR_{0.9LCI} = 7.093 \times MOE - 5.786$$

This lumber was evaluated for the production of a number of MSR grading alternatives (Cisternas 2000). While a significant amount of the lumber would make a grade of 900Fb-1.0E, there is currently no market for such a grade. In fact, the lowest MSR grade with much of an established market is 1450f-1.3E (James 2001). Only about 7 percent of the volume (425 BF) of these 2 by 4's would make 1450f. With no established market for ponderosa pine (or Western Woods) MSR, it would not be economical to consider such production. This conclusion is consistent with what we found in our previous study for ponderosa pine from near Grangeville, Idaho (Erickson et al. 2000).

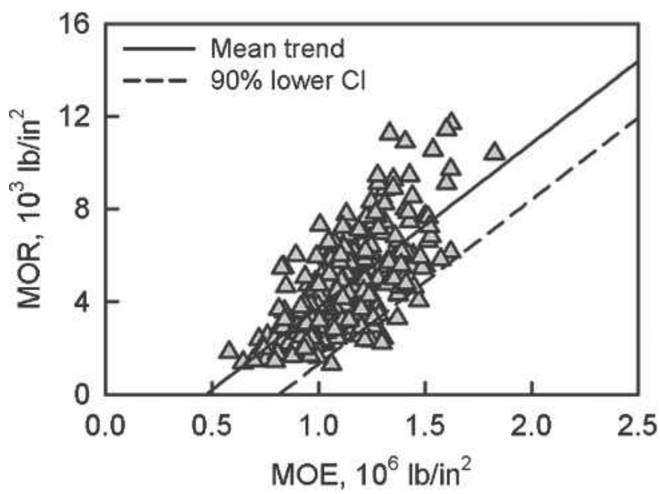


*Figure 1. — Relationship between modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending for 2 by 4's cut from suppressed-growth ponderosa pine.*

## Glulam

**Table 6** shows the distribution of flatwise Etv values for our data by edge knot size classes. Most of the pieces were either in the classes with 1/6- or 1/2-in. edge knots, and had Etv values below 1.4 million pounds per square inch (9.8 GPa). When graded by the visual glulam grades, only about 20 percent of the lumber would make at least an L3 grade (**Table 7**). The largest single grade-limiting factor for glulam with this

*Table 6. — Distribution of flatwise MOE values by transverse vibration (Etv) by knot size class for 2 by 4's cut from suppressed-growth ponderosa pine.*

| | No. of pieces by edge knot displacement[a] | | | |
|---|---|---|---|---|
| Etv[b] | 1/6 | 1/4 | 1/3 | 1/2 |
| ($10^6$ psi) | | | | |
| 0.9[c] | 4 | 2 | 3 | 18 |
| 1.0 | 14 | 6 | 10 | 14 |
| 1.1 | 20 | 4 | 3 | 18 |
| 1.2 | 14 | 10 | 14 | 22 |
| 1.3 | 18 | 8 | 7 | 15 |
| 1.4 | 14 | 10 | 2 | 10 |
| 1.5 | 8 | 1 | 1 | 3 |
| 1.6 | 4 | 3 | 4 | 1 |
| 1.7 | 5 | 0 | 1 | 0 |
| 1.8 | 2 | 0 | 0 | 0 |
| Mean Etv value for knot class, $10^6$ psi | 1.259 | 1.241 | 1.202 | 1.140 |
| Number of samples | 103 | 44 | 45 | 101 |
| COV of Etv[d] | 18.1 | 15.1 | 16.5 | 15.4 |

[a]Fraction of cross section occupied by edge knot.
[b]$10^6$ psi × 6.894 = GPa
[c]Values represent the average of the range. The range is from 0.05 below to 0.05 above the listed average.
[d]COV = coefficient of variation (%)

*Table 7. — Grade yield of laminating stock from suppressed-growth ponderosa pine 2 by 4's from Flagstaff, Arizona.*

| Grade | No. of pieces | Volume (BF) | Percentage yield |
|---|---|---|---|
| L1 | 29 | 204 | 3.5 |
| L2 | 36 | 249 | 4.3 |
| L3 | 89 | 736 | 12.6 |
| Reject | 553 | 4641 | 79.6 |
| Total | 707 | 5830 | 100 |

lumber was warp (36%). Because laminations are pressed during the manufacturing process, bow is a less critical form of warp than are cup and twist. About 22 percent of the lumber was limited by cup, 7 percent by bow, and 6 percent by twist. These percentages are based on the primary limiting characteristic listed by the WWPA lumber inspector. It is common for more than one type of warp to occur simultaneously. About 1 percent of the limitations were just listed as "warp" (kind of warp unspecified). About 23 percent of the pieces had wane listed as the grade limiting characteristic. Had this lumber been sawn knowing that it was to be used for glulam production, it could have been sawn a little over size so that when planed to standard dimension there would have been less grade loss due to wane.

## Discussion

As has been found in previous studies, warp is the biggest factor limiting the utilization of lumber cut from small-diameter (less than about 16-inches (406 mm) DBH), young growth (less than 150 years old) ponderosa pine. The amount of warp in this study could have been reduced slightly if a top load of 150- to 200-pounds per ft$^2$ (psf) had been used during kiln-drying. Unfortunately, only enough weights were available to achieve a top load of about 75 psf. It is estimated that the increase in grade recovery might have been up to 17 percent had sufficient top load been applied (Simpson and Green 2001). Additional improvements in warp control could be obtained by employing kiln temperatures of 240 °F, or higher (Simpson 2004). Excess wane was another characteristic that limited grade in this study, especially for production of laminating grades. Sawing the 2 by 4's oversized could have reduced this problem, at the expense of overall yield.

*Table 8. — Lumber grade recovery from suppressed-growth ponderosa pine logs sawn for appearance grade products (Lowell and Green 2001).*

| Board grade | Lumber volume |
|---|---|
| | (%) |
| No. 1 Common | 3 |
| No. 2 Common | 22 |
| No. 3 Common | 66 |
| No. 4 Common | 7 |
| Molding | <1 |
| No. 3 Clear | <1 |
| No. 1 Shop | 1 |
| No. 2 Shop | 1 |

This study supports previous conclusions that structural lumber can be produced from small-diameter trees if careful attention is paid to kiln-drying procedures. However, yields will not likely be as good as those expected from small-diameter trees of other species (Green et al. 2005, Gorman and Green 2000, Willits et al.1997). For mills already cutting small-diameter trees for structural lumber, visual grading in the Light Framing or Structural Light Framing grading systems would provide the highest value. Although not evaluated in this study, production of Stud grade 2 by 4's should also be attractive provided that wane and warp are controlled. Production of MSR lumber is not recommended for this resource. Grade yields would likely be quite low, and no established market currently exists for mechanically graded ponderosa pine or Western Woods. Glulam remains a possible market for ponderosa pine from suppressed-growth ponderosa pine (Hernandez et al. 2005), but potential producers are well advised to investigate the needs of specific glulam buyers before trying to compete in this market.

For this resource, sawing for appearance grades offers a higher value alternative for lumber production from this suppressed-growth ponderosa pine than does structural dimension lumber (Lowell and Green 2001). Had these logs been sawn for appearance-grade products, about 25 percent would have made No. 2 Common or Better with 66 percent grading as No. 3 Common (**Table 8**). The estimated premium for appearance products over dimension lumber at that time was \$53 per 1000 cubic feet (gross log scale). Other previous research (Lowell et al. 2000) showed that there are opportunities to increase the value of appearance lumber through further processing into cut-stock material. The Flagstaff resource had a high yield of No. 3 Common appearance lumber, and about 60 percent of the boards were 6 inches (152 mm) wide or wider. While not evaluated in our study, there may be an opportunity to recover additional value by further processing into secondary products.

## Conclusions

For the production of 2 by 4 structural lumber from 80- to 100-year-old suppressed-growth ponderosa pine 16 inches and less in diameter, we found that:

1. 34 percent of the 2 by 4's graded as No.2 and better (43% as Standard and Better). Warp (43%) and wane (17%) were the primary grade limiting defects, with only 7 percent of the grades being limited by knots.
2. Sawing the 2 by 4's slightly over size, and kiln-drying with a top load of 150 to 200 pounds per $ft^2$ would likely have improved the yield of dimension lumber.
3. The flexural properties of this lumber met or exceeded the allowable properties assigned to the species grouping containing ponderosa pine (Western Woods).
4. While about 7 percent of the 2 by 4's could qualify as 1450Fb-1.3E MRS lumber, such production is not recommended. This is the lowest grade of MSR lumber currently sold in any volume, and no market is currently established for this species group. For those already producing structural lumber grading, Light Framing, or Structural Light Framing grades are better alternatives.
5. If a market is readily available, this lumber is suitable for the production of stock for glulam beams. However, careful attention must be paid to the reduction of warp and wane.
6. Appearance grades offer the highest value alternative for lumber production from this suppressed-growth resource. A premium of about $53 per 1000 cubic feet (gross log scale) was estimated in a previous study.

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# Properties of wood from ice-storm damaged loblolly pine trees

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Jonathan Hartley

**Abstract**

Fifty-six trees were harvested to determine the properties of the wood produced by ice-storm damaged trees. There were 12 trees each for three classes of bend: 0 to 15, 16 to 30, and more than 30 degrees from the vertical. Also, 10 trees were selected for each of two classes of crown loss: 20 percent or less and more than 20 percent loss. Samples were taken from three positions in the tree: butt, 8 feet up the stem and at the base of the live crown. The variables analyzed were: the amount of compression wood produced, ovendry specific gravity (SG), modulus of rupture, and modulus of elasticity (MOE). The results indicated that the greater the degree of bend, the more compression wood produced, the higher the SG and the lower the MOE. It was recommended that trees with just a partial loss of crown be allowed to grow, but trees with more than 15 to 20 degrees of bend should be harvested.

During the Christmas Holiday period of 2000, South Arkansas experienced a devastating ice storm. Larger trees suffered minimal crown damage in the form of broken limbs or lost tops. In contrast, plantations of younger trees were severely damaged. Based on visual observations, it appeared that stands that had been thinned recently were hit the hardest.

Shortly after the ice storm, the U.S. Forest Service (USFS) initiated a study of nearly 300 trees in six loblolly pine plantations. In selected plantations, USFS personnel selected and marked trees that were leaning (root thrown), bent, and exhibiting crown loss. During each of the following five dormant seasons, data were collected on the marked trees. After five growing seasons, the trees were divided into three groups. The first group died within 2 years of the ice storm. The second group were surviving but had no measurable diameter growth in the 5 years. The third group had measurable diameter growth each year. From a monetary prospective, the first two groups should have been harvested following the ice storm. The purpose of this study was to evaluate the properties of the third group in an effort to determine if the material produced by the trees was worth growing. It should be noted that all of the leaning trees were in group one. Given this fact, the study included only trees that were bent and those with some degree of crown loss. The information derived from this study should aid forest managers in harvest and clean up decisions following future events such as ice storms.

When softwood trees are bent, future growth results in compression wood being formed on the lower side of the stem. This response is the tree's way of forcing the stem back into a vertical position. This abnormal wood has properties that are different and less desirable than normal wood. Considerable care must be used in pulping compression wood, and even then an inferior product is produced. With solid products such as lumber, differential shrinkage is of great concern. Density of compression wood is 10 to 20 percent higher and sometimes as much as 40 percent higher than normal wood, but its strength is about the same as normal wood (Bowyer et al. 2003).

The amount of bending, rather than the reason behind it, seems to be the only important factor in the amount of compression wood that is produced. Clark and Dunham (2001) studied bent trees 10 years after Hurricane Hugo and investigated the influence of the amount of bend and age at the time of Hugo on the properties of the resulting wood. Their conclusions were:

- Angle of lean did not significantly affect stem wood specific gravity (SG) or moisture content (MC).

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- Average compression wood SG was about 2 percent higher than normal wood.
- Compression wood toughness was 21 percent lower than normal wood.
- Proportion of stem in compression wood increased significantly with increasing tree age at time of storm in tree with >25 degrees of lean.
- Trees of age 4 years or less with 45 degrees of lean or more and trees of 8 years with 25 degrees of lean or more, should be harvested and replanted because of the large amount of compression wood that would be produced.

In this study the modulus of elasticity (MOE) and modulus of rupture (MOR) were used to compare the mechanical properties of the wood. American Society for Testing and Materials (ASTM) (ASTM-D143 2005) provides a standard for determining MOE and MOR based on testing of sample beams that are 2 inches by 2 inches and tested over a 28-inch span. The standard also provides an alternative size (method b) of 1 inch by 1 inch over a 14-inch span which is used when the material to be studied cannot be processed into larger size (McAlister and Clark 1991, McAlister and Powers 1992, McAlister and Powers 1994). Others have found that the alternative size (method b) is still too large for many studies. Therefore, smaller specimens have been used but the span to depth ratio has always been maintained at 14 to 1. The extreme case is an 1/8-inch beam tested over a 1 3/4-inch span (Bendtsen and Senft 1986, Wolcott et al. 1986, Shepard and Shottafer 1992).

## Procedures

The group three trees were divided into five classes: class one trees were those bent 0 to 15 degrees from the vertical, class two trees were bent 16 to 30 degrees, class three trees were bent more than 30 degrees, class four trees had up to 20 percent crown loss and class five trees had more than 20 percent crown loss. The top 12 trees in diameter growth since the storm were selected for each of the first three classes and the top 10 were selected for classes four and five. Thus, samples from 56 trees were included in this study.

The trees were harvested during June 2006, which was the middle of the sixth growing season. Prior to felling, a paint line was sprayed up the upper side of the tree so that the upper and lower side of the stem could be identified after felling. The trees were felled with a chain saw leaving a 6-inch stump. A 1-inch-thick cross section was removed from the main stem at the base of the live crown (top position) and placed in a preweighed plastic zip lock bag. An 18-inch-long segment was cut from the stem below the cross section. Next a 1-inch cross section was cut at 8 feet from the butt end of the stem (mid position), placed in a plastic bag, and an 18-inch segment was cut above it. Finally, from the butt end, a 1-inch cross section and an 18-inch segment were cut (butt position). The harvested materials were taken to the lab each afternoon. The cross sections and bags were weighed, and the wood was placed in the oven to dry for MC determination. The 18-inch segments were stacked for later processing.

The cross sections were reweighed after drying and placed back in their respective plastic bags. Later, they were analyzed for growth patterns. Digital calipers were used to measure the width of the last six growth rings on both the upper and the lower side of the stem. Also, the width of any compression wood present was measured for each growth ring since the ice storm.

*Table 1. — The difference in inches between the lower side 6-year growth minus the upper side 6-year growth by study class. Values in same position with the same letter are not significantly different.*

| | Position | | |
|---|---|---|---|
| Class | butt | mid | top |
| 1 | 0.1871ab | 0.0967b | 0.0724b |
| 2 | 0.2948ab | 0.2259b | 0.2315ab |
| 3 | 0.4471a | 0.5661a | 0.2920a |
| 4 | 0.1163b | 0.0126b | 0.1540ab |
| 5 | 0.0779b | 0.0316b | 0.1797ab |

Classes: 1 = 0 to 15 degrees; 2 = 16 to 30 degrees; 3 = >30 degrees; 4 = 0 to 20 percent crown loss; and 5 = >20 percent crown loss.

The 18-inch segments were positioned on a portable sawmill so that the blade would pass parallel to the bark and remove only the last six growth rings. This cut was done for both the upper and lower sides of the stem. The segment slabs were further processed on a table saw to produce the largest beam possible based on the width of the growth rings. When the bark side was removed from the beam, the sixth growth ring and possibly some of the fifth growth ring were lost; therefore the static bending beams consisted of only the first five growth rings after the ice storm. The 336 beams were kiln-dried and then placed in a conditioning chamber.

The beams were tested according to ASTM standards (2005) except for size. There were four sizes of beams: 1-inch over a 14-inch span, 3/4-inch over a 10 1/2-inch span, 5/8-inch over an 8 3/4-inch span and 1/2-inch over a 7-inch span. After failure, an end was cut from each beam for MC and oven dry SG determination.

SAS® (2003) was used in all statistical analyses involving t-tests and ANOVA and a $p$-value of 0.05 was used to determine significance.

## Results and discussion

For wood from the same position of the trees, there was no significant difference in MC between the classes or plantation sites. However, there was a significant difference in MC by position. The study averages were 91, 96, and 116 percent for the butt, mid and top positions, respectively. This is similar to the relationship of MC to position shown in Patterson and Doruska (2005).

When trees produce compression wood, the growth rings on the upper side of the stem are usually narrow while the same growth rings on the lower side are usually wider. **Table 1** shows the difference in width between the last six growth rings on the lower side and those on the upper side. The variation in the data prevents any identification of a statistical trend; although, trees with more than 30 degrees of bend had the highest average for all three positions. It is noted that in some processes, such as veneer production, out-of-round logs make it difficult for plywood plants to peel quality veneer even if there is clear material outside the compression wood because the knife is cutting across growth rings instead of around them.

Some trees in all three classes of bent trees were producing compression wood in the mid position during the fourth year after the ice storm and some in class 3 were still producing compression wood in the sixth year (**Table 2**). The mid position is 8 feet from the stump which places it in the middle of

*Table 2. — The average amount of compression wood in inches laid down each year since ice storm by study class and position.*

| | | Year | | | | | |
|---|---|---|---|---|---|---|---|
| Class | Position | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | butt | 0 | 0 | 0 | 0 | 0 | 0 |
| | mid | 0.103 | 0.017 | 0.024 | 0.015 | 0 | 0 |
| | top | 0.105 | 0.013 | 0 | 0 | 0 | 0 |
| 2 | butt | 0.067 | 0.005 | 0.021 | 0.018 | 0 | 0 |
| | mid | 0.272 | 0.009 | 0.026 | 0.029 | 0 | 0 |
| | top | 0.210 | 0.016 | 0.015 | 0.015 | 0.004 | 0 |
| 3 | butt | 0.211 | 0.093 | 0.031 | 0.014 | 0.006 | 0 |
| | mid | 0.267 | 0.132 | 0.123 | 0.086 | 0.050 | 0.019 |
| | top | 0.191 | 0.093 | 0.051 | 0.039 | 0.008 | 0.003 |
| 4 | butt | 0.021 | 0.008 | 0.012 | 0 | 0 | 0 |
| | mid | 0 | 0 | 0 | 0 | 0 | 0 |
| | top | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | butt | 0 | 0 | 0 | 0 | 0 | 0 |
| | mid | 0 | 0 | 0 | 0 | 0 | 0 |
| | top | 0.018 | 0.012 | 0.017 | 0 | 0 | 0 |

Classes: 1 = 0 to 15 degrees; 2 = 16 to 30 degrees; 3 = >30 degrees; 4 = 0 to 20 percent crown loss; and 5 = >20 percent crown loss.

*Table 3. — Average SG values for the lower side and upper side for each position and study class. The ** denotes significant difference in lower side value compared to upper side value.*

| | Position | | | | | |
|---|---|---|---|---|---|---|
| | butt | | mid | | top | |
| Class | lower | upper | lower | upper | lower | upper |
| 1 | 0.601 | 0.624 | 0.579 | 0.574 | 0.487 | 0.461 |
| 2 | 0.646 | 0.648 | 0.621 | 0.619 | **0.527 | 0.483 |
| 3 | 0.645 | 0.634 | **0.655 | 0.597 | **0.596 | 0.462 |
| 4 | 0.636 | 0.625 | 0.558 | 0.558 | 0.453 | 0.448 |
| 5 | 0.587 | 0.586 | 0.548 | 0.548 | 0.443 | 0.428 |

Classes: 1 = 0 to 15 degrees; 2 = 16 to 30 degrees; 3 = >30 degrees; 4 = 0 to 20 percent crown loss; and 5 = >20 percent crown loss.

*Table 4. — Average MOR values (x1,000 PSI) for the lower side and upper side test specimens for each position and study class. The ** denotes a significant higher value as compared to its opposite side.*

| | Position | | | | | |
|---|---|---|---|---|---|---|
| | butt | | mid | | top | |
| Class | lower | upper | lower | upper | lower | upper |
| 1 | 11.6 | **12.5 | 14.0 | 13.4 | 11.9 | 10.7 |
| 2 | 11.9 | 13.2 | 13.6 | 14.6 | 11.1 | 10.6 |
| 3 | 11.7 | 13.0 | 11.6 | 12.5 | 11.4 | 10.3 |
| 4 | **13.1 | 11.8 | 12.8 | 13.3 | 10.7 | 9.9 |
| 5 | 12.2 | 11.5 | 11.7 | 13.7 | 10.3 | 9.8 |

Classes: 1 = 0 to 15 degrees; 2 = 16 to 30 degrees; 3 = >30 degrees; 4 = 0 to 20 percent crown loss; and 5 = >20 percent crown loss.

the butt log. The butt log is the "money" log of the tree and anything that degrades the butt log may greatly reduce the value of the whole tree. Even though it is the same growth ring, there appears to be less compression wood produced at the base and the crown area than in the main stem.

Bowyer et al. (2003) stated that compression wood generally has a SG that is 10 to 20 percent and as much as 40 percent higher than normal wood. The data analysis showed that there were significant differences in ovendry SG values for the mid position in class 3 trees and top position in classes 2 and 3 trees (**Table 3**). In these three cases, the lower side SG values were 9 to 29 percent higher than those from the opposite side of the tree. The values in **Table 3** basically correspond to the amount of compression wood shown in **Table 2**.

The analysis indicated no significant trends in MOR values. **Table 4** shows two cases where there were significant differences; in one case the upper side of the butt position had the higher MOR value while in the other case the lower side was higher. These results are in agreement with a statement by Bowyer et al. (2003) stated that compression wood had the same strength as normal wood even though it was heavier.

MOE is a measure of stiffness, and the results of this study would indicate that compression wood is less stiff than normal wood. The values in **Table 5** show that the upper side had a higher average MOE than the lower side with the exception of the butt position of class 4 trees in which the lower side was stronger and stiffer. There were five cases where the upper side had significantly higher MOE values. The extreme case was the mid position of class 3 trees where the lower side was only 60 percent as stiff as the upper side even though it had a 29 percent higher SG. The beams containing predominately compression wood had the same strength as their opposite side counterparts, but because of their lack of stiffness, with a constant loading rate, the test to the maximum strength required a long time period and great deflection of these beams.

The MC at the time of testing was 14 percent instead of 12 percent as planned. It appears that the calibration of the conditioning chamber was a little off. Given the comparative nature of the study, values were not corrected to 12 percent.

## Conclusions

The results of this study demonstrate that ice storm damaged trees can be adversely affected (e.g., reduction in MOE) even if they survive and produce diameter growth. Some senior foresters working in the study area stated that in the 1970s there was a severe ice storm, and their instructions at that time

*Table 5. — Average MOE values (x 1,000,000 PSI) for the lower side and upper side test specimens for each position and study class. The ** denotes a significant higher value as compared to its opposite side.*

| | Position | | | | | |
|---|---|---|---|---|---|---|
| | butt | | mid | | top | |
| Class | lower | upper | lower | upper | lower | upper |
| 1 | 0.878 | **0.984 | 1.422 | 1.441 | 1.186 | 1.189 |
| 2 | 0.849 | 0.931 | 1.138 | **1.576 | 1.060 | 1.158 |
| 3 | 0.683 | **0.949 | .777 | **1.294 | 0.838 | **1.146 |
| 4 | **1.157 | 0.997 | 1.326 | 1.453 | 1.099 | 1.136 |
| 5 | 0.887 | 0.942 | 1.287 | 1.473 | 1.088 | 1.135 |

Classes: 1 = 0 to 15 degrees; 2 = 16 to 30 degrees; 3 = >30 degrees; 4 = 0 to 20 percent crown loss; and 5 = >20 percent crown loss.

were to ask two questions. First, is the tree straight? Second, are there three or more limbs? If the answer to either question was no, the tree was to be harvested.

The study results indicated that the loss of part of the crown did not cause compression wood to be produced in the main part of the stem. Therefore, the partial loss of crown did not cause a reduction in quality of future growth, but there may be a reduction in the amount of growth.

Clark and Dunham (2001) recommended that trees 8 years or older should be harvested if the amount of bend is greater than 25 degrees. The results of this study indicate that if the amount of bend is over 15 to 20 degrees from the vertical, they should be harvested.

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# Migration of boron from Douglas-fir lumber subjected to simulated rainfall

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**Abstract**

The potential for migration of boron from wood pressure-treated with disodium octaborate tetrahydrate (DOT) during rainfall events was assessed using sawdust, small blocks, and sections of Douglas-fir boards. Boron was rapidly leached from blocks and sawdust; however, boron losses from boards were much lower, suggesting that accelerated leaching methods are a poor predictor of loss from water diffusible systems.

Boron has a long history of performance as a fungicide and insecticide for wood protection (Becker 1976). The major advantage, and at the same time, drawback, to the use of this chemical is its ability to move through wood with free water (Smith and Williams 1969). Thus, treatment of green timbers with boron solutions followed by a diffusion period is a common method for obtaining treatment of normally refractory wood species. However, exposure of boron-treated material to rainfall or direct soil contact allows this same chemical to leach from the wood. As a result, the use of boron has been limited to applications where wetting is unlikely, and the current specifications in the American Wood-Preservers' Association Book of Standards limit use to areas not subjected to continuous wetting (AWPA 2004a).

Despite these limitations, there are clearly instances when boron-treated lumber can be subjected to periodic rainfall, particularly in the time between treatment and installation. In some climates, freshly treated lumber can be exposed to substantial volumes of rainfall in storage. While some boron loss is inevitable under these circumstances, the amounts remain largely unknown, and it is unclear if these losses would result in levels below the protective threshold (Williams and Amburgey 1987). Wetting might also redistribute boron in the wood, which could be advantageous in some applications (Orsler and Holland 1993, Peylo and Willeitner 1999, Hedley and Page 2006).

One approach to assessing boron losses is to subject small treated blocks to various periods of soaking. While this approach produces dramatic boron losses, it poorly represents the actual leaching risk to which the materials are exposed. Alternatively, whole units of treated lumber can be subjected to simulated rainfall or showers. The runoff is collected for analysis, and the wood in the units can be analyzed for residual boron. While this approach is useful, it suffers from variability in that not all boards are initially treated to the same retention, but more important, the rainfall tends to move through the bundle in a nonuniform fashion. Thus, some boards may be subjected to more water exposure than others.

A third approach is to treat boards to known retentions of boron, then subject individual boards to known amounts of rainfall. The resulting runoff can be analyzed for boron content, and the boards can be individually analyzed for boron between rain cycles. This approach is more time consuming, but it allows for a better understanding of the relationship between precipitation and migration.

Studies of an overhead rainfall system on pentachlorophenol (penta) treated Douglas-fir lumber showed that penta concentrations in the runoff were fairly stable regardless of rainfall rate or temperature (Morrell et al. 2005). Similar studies of wood treated with ammoniacal copper zinc arsenate

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(ACZA) showed a gradual reduction in leaching losses with repeated wet/dry cycles, suggesting that migration would reach a low, steady state over time (Morrell et al. 2004). However, penta has exceptionally low water solubility compared to boron, while ACZA components are either reactive with the wood or are largely insoluble once the ammonia is evolved from the wood. Given the exceptional water solubility of boron, one might expect repeated rainfall events to produce continued large boron losses.

In this paper, we assess boron losses from boron treated Douglas-fir lumber subjected to controlled rainfall exposures.

## Materials and methods

Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) lumber (50 mm by 150 mm by 1.2 m long) was commercially treated with disodium octaborate tetrahydrate (DOT) to a target retention of 6.4 kg/m$^3$ (as $B_2O_3$). The treatment cycle consisted of a 30-minute vacuum (−77 kPa), followed by the addition of a 10 percent solution of disodium octaborate tetrahydrate heated to 65 °C. The pressure was then raised to 1050 kPa and held for 1 hour. The pressure was released, the solution was drained and the wood was subjected to a 1 minute vacuum to recover excess solution (−77 kPa). Two boards were collected from each of two different charges. One charge had been recently treated, while the other charge had been in covered storage for 2 months after treatment. The stored boron-treated boards might be expected to have more even chemical distribution than the freshly treated boards since the boron would have more time to diffuse through the wood (Lebow and Morrell 1989, Morrell and Lebow 1991).

Each of the 1.2-m-long boards were cut into four 250-mm-long sections, and the end 50 mm of each board was discarded since it was likely to have higher boron levels as a result of longitudinal penetration. The 250-mm sections were end-sealed with a two-part epoxy system, then conditioned to constant weight at 23 °C and 65 percent relative humidity (RH).

Two sections (replicates A and B) from each of the four boards were selected and placed into slots on an overhead rainfall system. Briefly, a series of nozzles delivered a spray mist at a controlled rate and temperature over a 4-hour period. The board sections rested beneath the nozzles at a slight angle (5°) to allow for water runoff. All runoff from an individual board was collected. Runoff samples were collected after 5, 10, 20, 30, 60, 120, 180, and 240 minutes of rainfall applied at a rate of 1.4 cm per hour. While this represented a substantial amount of rain, it was the lowest amount that could be reliably delivered.

The boards were subjected to four rainfall events of 4 hours each. Boards were conditioned to constant weight at 32 °C and 30 percent RH between events.

Boron levels in the runoff were quantified using the Azomethine H method as described in AWPA Standard A2–04 Method 16 (AWPA 2004b). Residual boron levels in the wood were determined initially and after each wet/dry period by removing 12-mm-diameter plugs from the upper surface of each board. These plugs were divided into zones corresponding to 0 to 5, 5 to 10, and 10 to 15 mm from the upper surface. These segments were ground to pass a 20 mesh screen, extracted in hot water, and analyzed using the Azomethine-H method. The holes were plugged with a silicone sealant and conditioned for 24 hours at 32 °C and 30 percent RH.

In order to better understand the nature of the maximum possible boron losses from the boards, 10-mm cubes of Douglas-fir sapwood were ovendried and weighed prior to being pressure impregnated with 0.25, 0.625, 1.25, and 2.5 percent boric acid equivalent solutions of DOT using a 20-minute vacuum at 80 kPa followed by 20 minutes of pressure at 440 kPa. The cubes were then left submerged for an additional 30 minutes before being weighed to determine net solution absorption. The cubes were then ovendried at 105 °C. Each treatment concentration was replicated on 15 blocks. Ten cubes treated with a given solution were then individually ground to pass a 20 mesh screen. Sawdust from a given block was then placed into a nylon mesh bag. Five of these bags were used for extraction and retention analysis as described earlier to provide a measure of the initial boron loadings.

The remaining five nylon mesh bags were then subjected to the leaching procedures described in AWPA Standard E11 (AWPA 2004c). The bags from each treatment level were removed after 336 hrs of leaching, ovendried, then extracted and analyzed for residual boron as described earlier. Leachate was collected after 6, 24, 48, 96, 144, 192, 240, 288, and 336 hours of leaching and analyzed for boron as described earlier.

The remaining 45 nonground cubes were then subjected to the same AWPA Standard E11 leaching procedures. At the end of the 336 hours leaching period the blocks were ovendried and ground individually to pass a 20 mesh screen. The resulting sawdust was analyzed for boron as described earlier.

The results from the small block and sawdust tests were used to calculate flux rates for boron loss at a given time point according to procedures described by Waldron et al. (2005). The results were expressed on a mg of boron/g of wood/hour basis. The results from the larger blocks were then plotted and compared with the small block fluxes.

The results from the board block and sawdust tests were used to calculate flux rates for boron migration expressed on a mg boron/g of wood/hour basis (Waldron et al. 2005). The block and sawdust tests were based upon simple volume or weight, respectively. For the board tests, flux was calculated using the surface area of the board (150 by 250 mm) and using a 5 mm deep zone from the upper surface as the area affected by rainfall. This allowed for comparison between the large boards and the other wood forms.

## Results and discussion

Virtually all of the boron in the sawdust and small blocks had been removed after 96 hours of leaching, regardless of the initial treatment level (**Table 1**). Leaching was slightly slower in blocks than in sawdust, but the fluxes were fairly similar in the first 24 hours at the two lowest treatment levels. Fluxes in the first 6 hours of leaching tended to be proportional with initial treatment level, then became more variable with time. Fluxes in the blocks tended to be similar to those in the sawdust for the first 6 hours of leaching but were then higher in solid blocks over time (**Fig. 1**). In general, the results were similar to those found in previous trials with small samples and reflect the high water solubility of boron (Waldron et al. 2005).

Losses of boron from boards subjected to 4-hour rainfall periods were initially very high, then declined sharply after the first 10 minutes of rainfall in the first rainfall cycle (**Fig. 2**). Boron levels ranged from 80 to 175 ppm in runoff from the

*Table 1. — Boron levels in wood blocks and sawdust treated with 0.25 to 2.5 percent boric acid equivalent disodium octaborate tetrahydrate and subjected to AWPA Standard E11 leaching.*

| | | Boron level (mg BAE/g of wood) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment level | Block or Dust | 0 | 6 | 24 | 48 | 96 | 144 | 192 | 240 | 288 |
| (percent BAE) | | (hr) | | | | | | | | |
| 0.25 | Block | 0.86 | 0.34 | 0.11 | 0.04 | 0.01 | 0 | 0 | 0 | 0 |
| 0.625 | -- | 2.19 | 0.72 | 0.16 | 0.04 | 0.01 | 0 | 0 | 0 | 0 |
| 1.25 | -- | 3.98 | 1.21 | 0.29 | 0.07 | 0.02 | 0.01 | 0 | 0 | 0 |
| 2.50 | -- | 7.94 | 2.10 | 0.49 | 0.14 | 0.04 | 0.01 | 0.01 | 0 | 0 |
| 0.25 | Dust | 0.66 | 0.07 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0 | 0 |
| 0.625 | -- | 1.55 | 0.14 | 0.04 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0 |
| 1.25 | -- | 2.41 | 0.23 | 0.02 | 0.01 | 0 | 0 | 0 | 0 | 0 |
| 2.50 | -- | 5.24 | 0.66 | 0.06 | 0.02 | 0.01 | 0.01 | 0.01 | 0 | 0 |

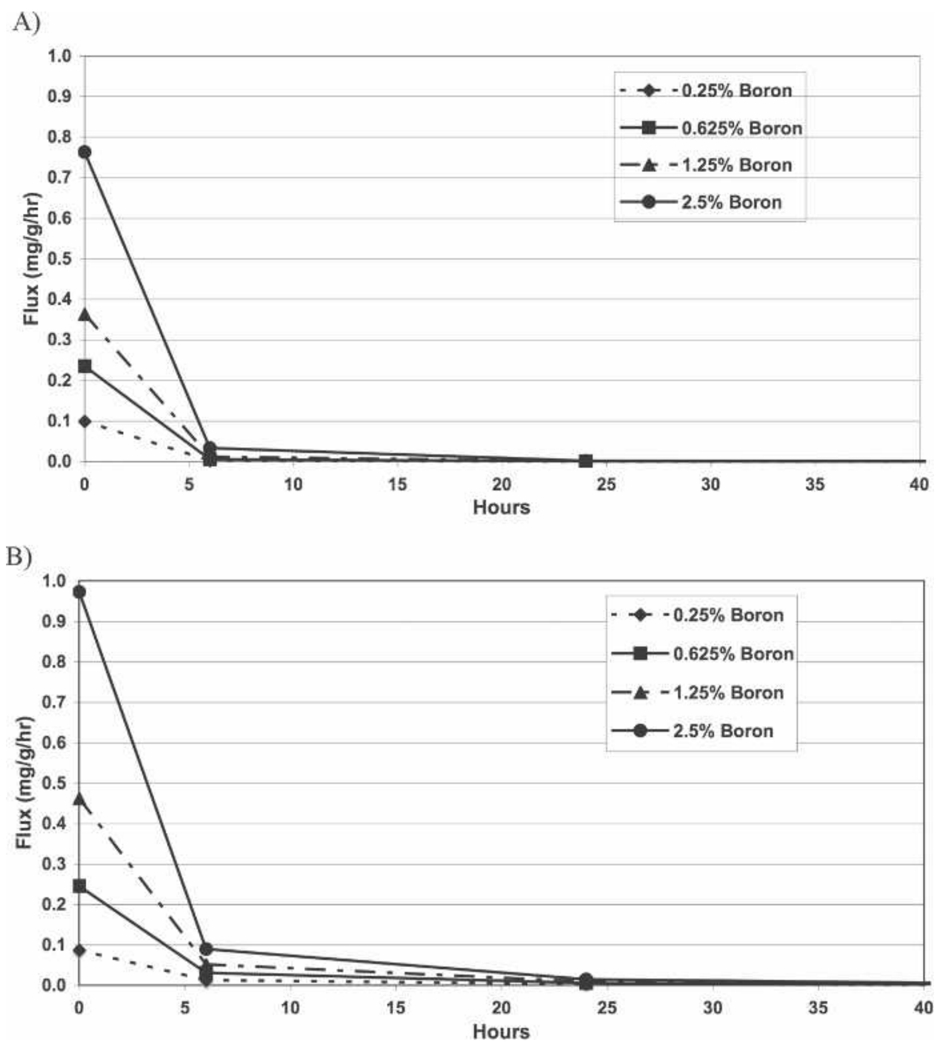


*Figure 1. — Boron fluxes (mg/g/hr) from A) sawdust, and B) 10-mm cubes treated with 0.25, 0.625, 1.25, or 2.50 percent boric acid equivalent of DOT and subjected to leaching according to AWPA Standard E11. Data for 40 to 288 hours are not shown.*

first 5 minutes of rainfall from freshly treated boards compared with 15 to 30 ppm in boards that had been stored for several months after treatment. Boron levels in freshly treated boards declined slowly with rainfall time and still ranged from 10 to 22 ppm at the end of the 4 hour cycle. Boron levels in runoff from the stored boards were less than 5 ppm at the same time point. The differences in boron levels in runoff from freshly treated and stored boards may reflect diffusion of boron away from the surface in the stored material, leaving less boron on the wood surface where it can immediately interact with the rainfall.

The initial spike in boron in the runoff water reflects the tendency of residual chemical to remain on the surface of

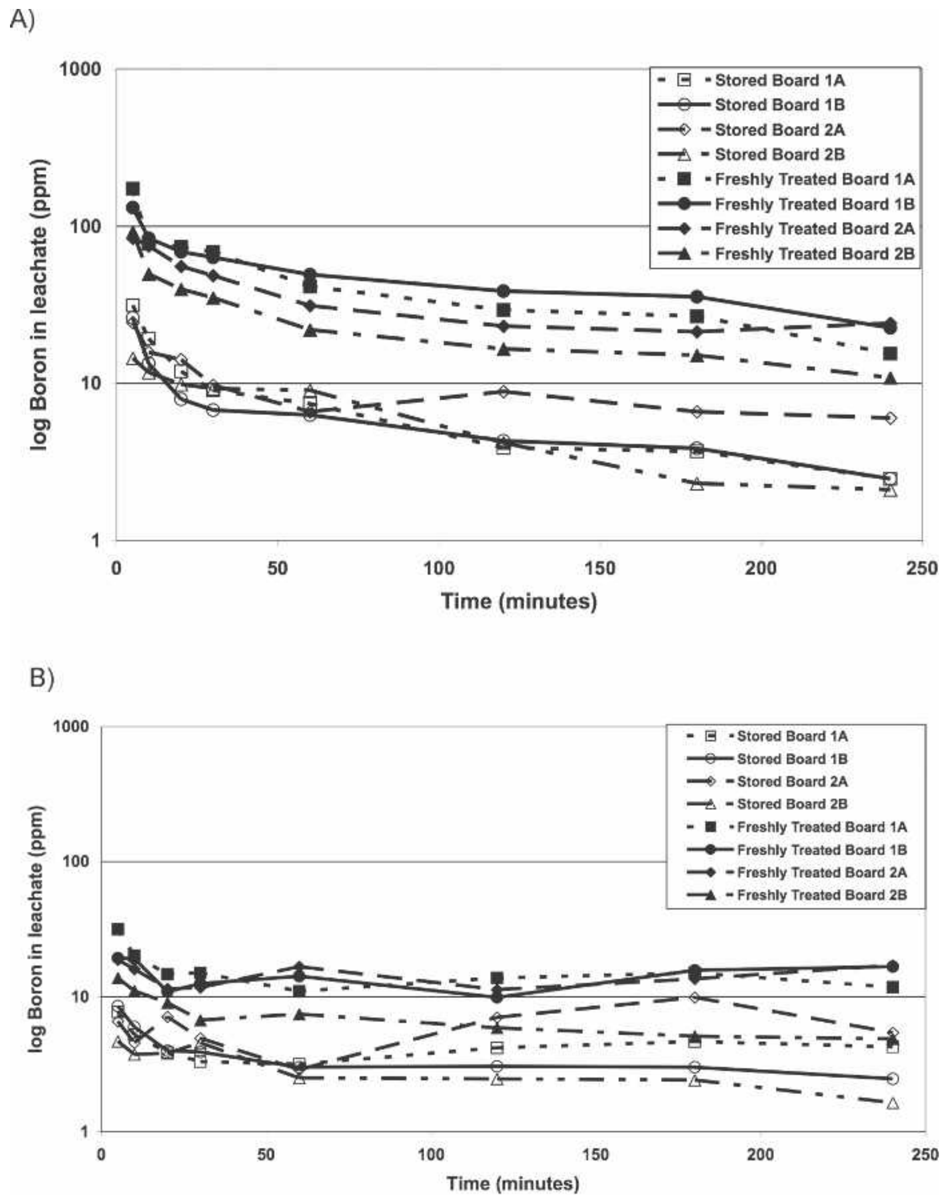


*Figure 2. — Log boron concentrations in runoff collected at selected times from DOT-treated Douglas-fir boards subjected to A) one, B) two, C) three, or D) four cycles of 1.4 cm of rainfall per hour for 4 hours followed by drying to 12 percent MC.*

wood after pressure treatment, leading to subsequent solubilization by wetting events. The high water solubility of boron makes this solubilization especially likely, and suggests that concerns about boron losses from surface wetting could be mitigated to some extent by post-treatment processes that reduce surface blooming.

Exposure of the boards to a second 4 hour rainfall period resulted in much lower levels of boron in the runoff, although the levels were still slightly higher in the freshly treated boards (**Fig. 2**). Boron levels in runoff from freshly treated boards ranged from 12 to 30 ppm after 10 minutes of rainfall, compared to less than 10 ppm for the stored boards. The boron levels in runoff from the first 5 minutes of the second rainfall cycle still represented a nearly 6-fold reduction from the same time period in the first cycle. Boron levels in runoff collected during the remainder of the rainfall cycle ranged from 5 to 18 ppm for the freshly treated boards and were <5 ppm for the stored material.

Boron levels in runoff from the first 10 minutes of boards exposed to a third rainfall cycle were slightly lower than those found for the second cycle, ranging from 10 to 24 ppm for the freshly treated boards and 3 to 10 ppm for the stored materials. Boron levels in runoff collected later in the rainfall cycle were all uniformly below 7 ppm.

Boron levels in runoff from the first 10 minutes of a fourth rainfall cycle were all below 5 ppm regardless of whether the boards were freshly treated or stored for some period after treatment. The low levels of boron in the runoff could imply that the initial boron loading has completely depleted from the boards, however.

Calculation of boron fluxes from the boards produced values ranging from 0.75 to 0.011 mg/g/hr (**Fig. 3**). Fluxes from the freshly treated boards were almost five times higher than those from the stored boards in the first rainfall cycle. The differences narrowed somewhat with cycle, but fluxes from the freshly treated boards were always higher at a given time.

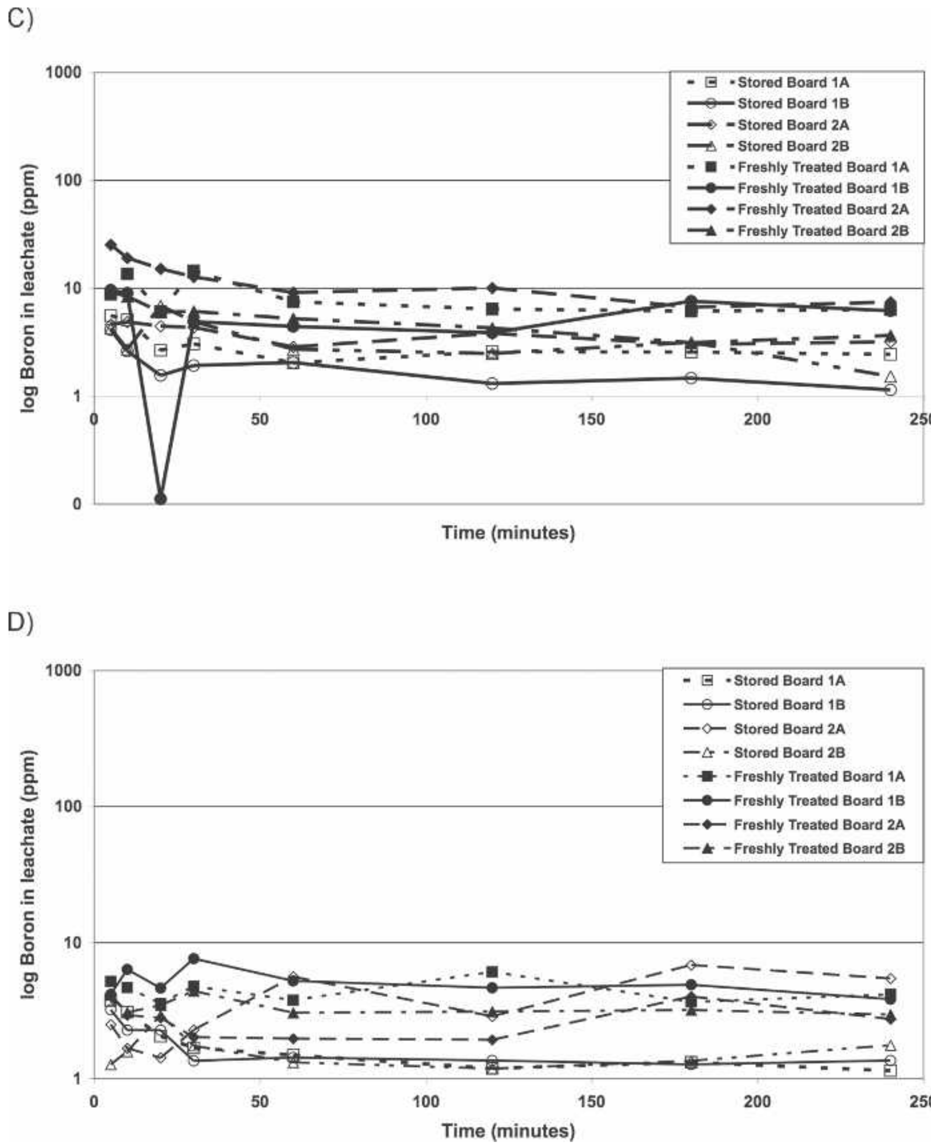


*Figure 2. — Continued*

Fluxes for the freshly treated materials after 5 minutes of rainfall approached the fluxes for the small blocks over the first 6 hours of leaching, but then declined to almost 10 percent of that level after 4 hours of rainfall. Fluxes for the stored boards were only 10 percent of those for the small blocks then declined to less than 3 percent of that level at the 4 hour point. Clearly, boron migration in the larger material differed substantially from that found in either the smaller blocks or the sawdust. The reasons for these differences reflect accessibility. Sawdust provides an exceptionally larger surface area for solubilization. Similarly, the small blocks provide excellent longitudinal access, resulting in rapid loss of boron. Conversely, the boards have limited surface area and most of this area consists of radially or tangentially oriented cells. Furthermore, Douglas-fir is more resistant to fluid penetration, even with water diffusible compounds (Lebow and Morrell 1989), further reducing the risk of chemical loss. As a result, the ability of boron to become solubilized is sharply reduced in comparison with the smaller materials. The results clearly highlight the inappropriateness of using small block tests to predict migration of water soluble biocides.

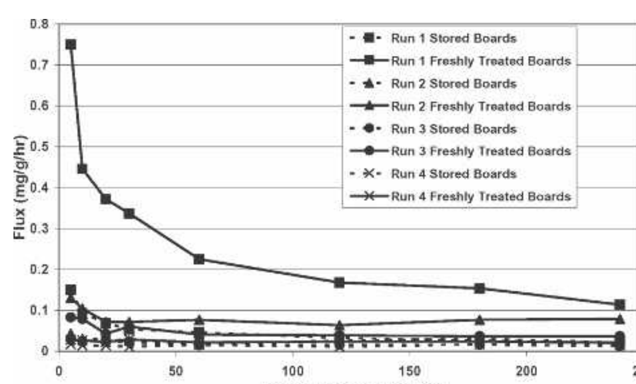


*Figure 3. — Boron fluxes as calculated from runoff from DOT-treated Douglas-fir boards subjected to one to four cycles of 1.4 cm/hour rainfall followed by drying.*

## Boron depletion from boards

The water monitoring from the boards subjected to leaching clearly showed that boron migrated from the boards when

*Table 2. — Boron levels at selected distances inward from the surfaces of Douglas-fir boards treated with disodium octaborate tetrahydrate and subjected to one to four rainfall/drying cycles (1.4 cm/h for 4 h).*

| Board | Distance from surface | Boron level ($kg/m^3$ BAE)[a] | | | | |
|---|---|---|---|---|---|---|
| | | Initial | One rain cycle | Two rain cycles | Three rain cycles | Four rain cycles |
| | (mm) | | | | | |
| Stored board 1 | 0 to 5 | 4.01 | 3.76 | 3.86 | 3.47 | 4.26 |
| | 5 to 10 | 3.65 | 3.41 | 3.69 | 4.62 | 4.53 |
| | 10 to 25 | 3.36 | 3.00 | 3.33 | 2.83 | 3.60 |
| Stored board 2 | 0 to 5 | 16.71 | 3.31 | 3.34 | 2.61 | 2.57 |
| | 5 to 10 | 10.18 | 3.46 | 3.50 | 2.81 | 2.50 |
| | 10 to 25 | 14.02 | 3.36 | 3.48 | 2.79 | 2.37 |
| Freshly treated board 1 | 0 to 5 | 6.55 | 5.80 | 3.18 | 6.97 | 6.02 |
| | 5 to 10 | 3.70 | 1.61 | 0.78 | 1.46 | 2.18 |
| | 10 to 25 | 2.94 | 0.94 | 0.20 | 0.19 | 1.26 |
| Freshly treated board 2 | 0 to 5 | 10.02 | 4.39 | 3.57 | 3.19 | 5.06 |
| | 5 to 10 | 10.49 | 0.82 | 1.99 | 0.71 | 1.67 |
| | 10 to 25 | 11.25 | 0.21 | 1.20 | 0.30 | 0.46 |

[a]Values represent the average of two sections from each board.

subjected to rainfall. Given the small block results, this migration might be expected to deplete the wood surface, rendering the wood susceptible to fungal or insect attack. However, boron analysis of plugs cut from the boards and sectioned into zones 0 to 5, 5 to 10, and 10 to 25 mm from the wood surface indicated that, while boron levels tended to vary widely between boards, the relative proportion of boron in the zones remained remarkably similar over the four samples. Analysis of wood plugs taken from the two stored boards indicated relatively shallow preservative gradients from the surface to the interior, reflecting the additional time following treatment when the boron could continue to diffuse into the wood (**Table 2**). This gradient appeared to change little with rainfall cycle, suggesting that losses from the surface had not yet begun to deplete the residual chemical deeper in the wood.

Boron levels in the freshly treated boards tended to follow a much steeper preservative gradient, particularly for one of the boards, reflecting the limited time available for redistribution following treatment. Boron levels in the freshly treated boards also varied only slightly over the 4 rainfall cycles, again suggesting that the majority of the boron was not available for leaching. The lack of change in boron levels deeper in the wood indicates that exposure of boron treated wood to periodic heavy rainfalls will have little overall negative impact on boron levels in the wood. This does not mean, however, that continued exposure would be without consequence in terms of gradual depletion over time.

## Conclusions

Exposure of DOT-treated wood to periodic heavy rainfall events leads to an immediate loss in residual boron from the wood surface; however, these losses decline sharply with time. The exposure of DOT-treated Douglas-fir boards to limited rainfall does not appear to be detrimental to the residual boron in the lumber.

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# Control of discoloration in pitch pine

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**Abstract**

Specific drying conditions for control of discoloration in pitch pine were analyzed and evaluated to determine best drying temperature and moisture content (MC) to maximize high value-added uses. High-temperature kiln-drying with restraint effectively reduced twist but also caused an excessive darkening stain. Further experiments showed that this stain generation is controlled by drying at conditions exceeding 100 °C dry-bulb only until before wood core temperature reached 100 °C. Results also showed accurate control of MC and finishing the drying process at the most suitable time to be important. Boards of excellent color were produced by applying a newly developed reducing temperature drying schedule for stain control. It is anticipated that higher additional value can be obtained from pitch pine, with continued studies on stain control, resin exudation, and twist restraint.

Pitch pine (*Pinus rigida*) has been widely used for structural lumber in construction, interior wood, and packaging materials throughout the world. For several decades it has been widely planted in Korean forests, initially primarily for erosion control and use as a fuel supply. Currently, the Korean wood industry sector mostly uses pitch pine logs as raw material for such low value uses as nonstructural boards and where visual appearance is not important, or as furnish for such process industries as particleboard, fiberboard, and pulp and paper.

Efforts to use pitch pine as a higher value lumber product have continued through wood-drying research in Korea. Due to the lack of pruning, pitch pine trees typically have big and crowded knots. Unfortunately, the sloped grain caused by these knots commonly causes excessive twist during drying. Also, if much of the resin in pitch pine is not eliminated or set during drying, it can be a principal factor obstructing adhesion of glue and paint. It is well known that suppression of twist and reduced resin exudation from products in use are among the benefits of high-temperature drying. While this supports high-temperature drying as a suitable drying method, generation of an undesirable discoloring stain during high-temperature drying can decrease the economic value and price of pitch pine products.

Jung et al. (1986) estimated moisture content (MC) losses of air-drying related to meteorological variables, and developed an air-drying calendar for Korean pitch pine lumber. Lee and Jung (1988) worked on development of a kiln-drying schedule for pitch pine using drying resistance. In carrying out their work, these researchers found difficulty with problems such as the twist that occurred due to the extreme fiber gradient around knots, long drying time due to high initial MC, and pitch trouble caused by residual resin not completely eliminated or set in lumber during drying. The pitch trouble was

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particularly problematic as it obstructed adhesion and painting on the surface of lumber even after drying.

In an attempt to eliminate resin completely, increase the drying rate, and decrease twist, a study of press-drying of pitch pine using a high-pressure hot plate was carried out by Jung et al.(1993). However, it was concluded that a high-pressure hot plate is unsuitable for this species for three reasons: resin contamination of the hot plates, the cauls in press drying retard the drying process, and a press dryer cannot dry a large amount of lumber at a time..

Yeo and Shim (2004) evaluated the applicability of high-temperature drying while applying a heavy top load on a large lumber stack and showed that it is a suitable method for drying of Korean pitch pine, due to the resulting restraint of twist, minimization of drying time, and the reduction of resin exudation and residual internal stress after drying. The reduction in twist with high temperature and restraint is comparable to that found by Koch (1971) with southern pine and Smith and Siau (1979) with red pine. During high-temperature drying, however, a discoloration develops in lumber which acts as a factor to decrease value in many products. Boutelje (1990) reported that discoloration occurs by redistribution of soluble nitrogen. Theander et al. (1993) investigated relationships between discoloration, nitrogen content, and low-molecular weight sugars at wood surfaces. McDonald et al. (2000) concluded that in the presence of amino compounds certain carbohydrates might be converted to precursors for yellowish-colored substances by the Maillard reaction. Stenudd (2004) investigated the color responses to process parameters at different stages in the drying process of birch, and Rappold and Smith (2004) concluded that drying schedule was a much more important factor in determining wood color in hard maple than log age or harvest season. Comparably, this work was carried out to find reasons for discoloration in pitch pine as there has not been much research on the detail and practical drying methods to control discoloration in this species.

Specific objectives of this study were determination of critical temperature and MC which cause discoloration and developing suggestions for drying conditions to control discoloration.

## Materials and methods

### Comparison of lumber color dried by different drying conditions

Eighty-seven predominately flat sawn boards, 20 mm (thickness) by 120 mm (width) by 3600 mm (length) dimension, were sawn from 42 pitch pine trees freshly cut from a 37-year-old plantation forest at Yangpyeong-gun, Gyeonggi-do, Korea in April 2004. These were kiln-dried as two separate bundles of 42 boards each, stacked seven wide by six high, along with other lumber, using either a high-temperature kiln schedule in a SKD-90HPT dryer manufactured by the Shinshiba Co., or dried at low temperature in a DC-123 dryer manufactured by the Incomac Co. In both cases, the boards were separated by 25-mm-square stickers laid 600 mm apart, air velocity was 2 m/sec, and a top load weight of 660 kg/m$^2$ was applied to control warp during drying. The three remaining boards were air-dried without top load restraint. The drying conditions utilized for each condition are illustrated in **Figure 1**. Electrical resistance moisture meter probes were used to monitor drying progress during these experiments. Most of the boards contained both sapwood and heartwood,

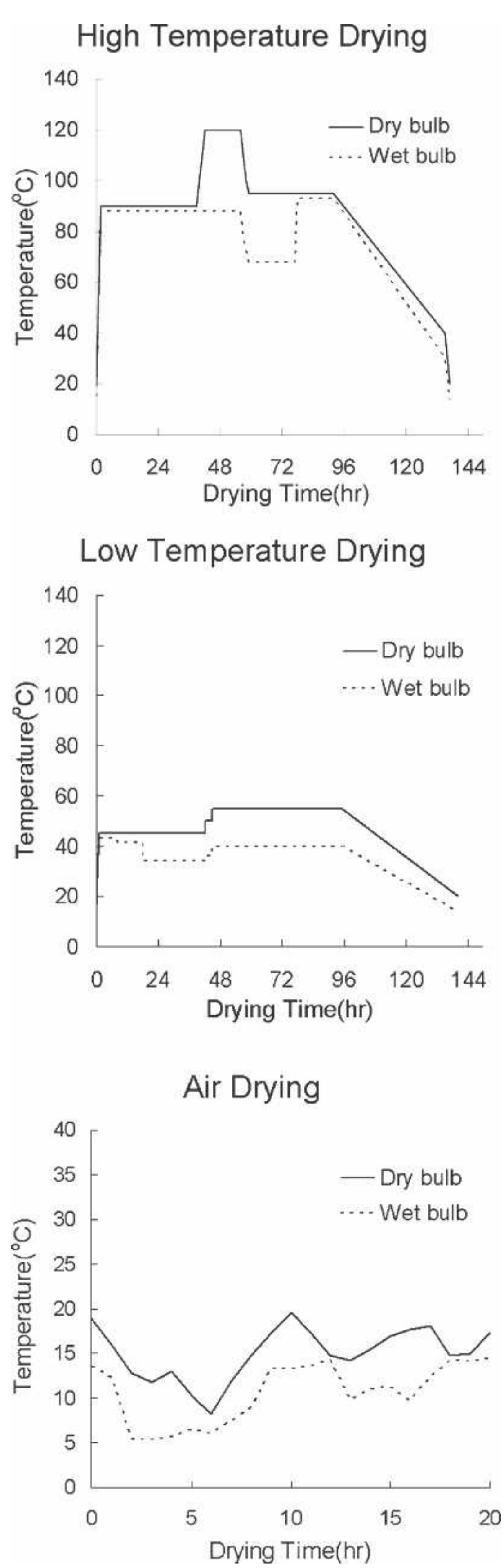


*Figure 1. — High- and low-temperature drying schedules and air-drying conditions.*

*Table 1. — Average final percent MC and color values of lumber dried by high temperature, low temperature, and air-drying.*

| Drying method | MC | | Shrinkage | | Warpage | Color value after drying[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (percent) | | | | (mm) | Earlywood | | | Latewood | | |
| | After drying | After 10-day piling | Thick. | Width | Twist | L* | a* | b* | L* | a* | b* |
| High temp. | 7.7 | 8.8 | 3.5 | 3.4 | 6.8 | 77.3 (1.9) | 7.0 (0.9) | 28.5 (1.8) | 69.4 (4.9) | 10.6 (1.6) | 31.6 (2.3) |
| Low temp. | 8.6 | 11.6 | 3.0 | 3.2 | 11.7 | 85.6 (2.2) | 3.8 (2.7) | 21.4 (2.2) | 76.3 (3.9) | 11.1 (3.5) | 29.3 (2.2) |
| Air-drying | -- | 13.4 | 2.6 | 1.7 | 51.0 | 86.2 (0.2) | 3.1 (0.2) | 20.0 (0.2) | 78.7 (0.1) | 9.6 (0.1) | 28.3 (0.5) |

[a]SD values in parentheses.

the color of which was not particularly different especially when green.

After drying, each board was measured to determine shrinkage and weighed, and its final MC was determined by oven-drying sample wafers. Twist was found by holding three points of the wide face of each board flat on a large glulam beam and measuring the rise of the fourth corner.

Earlywood and latewood zone color was measured from tangential surfaces, within an 8-mm-diameter area, using a CR-10 colorimeter ( manufactured by the Minolta Co. The instrument was operated utilizing CIE (Commission Internationale d'Eclairage) standard $D_{65}$ daylight illumination, 10° observer angle, and provided color data in units of L*a*b* values. The L*a*b* color space system was defined by the CIE in 1976 and is widely considered to most nearly model human color perception. It quantifies color in a three-dimensional uniform space based upon the opponent theory of color vision, which states that colors cannot be perceived as both green and red, or blue and yellow at the same time, only as combinations of green and blue, green and yellow, red and blue, and red and yellow. L* is the lightness coordinate (100 = white, 0 = black), and +a* indicates red, –a* green, +b* yellow, and –b* blue (Billmeyer and Saltzman 1981). To compare differences between three-dimensional color space L*a*b* values, researchers typically use the color difference metric equation, which mathematically calculates $\Delta E^*_{ab}$, the Euclidean distance between two colors.

$$\Delta E^*_{ab} = \sqrt{((L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 — b^*_2)^2)}$$

Lightness values (L*) alone have been shown by several researchers to often sufficiently communicate wood color differences and facilitate color sorting of lumber, with differences in color values greater than 3 considered visually distinguishable by humans (Stokke et al. 1995). This was also found to be true during these experiments, and so much of the color results are presented simply as L* values and differences.

## Determination of critical temperature and MC for color change

To evaluate more specifically the relationship between drying temperature and color in pitch pine lumber, green boards sawn from the same set of logs were dried in an oven at 60, 75, 90, 100, 110, 120, 135, and 150 °C. Forty flat sawn specimens were prepared for these experiments, 60 mm (thickness) by 120 mm (width, tangential direction) by 600 mm (length) dimension, with five dried at each temperature. One of the specimens at each drying condition was dedicated for the measurement of internal temperature at three depths during drying, using thermocouples inserted in the radial direction through the tangential face, tightly into holes sealed with silicone sealant 10-mm (outer layer), 20-mm (intermediate zone), and 30-mm deep (middle zone) through the tangential face in the radial direction. Temperatures were recorded every minute during drying with a datalogger. To assure that these 600-mm-long specimens behaved as full-size boards during drying, the end surfaces were sealed and thermally insulated with a thick piece of sheet rubber, held tightly between two metal plates with four threaded rods and wing nuts. This device and procedure enabled limiting moisture and heat movement to only the radial and tangential directions. After being prepared, while waiting to be dried at each particular temperature condition, the specimens for each group were wrapped tightly with polyethylene and stored in a freezer at −7 °C. Then, just prior to each experimental run the specimens for that group were stored still wrapped, to prevent drying, to thaw for 1 day at 20 °C.

To evaluate MC, discoloration, and organic-solvent extractive content, at time intervals during drying of 1, 3, 6, 9, 12, 24, 31, 48, 55, and 72 hours, the four specimens were briefly removed from the oven and a 40-mm-thick (longitudinal direction) section was cut from each piece. The threaded rods enabled effective resealing of the endgrain of the subsequently shorter boards with the rubber sheets, for continued full-size-board simulated drying. Each of these four 60-mm (radial) by 120-mm (tangential) by 40-mm (longitudinal) section specimens were promptly cut from the bark side sapwood face into four 5-mm-thick (radial) by 120- (tangential) by 40-mm (longitudinal) wafers from the shell to the core, using a thin kerf bandsaw. The four wafers, from the outer layer, middle outer layer, middle inner layer, and the core, were each split in two pieces, with one being used for color and MC and the other for extractive content determination.

Each color and MC determination wafer was promptly weighed and then conditioned in a 20 °C and 60 percent RH environmental room until equilibration. L*a*b* color values of tangential surface earlywood and latewood were measured with the Minolta CR-10 colorimeter. Also, a color image of each wafer was made using an Epson 4870 photo scanner, results of which are not presented in this paper, after which the wafer was oven dried.

Because it was anticipated that the presence and concentration of organic solvent soluble resin extractives may be related to color change with temperature, and that these extractives may migrate with heating and drying, organic solvent extraction was carried out. Wood flour was obtained from each wafer section by grinding until it was comminuted to pass a 40 to 60 mesh screen. Extraction was with 2 g of wood flour using a 1 to 2 ratio of hot alcohol to benzene solution in an apparatus at 100 °C for 6 hours.

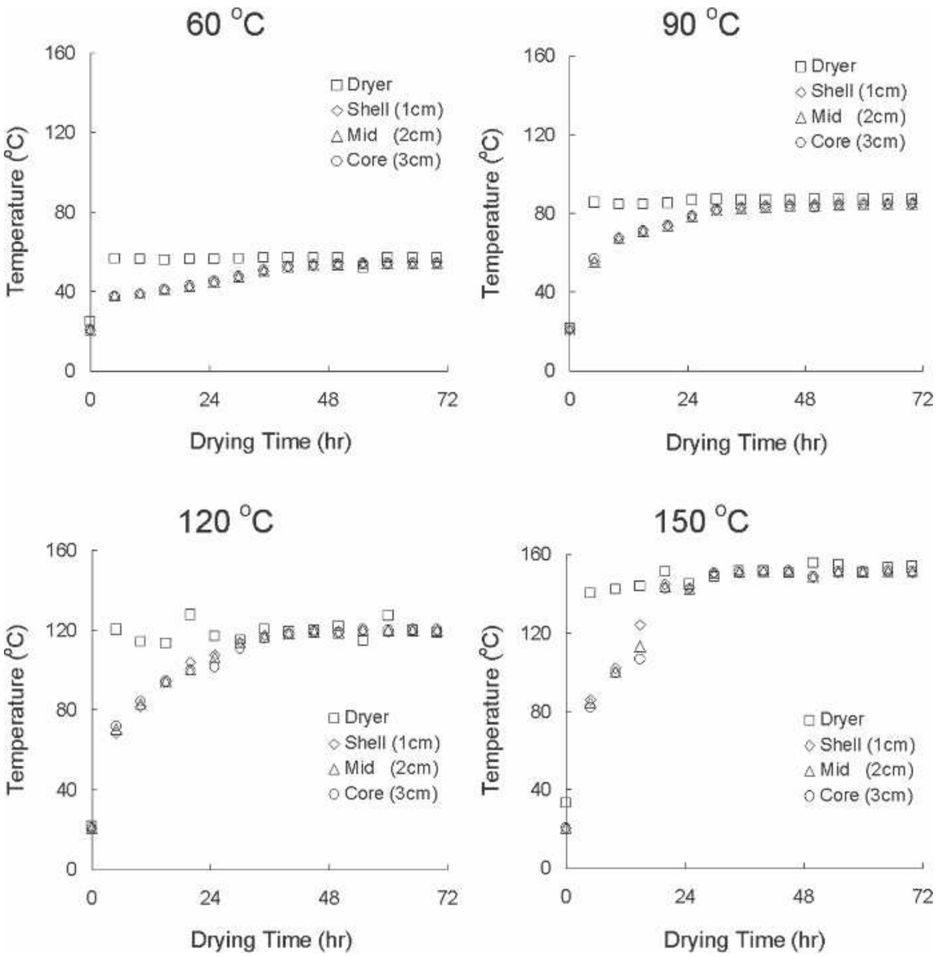


*Figure 2. — Internal temperature changes in pitch pine lumber while drying at several dry-bulb temperatures.*

## Results and discussion

### Twist and color of boards dried by high temperature, low temperature, and air-drying

High-temperature drying with top load restraint resulted in substantially less twist, and reduced hygroscopicity (**Table 1**). In use, these boards will change less in moisture with relative humidity differences, and stay straighter. These results are similar to those of Koch (1971) and Smith and Siau (1979).

Analysis of color of the pitch pine boards dried by high temperature, low temperature, and air-drying, using L*a*b* color values, found little difference between low-temperature drying and air-drying (**Table 1**), with color metric difference values ($\Delta E^*_{ab}$) of 1.7 in earlywood and 3 in latewood. High-temperature drying, however, resulted in considerable darkening and substantial color change from low-temperature kiln-drying, with $\Delta E^*_{ab}$ values of 11.4 in earlywood and 7.3 in latewood.

### Investigation of drying condition for occurrence of discoloration

*Internal temperature.* — Though these drying experiments were performed at eight temperatures, the results only for drying at 60, 90, 120 and 150 °C are being presented as it was determined these sufficiently represent the entire set. At the 60 and 90 °C drying conditions small differences are shown in internal temperature (**Fig. 2**), whether between the outer layer, middle layer, or core, as these increased to the temperature of circulated air in the drying oven. However, at the 120 and 150 °C conditions, there was somewhat of a temperature gradient, observed by a tendency of temperature change between the outer and inner layers. When the temperature of an inner layer reaches 100 °C, it maintains at that temperature for a few minutes to several hours. The existence of this plateau in temperature means that free water exists in that location. Subsequently, as free water is removed and evaporated and the MC drops below the fiber saturation point, the temperature of the inner layer rises again. The temperature of the outer layer increased to the temperature of the environmental chamber without showing a plateau, because MC there decreases to below the fiber saturation point before its temperature reaches 100 °C. When analyzing the relationship between color value, MC, and temperature at the same location in wood, the curves illustrated in **Figures 2, 3,** and **4** show internal temperature changes can be used to examine critical temperature and exposure time which generate discoloration in particular regions or zones in wood.

*Moisture content.* — The average initial MC of the pitch pine specimens used in this study exceeded 100 percent. As expected, MC decreased more rapidly at higher temperature (**Fig. 3**). Drying times for specimens dried to ovendry conditions at 120 and 150 °C, were about 48 and 24 hours, respectively. After 72 hours drying at 60 and 90 °C, MCs of specimens averaged about 16 and 6 percent, respectively.

*Discoloration.* — Discoloration did not develop in the earlywood of pitch pine when drying at the 60 °C condition, with a lightness of 85, redness of 5, and yellowness of 20 maintained from beginning to the end of drying. Only the earlywood color results are being presented in this paper (**Fig. 4**) as, being naturally lighter than latewood, any darkening in the earlywood is more noticeable. At the 90 °C drying condition there appears only minor discoloration, as the specimens were still bright, with lightness values just below about 85 after drying for 72 hours. When drying at 120 °C, as the average MC reached 30 percent there was a marked decrease in lightness, and an increase in redness, with further darkening as drying progressed.

At 150 °C drying temperature, the darkening stain in the earlywood occurred rapidly as the internal temperature reached 100 °C at about 32 percent MC after 9 hours. As the wood specimens were ovendried to dryness, the stain was continuously generated till at 72 hours the lightness value had decreased to approximately 70.

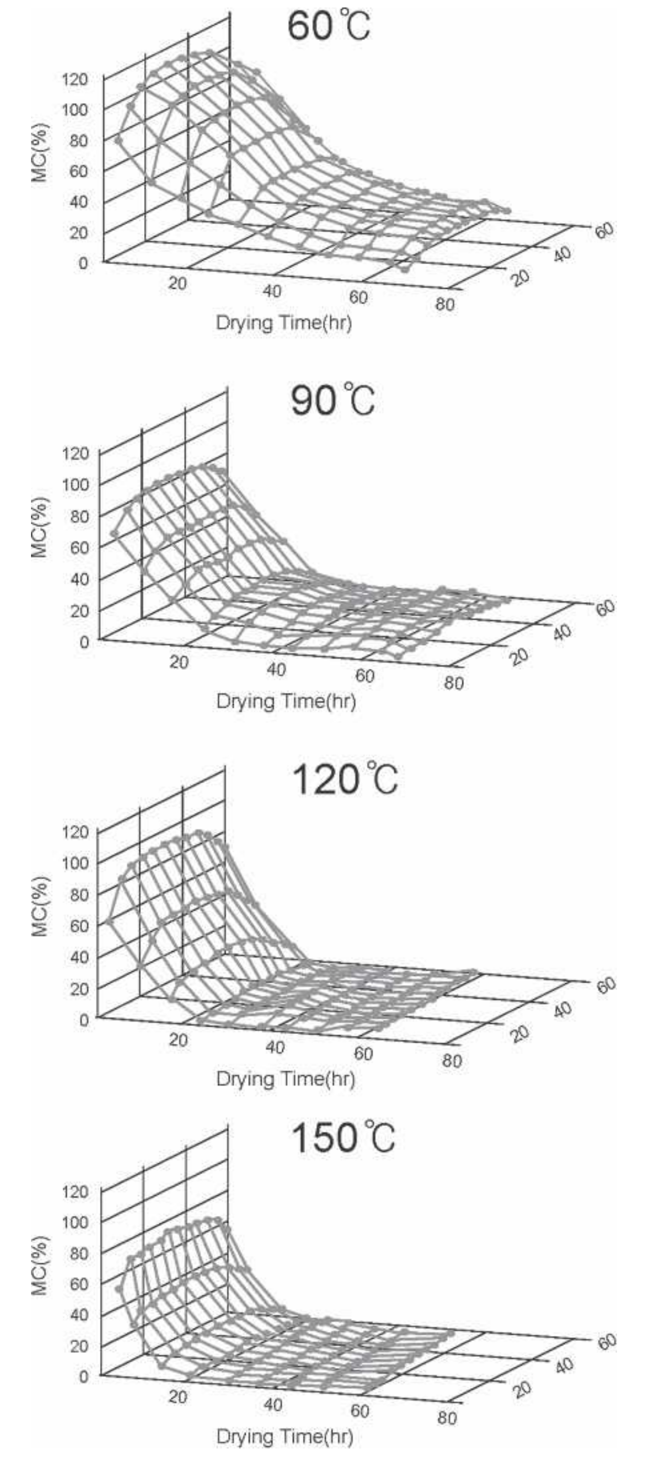


*Figure 3. — Internal moisture profiles in pitch pine lumber while drying at several dry-bulb temperatures.*

These results show that with pitch pine lumber darkening stain develops readily at high temperature conditions, and especially abruptly when the internal temperature reaches 100 °C while MC is still high. An additional interesting observation was that when the wood was exposed to 120 and 150 °C temperature even after reaching ovendry, 0 percent MC, at 24 and 48 hours, respectively, the darkening stain continued to progress further. It thus appears important that to produce bright color lumber when kiln-drying with high temperature air over 100 °C, that the heat should only be applied until before the internal temperature reaches 100, and that the drying process should then be completed at lower temperature and ended just after the target MC is achieved.

### Organic solvent extractives profile

*Extractive movement.* — The concentration and distribution of organic solvent extractives remaining in each layer were measured at the initial, middle, and end stages of drying at 60, 90, 120, and 150 °C. **Figure 5** shows that the concentration of extractives in the core generally decreased while that in the shell increased, indicating that these organic solvent soluble extractives tend to move to outer layers of wood during drying.

*Effect of temperature on extractive movement.* — When dried at 60 °C there appears not much change in the concentration of extractives in the outer layers (**Fig. 5**). However, at 90 °C the concentration of extractives in the shell increased about 38 percent during drying. At 120 and 150 °C drying the concentration of extractives in the shell layer seemed to increase after the initial drying stage, but then did not change or perhaps even decreased somewhat as drying finished. This would seem to indicate that at these temperature conditions these extractives move primarily during the initial and middle drying stage when liquid water is present in wood.

*Effect of extractives on discoloration.* — The concentration of extractives in the shell layer increased about 38 percent and 30 percent, respectively, after drying at 90 and 150 °C. This suggests that a similar amount of extractives from the core region are transferred to this outer layer. Interestingly, while a similar quantity of organic solvent extractives remained in the wood after drying at the temperatures of this study (**Fig. 5**), the degree of darkening stain was different. This shows the degree of discoloration to be independent of extractive content, as it was affected only by the elevated temperature drying. Though these results could not demonstrate an interrelationship between the organic solvent extractive concentration and degree of darkening discoloration in pitch pine while drying, they are of value in showing the movement and concentration change of extractives, presumably resin, and may be utilized to control such subsequent troublesome resin issues as bleeding in painting and adhesion processes.

*Development and application of a drying temperature schedule to control darkening stain.* — In an attempt to control both darkening stain generation and resin exudation in pitch pine lumber, the drying schedule shown in **Figure 6** was developed and applied to dry several boards. High-temperature drying conditions up to 120 °C dry bulb were applied until just before the wood core reached 100 °C, after which the dry bulb was dropped to 90 and then 60 °C. Thermocouples measured interior wood temperature, and as with the earlier experiment wafers were cut off for internal moisture and color measurement with subsequent re end sealing of the drying boards with the sheet rubber and threaded rods. MC was determined by weighing and oven drying, and earlywood tangential surface color measured at 0, 20, 28, and 48 hours when the lumber reached the target MC of about 15 percent. Overdrying was particularly avoided to minimize excessive exposure to high temperatures. This 48-hour, reducing temperature drying schedule successfully resulted in minimal change in earlywood lightness, L*, with bright color wood from the shell through to the core.

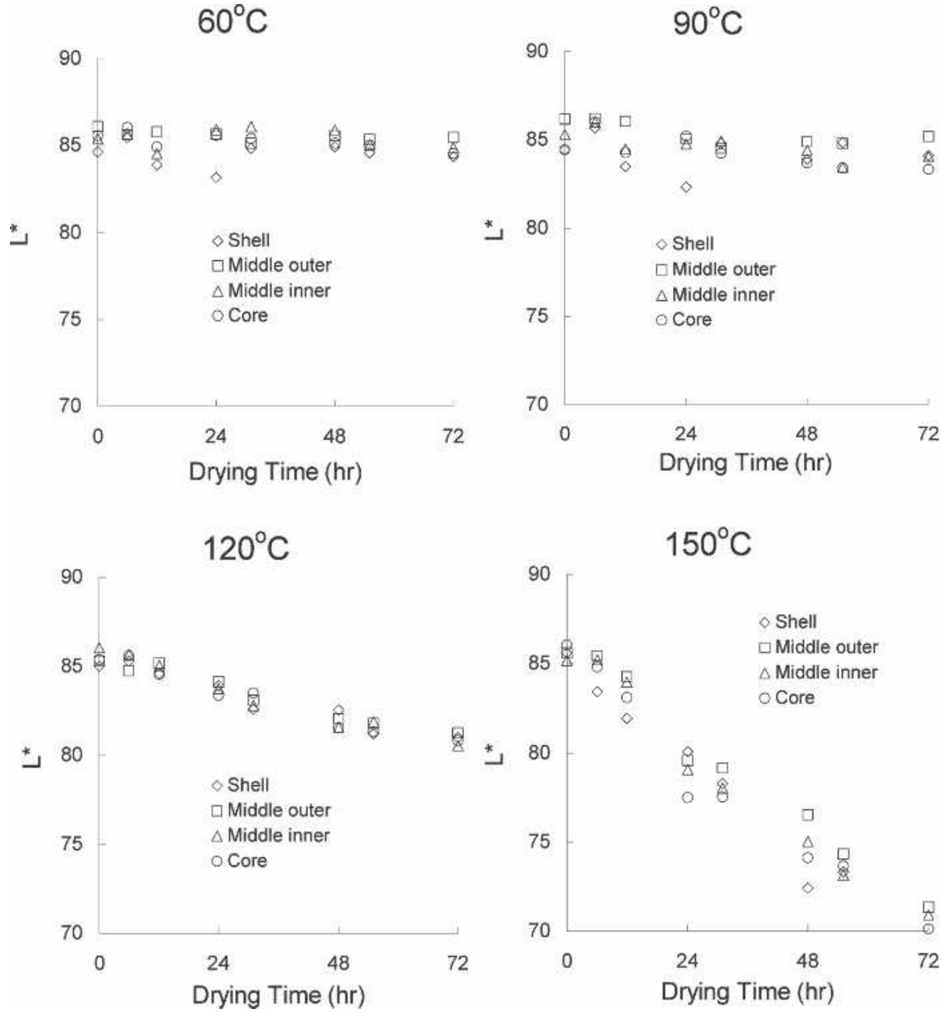


*Figure 4. — Lightness change in pitch pine lumber earlywood while drying at several dry-bulb temperatures.*

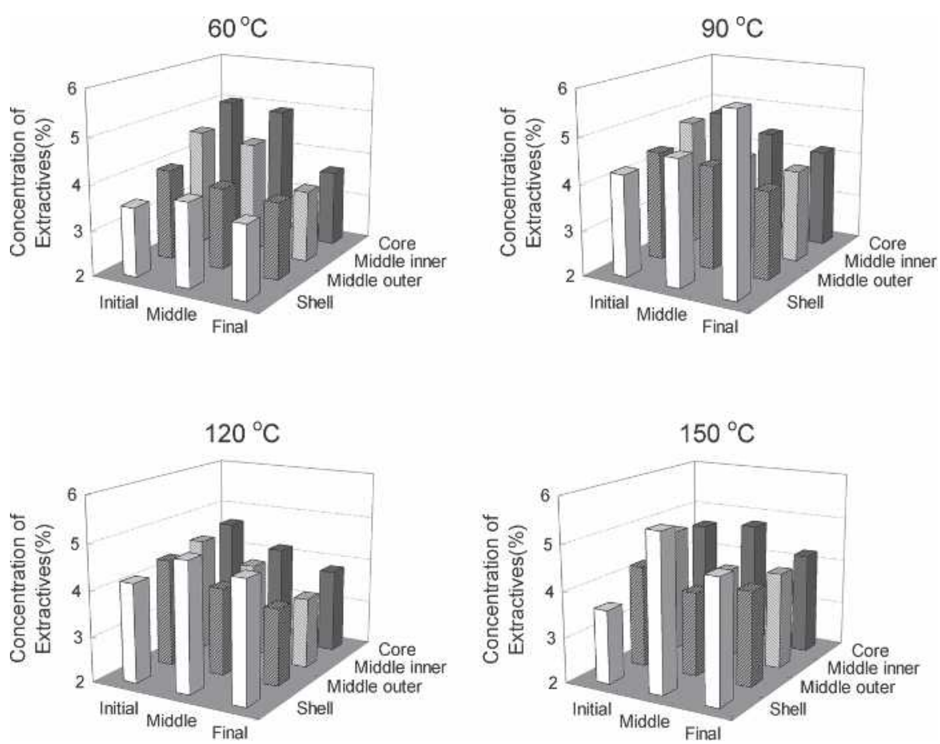


*Figure 5. — Extractive content profile change in pitch pine at initial, middle, and final drying stages, for drying at 60, 90, 120, and 150 °C dry bulb.*

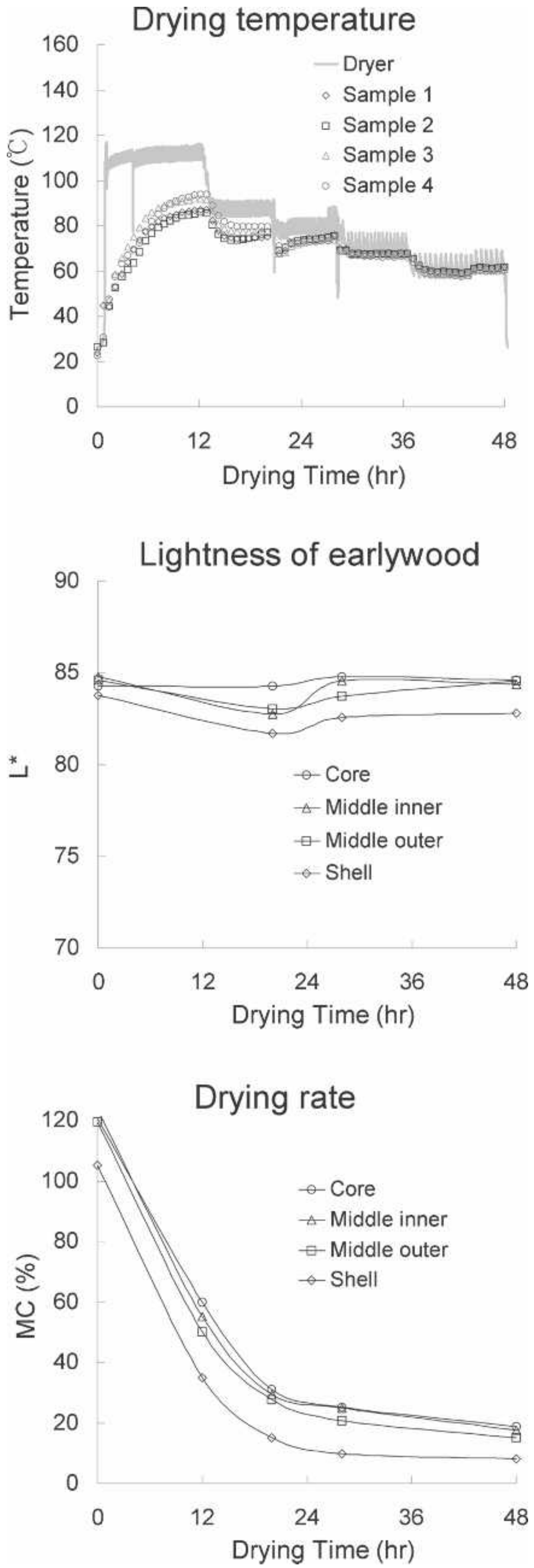


*Figure 6. — Newly developed reducing temperature drying schedule showing drying rate, temperature and that there was no darkening color change stain when applying this schedule.*

## Conclusions

Specific drying conditions for discoloration control were evaluated and analyzed in this study to determine best drying temperature at particular MCs for achieving brighter color in pitch pine. It was determined that during high-temperature drying, temperatures exceeding 100 °C dry bulb should only be applied until before the wood core reaches 100 °C. Further, results lead to the conclusion that stain generation is also restrained by accurate control of MC and finishing the drying process at the most suitable time. Experimental validation demonstrated that boards of excellent color were produced by applying the newly developed drying temperature schedule specifically for stain control. It is expected that higher additional value can be obtained from pitch pine, with continued studies such as this on stain control, resin exudation, and twist restraint.

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# Relationship between bending and tensile stress distribution in veneer plywood

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## Abstract

This paper presents an optimization of plywood construction aimed at achieving the desired relationship between the bending and tensile properties of plywood. The optimization is based on the analysis of stress and strain distribution, the values of which were computed using the finite element method. The control panel was seven-ply okoume plywood. The control plywood had approximately the same bending properties parallel and perpendicular to the face grain direction, however, the tensile strength parallel to the face grain direction was substantially lower than that perpendicular to the face grain direction. Consequently, the objective of the research was to change the values of tensile stress without changing the values of bending stress, nominal plywood thickness or total number of layers. The research results show that by changing the thickness of only three layers located closest to the middle surface of the panel, full optimization of tensile stress was achieved, while retaining the three said parameters.

The properties of plywood panel are closely related to its structural design, i.e., the veneer layup and the orientation of individual layers. In standard plywood, there is a considerable difference between the mechanical properties parallel and perpendicular to the face grain direction. However, in some cases, such differences are undesirable, leading to efforts to minimize such.

The optimization of plywood properties may be achieved in several ways: by defining the total number of layers (Kollmann et al. 1975), changing the thickness of the outer layers alone (Kljak et al. 2006) or by using nonwood materials, i.e., inserting synthetic fibers in the gluelines of plywood (Xu et al. 1998, Brezović et al. 2003).

The procedure for optimizing plywood, at a given thickness and fewer layers, is a much more complex problem considering the reduced possibility of combinations of structural elements. However, such a procedure is more desirable if plywood optimization is observed from the aspect of cost-effective manufacturing.

The most commonly considered mechanical properties of primary importance to plywood are bending and tensile properties. Both properties depend directly on the plywood construction and it is quite certain that a change in one property will influence the other to a greater or lesser extent.

Therefore, the objective of this study is to change the values of tensile stress, provided that the following values remain unchanged: bending stress, nominal thickness of plywood and the total number of layers.

An optimal ratio of bending to tensile strength is important in cases when plywood is subjected to simultaneous bending and tension. Plywood with varying ratios of bending to tensile strength would provide designers with adequate selection in the design of structural constructions.

## Theoretical background

**Figure 1** shows in-plane forces, whereas **Figure 2** shows the moments on the flat plate. Considering that veneer plywood has a laminate structure, it is analyzed in accordance with the rules applicable to laminate panels.

The basic constitutive equations according to the laminate theory have the following form (Herakovich 1998):

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} \quad [1]$$

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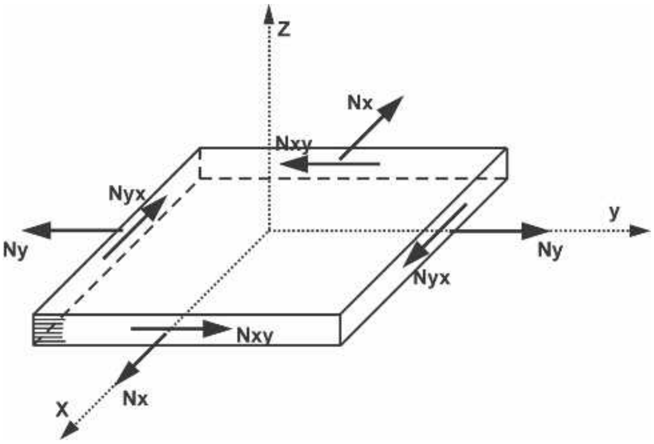


Figure 1. — Forces on plywood panel.

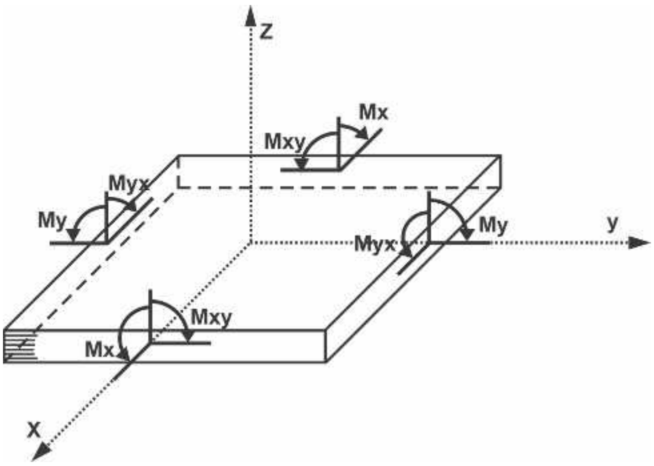


Figure 2. — Moments on plywood panel.

$$[A] = \sum_{k=1}^{N} [\overline{Q}]^k (z_k - z_{k-1}) \qquad [\mathbf{2}]$$

$$[B] = \frac{1}{2}\sum_{k=1}^{N} [\overline{Q}]^k (z_k^2 - z_{k-1}^2) \qquad [\mathbf{3}]$$

$$[D] = \frac{1}{3}\sum_{k=1}^{N} [\overline{Q}]^k (z_k^3 - z_{k-1}^3) \qquad [\mathbf{4}]$$

where $z_k$ is the coordinate of the middle surface of the $k$-th layer (**Fig. 3**), and $[\overline{Q}]^k$ is the $k$-th layer reduced stiffness matrix.

The 6 by 6 stiffness matrix is composed of three submatrices [$A$], [$B$], and [$D$], each 3 by 3 in size and all three symmetrical. Matrix [$A$] is the in-plane stiffness matrix because it directly relates the in-plane strain ($\varepsilon_x^0$, $\varepsilon_y^0$, $\gamma_{xy}^0$) to in-plane forces ($N_x$, $N_y$, $N_{xy}$) (Barbero 1998). Matrix [$D$] is the bending stiffness matrix because it relates curvatures ($\kappa_x$, $\kappa_y$, $\kappa_{xy}$) to bending moments ($M_x$, $M_y$, $M_{xy}$). Matrix [$B$] is the bending-extension coupling matrix because it relates the in-plane strain to bending moments and curvatures to in-plane forces.

It is apparent from expressions [**2**], [**3**], and [**4**] that matrix [$A$] is the function of the layer thickness $t_k = (z_k - z_{k-1})$, but also that it is independent from the stacking sequence of the layers, whereas matrices [$B$] and [$D$] strongly depend on the

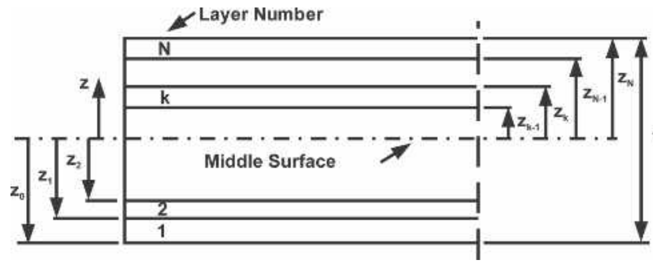


Figure 3. — Geometry of an N-layer laminate.

stacking sequence of the individual layer. In laminates with a symmetrical structure with respect to their middle surface, [$B$] = 0 and the in-plane response is decoupled from the bending response.

On the basis of the relations mentioned above, it may be assumed that virtually any change in the thickness and position of an individual layer will have some effect on the bending stress of plywood. This is particularly so in the case of the outer layers, at the far end from the middle surface of the plate, which are subjected to have maximum stress under the bending load.

For this reason, the optimization of plywood tensile stress (without changes to bending stress) should be based on changes of the thickness of veneer layers next to the middle surface of the panel.

## Materials and methods

The research described in this paper is based on experimental values and numerical models. The control panel was seven-ply plywood made of okoume (*Aucoumea klaineana*) with a symmetrical structure. Its individual properties were determined in accordance with European norms. Plywood thickness was 15.5 mm (CEN EN-324–1; 1993d), density was 494 kg/m$^3$ (CEN EN-323; 1993c), and moisture content (MC) was 9.4 percent (CEN EN-322; 1993b). Bending strength parallel to the face grain direction was 50.583 N/mm$^2$, the modulus of elasticity (MOE) parallel was 5669.293 N/mm$^2$ and the MOE perpendicular to the face grain direction was 5007.837 N/mm$^2$ (CEN EN-310; 1993a). Tensile strength was determined in accordance with the EN-789 guidelines (CEN 2004). Parallel tensile strength was 18.406 N/mm$^2$ while perpendicular tensile strength was 27.205 N/mm$^2$.

Numerical models were created on the basis of experimental measurement results and also on reference values (USDA Forest Serv. 1999). Numerical models were analyzed using the finite element method (FEM), i.e., the COSMOS/M software package, module: static–linear elastic theory. The von Mises stress component is calculated form the stress components as shown below (SRAC 2001):

$$\sigma_{vm} = \{(1/2)[(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2] + 3(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)\}^{1/2} \qquad [\mathbf{5}]$$

Where:

$\sigma_{vm}$—von Mises stress component

$\sigma_x$, $\sigma_y$, $\sigma_z$,—normal stress in the -$x$, -$y$, -$z$ direction, respectively

$\tau_{xy}$, $\tau_{xz}$, $\tau_{yz}$,—shear stress in the -$xy$, -$xz$, -$yz$ plane, respectively

A total of eight numerical models were created: four to analyze bending stress and four to analyze tensile stress. Both

*Table 1. — Symbols and structure of veneer plywood (FEM models).*

| FEM model[a] | Structure | Symbols |
|---|---|---|
| BPA | $[0_{1,0}/90_{2,7}/0_{2,7}/90_{2,7}/0_{2,7}/90_{2,7}/0_{1,0}]$ | |
| BPE | $[90_{1,0}/0_{2,7}/90_{2,7}/0_{2,7}/90_{2,7}/0_{2,7}/90_{1,0}]$ | $[\theta_t/\ \theta_t/\ \theta_t/\ \theta_t]$ |
| BPA-o | $[0_{1,0}/90_{2,7}/0_{2,9}/90_{2,3}/0_{2,9}/90_{2,7}/0_{1,0}]$ | |
| BPE-o | $[90_{1,0}/0_{2,7}/90_{2,9}/0_{2,3}\ /90_{2,9}/0_{2,7}/90_{1,0}]$ | θ - grain angle (°) |
| TPA | $[0_{1,0}/90_{2,7}/0_{2,7}/90_{2,7}/0_{2,7}/90_{2,7}/0_{1,0}]$ | t - layer thickness (mm) |
| TPE | $[90_{1,0}/0_{2,7}/90_{2,7}/0_{2,7}/90_{2,7}/0_{2,7}/90_{1,0}]$ | |
| TPA-o | $[0_{1,0}/90_{2,7}/0_{2,9}/90_{2,3}/0_{2,9}/90_{2,7}/0_{1,0}]$ | |
| TPE-o | $[90_{1,0}/0_{2,7}/90_{2,9}/0_{2,3}/90_{2,9}/0_{2,7}/90_{1,0}]$ | |

[a] BPA – bending parallel, BPE – bending perpendicular, BPA-o – bending parallel optimized, BPE-o – bending perpendicular optimized, TPA – tensile parallel, TPE – tensile perpendicular, TPA-o – tensile parallel optimized, TPE-o – tensile perpendicular optimized

bending and tensile stress were analyzed on models with an identical structural design (**Table 1**).

The structural design of models BPA, BPE, TPA, and TPE is identical to the structural design of the control plywood for which the mechanical and physical properties were determined by experimental measurement. Models marked BPA-o, BPE-o, TPA-o, and TPE-o are models in which individual layers were optimized in order to achieve the optimum relationship between bending and tensile stress. **Table 1** shows that all models have cross-oriented layers of 0° and 90°. It is also visible that the optimized models differ from the control models only in the thickness of the three midlayers. This therefore equalized the thickness ratio of the layers of parallel and perpendicular direction. The total number of layers and the nominal thickness of plywood remained unchanged, satisfying two of the three conditions.

## Results and discussion

From the results obtained by the test methods for determining mechanical properties, it is apparent that the structural design of the control plywood (with inner layers of equal thickness and thin outer layers) is inadequate considering the equalized relationship between bending and tensile properties. Such a conclusion may be derived from the fact that in spite of the adjusted bending strength of plywood, parallel ($\sigma_{f||}$ = 50.583 N/mm$^2$) and perpendicular ($\sigma_{f\perp}$ = 48.056 N/mm$^2$) to the face grain direction, extremely large differences were recorded in the values of tensile strength. Moreover, the inadequacy of the relationship of tensile strength is not only presented in the great difference of values, but the tensile strength parallel ($\sigma_{t\,||}$ = 18.406 N/mm$^2$) is even smaller than the tensile strength perpendicular ($\sigma_{t\perp}$ = 27.205 N/mm$^2$) to the face grain direction. This is a direct consequence of an inappropriate structural design of plywood, i.e., the incorrect thickness of individual layers and their positioning relative to the middle surface of the panel.

In order to avoid such great differences in tensile properties without changing bending properties, the plywood construction was optimized. In order to equalize the thickness ratio of the parallel and perpendicular oriented layers, the thickness of only the three inner layers next to the middle surface was altered. Such a procedure to optimize plywood construction is necessary when the relationship referred to in expressions [**2**], [**3**], and [**4**] are considered.

*Table 2. — Stress in the layers of plywood under bending load.*

| Layer | Surface | BPA | BPA-o | BPE | BPE-o |
|---|---|---|---|---|---|
| | | ---------- von Mises (N/mm$^2$) ---------- | | | |
| 7 | Top | 46.1253 | 45.9699 | 3.1803 | 3.1810 |
| 7 | Bottom | 40.1737 | 40.0383 | 2.7703 | 2.7709 |
| 6 | Top | 2.8105 | 2.8082 | 36.9143 | 37.0292 |
| 6 | Bottom | 1.6879 | 1.6866 | 22.1486 | 22.2175 |
| 5 | Top | 24.1042 | 24.0230 | 1.6640 | 1.6643 |
| 5 | Bottom | 8.0348 | 6.9697 | 0.7520 | 0.4915 |
| 4 | Top | 0.5669 | 0.4973 | 7.3829 | 6.4459 |
| 4 | Bottom | 0.5669 | 0.4973 | 7.3829 | 6.4459 |
| 3 | Top | 8.0348 | 6.9697 | 0.7520 | 0.4915 |
| 3 | Bottom | 24.1042 | 24.0230 | 1.6640 | 1.6643 |
| 2 | Top | 1.6879 | 1.6866 | 22.1486 | 22.2175 |
| 2 | Bottom | 2.8105 | 2.8082 | 36.9143 | 37.0292 |
| 1 | Top | 40.1737 | 40.0383 | 2.7703 | 2.7709 |
| 1 | Bottom | 46.1253 | 45.9699 | 3.1803 | 3.1810 |

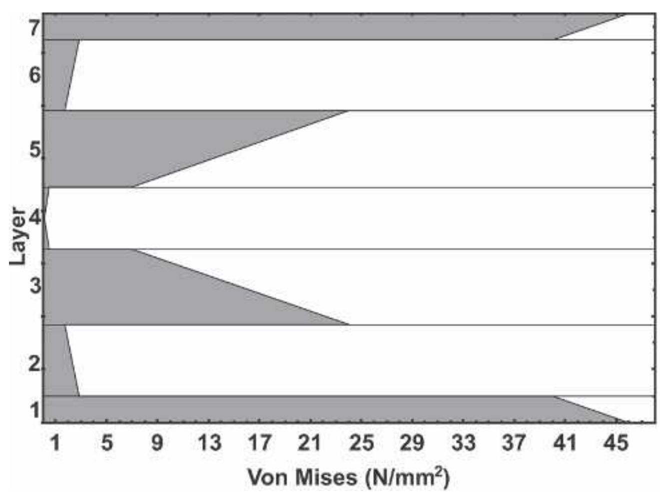


*Figure 4. — Distribution of stress in plywood under bending load.*

In the optimization of bending properties, it is essential to analyze stress in the outer layers, as the maximum stress values are distributed in those layers, making these a critical element of structural design. It is apparent from **Table 2** that the difference in bending stress between control and optimized plywood is negligible both in the parallel direction, (BPA = 46.1253 N/mm$^2$ and BPA-o = 45.9699 N/mm$^2$) and in the perpendicular direction (BPE = 3.1803 N/mm$^2$ and BPE-o = 3.1810 N/mm$^2$). Such results clearly suggest that the optimization of structural design did not affect the bending properties of plywood, thereby satisfying the third condition. These values apply only to the outer layers of plywood, i.e., of the top (seventh) and bottom (first) surface of layers respectively. The differences in stress between other inner layers are somewhat greater, but owing to their lower values they have a substantially smaller effect on the bending properties of plywood.

Other than the distribution of bending stress which extends in degrees across individual layers (**Fig. 4**), the distribution of strain is linear (**Fig. 5**). The values of strain also remain virtually unchanged. A slight decrease in strain is noticed in the

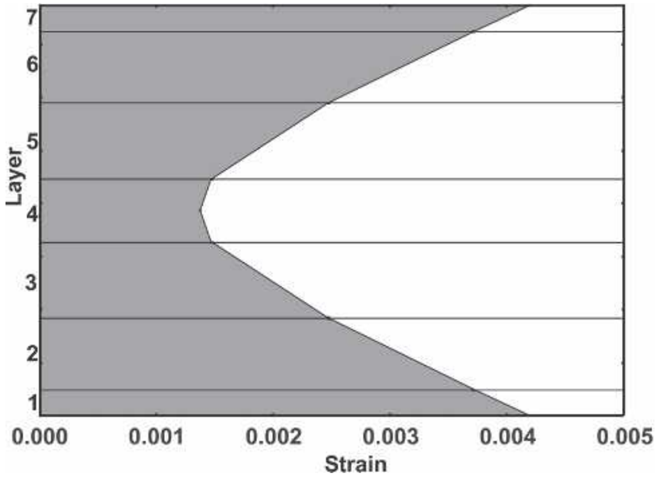


*Figure 5. — Distribution of strain in plywood under bending load.*

*Table 3. — Strain in the layers of plywood under bending load.*

| Layer | Surface | BPA | BPA-o | BPE | BPE-o |
|---|---|---|---|---|---|
| | | ----------------- Equivalent strain ----------------- | | | |
| 7 | Top | 4.217E-03 | 4.193E-03 | 3.897E-03 | 3.919E-03 |
| 7 | Bottom | 3.734E-03 | 3.711E-03 | 3.455E-03 | 3.477E-03 |
| 6 | Top | 3.734E-03 | 3.711E-03 | 3.455E-03 | 3.477E-03 |
| 6 | Bottom | 2.496E-03 | 2.471E-03 | 2.321E-03 | 2.345E-03 |
| 5 | Top | 2.496E-03 | 2.471E-03 | 2.321E-03 | 2.345E-03 |
| 5 | Bottom | 1.540E-03 | 1.468E-03 | 1.454E-03 | 1.451E-03 |
| 4 | Top | 1.540E-03 | 1.468E-03 | 1.454E-03 | 1.451E-03 |
| 4 | Bottom | 1.540E-03 | 1.468E-03 | 1.454E-03 | 1.451E-03 |
| 3 | Top | 1.540E-03 | 1.468E-03 | 1.454E-03 | 1.451E-03 |
| 3 | Bottom | 2.496E-03 | 2.471E-03 | 2.321E-03 | 2.345E-03 |
| 2 | Top | 2.496E-03 | 2.471E-03 | 2.321E-03 | 2.345E-03 |
| 2 | Bottom | 3.734E-03 | 3.711E-03 | 3.455E-03 | 3.477E-03 |
| 1 | Top | 3.734E-03 | 3.711E-03 | 3.455E-03 | 3.477E-03 |
| 1 | Bottom | 4.217E-03 | 4.193E-03 | 3.897E-03 | 3.919E-03 |

optimized plywood in the parallel direction (for the seventh layer and the top surface BPA = 4.217E-03 and BPA-o = 4.193E-03), whereas in the perpendicular direction there was a slight increase in strain (for the seventh layer and the top surface BPE = 3.897E-03 i.e., BPE-o = 3.919E-03), which is a very small difference (**Table 3**). Analyzing the values of stress and strain under bending load, it could be said that the values following plywood construction optimization remained approximately the same. Even a minimum decrease was achieved when the load direction was parallel to the face grain direction.

Unlike the stress under bending load, which remained virtually unchanged, the optimization of tensile stress resulted in significant changes. **Figure 6** shows that the distribution of tensile stress does not depend on the distance of individual layers from the middle surface of the panel but only on the strength of the individual layer, i.e., on the cross-orientation of veneer layers. However, despite the cross-orientation of layers, strain showed constant values throughout the plywood panel cross section (**Fig. 7**).

With an equalisation of the veneer thickness ratio in the parallel and perpendicular directions, there is a decrease (parallel) or increase (perpendicular) in the tensile strength in individual panel layers. Stress was decreased in the optimized plywood (notably in all layers) when the direction of tensile load was parallel to the face grain direction (i.e., for the seventh layer TPA = 53.7417 N/mm$^2$, whereas TPE-o = 51.5323 N/mm$^2$) (**Table 4**). On the other hand, an increase in stress was also noted in optimized plywood (in all layers), but only when the direction of tensile load was perpendicular to the face grain direction (i.e., for the sixth layer TPE = 49.4969 N/mm$^2$, whereas TPE-o = 51.5323 N/mm$^2$).

It is through such an alteration of tensile stress, i.e., stress decrease in the parallel direction and stress increase in the perpendicular direction, that optimized plywood panel is fully equalized with regard to stress distributions along its length and width. Adjusted stresses occurred in all parallel oriented layers (51.5323 N/mm$^2$) and in all perpendicular oriented layers (2.9874 N/mm$^2$), irrespective of load direction. Similar regularity was observed in the mutual relationship between strain values, which decreased in the parallel direction (from

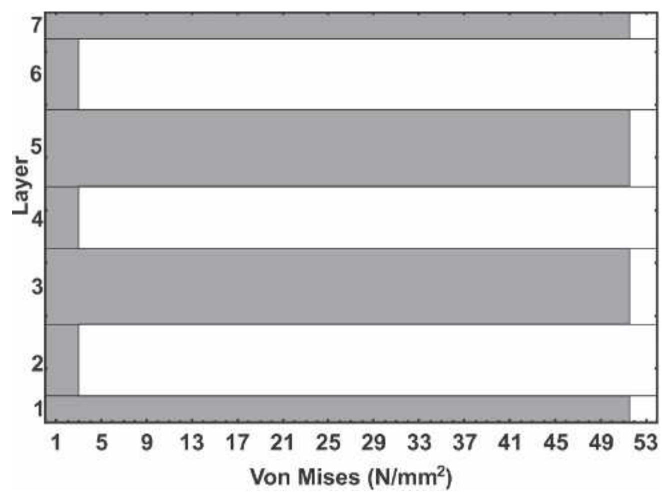


*Figure 6. — Distribution of stress in plywood under tension load.*

4.626E-03 to 4.439E-03) or increased in the perpendicular direction (from 4.267E-03 to 4.439E-03) with respect to plywood panel length (**Table 5**).

The distribution of the said stress and strain clearly indicate that the optimization objectives were achieved, i.e., equalizing tensile stress in the two main panel directions (length and width) without changing the present bending stress, nominal thickness of plywood or the total number of layers.

## Conclusions

Based on the research results obtained using the finite elements method and the results obtained by determining the mechanical properties of seven-layer veneer plywood, the following conclusions may be drawn:

— The analysis of bending stress and strain under bending load has shown that the control and optimized plywood have approximately the same adjusted stress and strain values in the directions parallel and perpendicular to the face grain direction.

— The analysis of stress and strain under tensile load has shown that there were significant differences between values

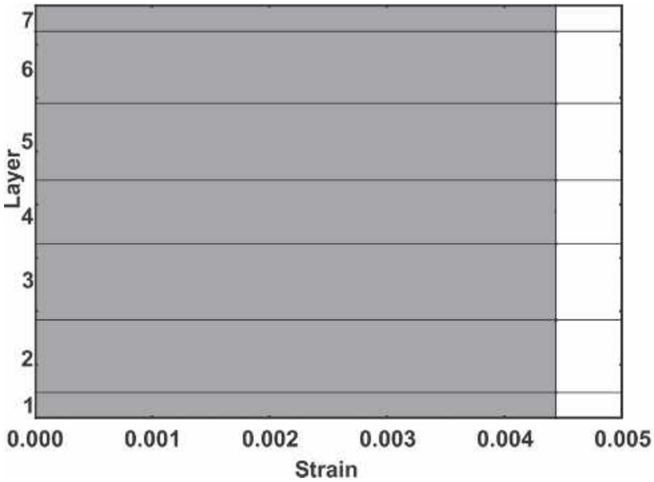


*Figure 7. — Distribution of strain in plywood under tension load.*

*Table 4. — Stress in the layers of plywood under tension load.*

| Layer | Surface | TPA | TPA-o | TPE | TPE-o |
|---|---|---|---|---|---|
| | | von Mises (N/mm$^2$) | | | |
| 7 | Top | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 7 | Bottom | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 6 | Top | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 6 | Bottom | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 5 | Top | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 5 | Bottom | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 4 | Top | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 4 | Bottom | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 3 | Top | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 3 | Bottom | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 2 | Top | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 2 | Bottom | 3.0560 | 2.9838 | 49.4969 | 51.5323 |
| 1 | Top | 53.7417 | 51.5323 | 2.9228 | 2.9874 |
| 1 | Bottom | 53.7417 | 51.5323 | 2.9228 | 2.9874 |

in parallel and perpendicular direction in the control plywood, whereas in the optimized plywood, stress and strain for both directions were equal.

— Due to the specific plywood construction, very small changes in the thickness of layers had a great effect on the change of relevant mechanical properties. Central veneer layers next to the middle surface have less effect on changes in bending stress, though these layers are of great importance in determining tensile stress. Consequently, an appropriate change in the thickness ratio for parallel and perpendicular oriented layers enables the change in tensile stress properties of plywood without affecting the bending properties, nominal thickness or the total number of layers.

*Table 5.— Strain in the layers of plywood under tension load.*

| Layer | Surface | TPA | TPA-o | TPE | TPE-o |
|---|---|---|---|---|---|
| | | Equivalent strain | | | |
| 7 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 7 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 6 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 6 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 5 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 5 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 4 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 4 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 3 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 3 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 2 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 2 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 1 | Top | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |
| 1 | Bottom | 4.626E-03 | 4.439E-03 | 4.267E-03 | 4.439E-03 |

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# Wood density in *Pinus taeda* × *Pinus rigida* and response 10 years after thinning in Virginia

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**Abstract**

The purpose of this study was to examine the differences between wood density of loblolly pine and selected pitch pine X loblolly pine crosses, differences in density of the different pitch pine X loblolly pine crosses, and to examine the effect of thinning on the hybrid crosses. 153 trees were sampled, including 17 loblolly pines and 136 pitch pine X loblolly pine hybrids grown in the Piedmont of Virginia (USA). The hybrid pines sampled included trees from 16 different crosses released at four different levels based on the free to grow (FTG) value: C = FTG <2, L = FTG 2 to 4, M = FTG 4 to 6, H = FTG >6. There was a significant difference between the wood density of the hybrid crosses and the loblolly pine ($p = 0.0428$). It was also found that there were significant differences between the crosses. The densities ranged from 483 kg/m$^3$ to 555 kg/m$^3$, with significant differences between many of the crosses ($p = 0.007$). These differences were associated with significant differences in the percentage of latewood produced ($p = 0.015$). The correlation between latewood percentage and wood density was calculated to be $r = 0.825$. Trees released at a FTG>6 were significantly less dense than the other release rates ($p = 0.007$); the difference was related to the percentage of latewood, which was also significantly different ($p = 0.004$). This study indicates that the wood density of pitch pine X loblolly pine hybrids is high enough with in crosses with low density and a FTG value >6 to produce wood similar to loblolly pine grown in the Piedmont of Virginia.

Hybrids between pitch pine (*Pinus rigida*) and loblolly pine (*Pinus taeda*) were developed to create a softwood timber species that combined the cold hardiness of pitch pine and the fast growth of loblolly pine (Dorman 1976). This effort was successful, and pitch pine X loblolly pine hybrids are planted in areas well north and west of the natural range of loblolly pine, including New Jersey, Pennsylvania, West Virginia, and Ohio (Kuser et al. 1987, Little and Trew 1979, Moss et al. 1989). The most widespread use of pitch pine X loblolly pine hybrids has been in Korea (Dorman 1976). The growth of pitch pine X loblolly pine hybrids is generally much better than the growth of pure pitch pine, and individual seedlots of the hybrid appears to grow as well or better than some of the better families of pure loblolly pine (Bailey and Feret 1982, Feret and Bailey 1981, Johnson et al. 1991). The wood properties of loblolly pine and pitch pine have been found to be similar (Koch 1972). However, density varies widely among different genotypes of loblolly pine and is strongly heritable trait (Talbert and Jett 1981, Zobel and Talbert 1984, Zobel and McElwee 1958). Little is known about the wood properties of individual sources of pitch pine or hybrids between loblolly pine and pitch pine.

Crown touching thinning or release is a method of crop tree management where individual crop trees are managed to maximize their growth rate. Generally, trees that show the greatest potential for moving from one product class to another (from chip-n-saw to sawtimber, for example) and have good form are identified as the trees to be left for final harvest. Trees that are determined to be less desirable that touch the crowns of the desired trees are then removed, maximizing the amount of area available for the crop trees. Depending on the number of trees removed from around each crop tree the tree receives a free to grow (FTG) rating to indicate the number of

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trees removed from the around the crop tree (Perkey et al. 1993).

A previous study examined the effectiveness of crown touch thinning on pitch pine X loblolly pine hybrids (Fox and Kreh 2003). It was determined that the growth rates of the hybrid pines increased significantly after thinning, making the technique a viable silvicultural treatment in the management of hybrid stands for the production of sawlog sized trees in a relatively short rotation. Silvicultural treatments that increase the growth of loblolly pine have had little effect on wood properties, other than increasing the diameter of the juvenile core (Clark et al. 2006a, Clark et al. 2006b, Clark and Edwards 1999, Clark and Saucier 1989).

Little research has focused on the difference between loblolly and pitch pine X loblolly pine hybrid wood density grown in the Piedmont of Virginia and the effect of crown thinning on the wood density of the hybrid pines. Therefore there are three hypotheses: 1) there is a difference in the wood density of loblolly pine and pitch pine X loblolly pine hybrids; 2) there are differences between wood density of the individual hybrid families; 3) the degree of crown touching thinning will have an effect on wood density of the hybrid pines.

## Materials and methods

### Study site

The study was conducted at the Reynolds Homestead Research Center, in the Piedmont, Patrick County, Virginia (Lat. 36°40′ N, Long. 80°10′ W). The elevation of the study site is approximately 354 m, and the topography is gently sloping with a 5 percent southern aspect. The soils are mapped as the Cecil series (fine, kaolinitic, and thermic Typic Kanhapludults), which are deep, well drained soils that formed from granite, gneiss, schist, and quartzite (Fox and Kreh 2003). This area was intensively farmed for row crops and tobacco from the early 19th century until the early to middle 20th century. Erosion during this period removed much of the original top soil.

The study site has a warm, humid continental climate. Precipitation averages approximately 1250 mm/year and is generally well distributed throughout the year, although late spring and late summer tend to have drier periods (Fox and Kreh 2003). The mean annual temperature is 14 °C with an average of −1 °C in January and 29 °C in July. This portion of the Piedmont is just west and north of the natural range of loblolly pine. In spite of this loblolly pine has been widely planted in the immediate vicinity and grows well. Ice storms are common in this region and can seriously damage loblolly pine (Amateis and Burkhart 1996). This area is just inside the natural range of pitch pine; however pitch pine is rarely found in current stands in the region.

### Plant material

The pitch pine X loblolly pine hybrid plantation used for this study was approximately 1.98 ha. The plantation was established with 1–0 containerized seedlings planted in 1981, following clearcutting of a 60-year-old mixed-oak stand. The area was site-prepared by burning the logging slash. This study was originally established as an $F_2$ pitch pine X loblolly pine hybrid progeny trial. The seedlings representing 112 half-sib $F_2$ hybrids were grown from wind-pollinated seed collected from a $F_1$ pitch pine X loblolly pine plantation located nearby. These hybrid families were previously used in several studies (Feret and Bailey 1981, Kuser et al. 1987, Little and Trew 1979). Half-sib loblolly pine seedlings were also planted at the site. Seedlings were planted at 2- by 2-m spacing, with four trees from each half-sib family planted in row plots.

Total height and diameter of all trees were measured in early 1987. Stem volume was calculated using equations developed by Amateis and Burkhart (1987) that were previously used for pitch pine X loblolly pine hybrids (Groninger et al. 2000). Based on the volume calculations from the 1987 measurements, crop trees from 39 of the better growing pitch pine X loblolly pine hybrid families were selected for crown touching release. Trees adjacent to selected crop trees were hand felled with chain saws in late 1987. The degree of release varied among the crop trees and was evaluated based on the free to grow (FTG) rating of each tree. Because the planting was evenly spaced, each tree had 8 adjacent trees; if none of the adjacent trees were removed the FTG value was recoded as 0, if 1 tree was removed the FTG value was 1, and a FTG of 2 was recoded if 2 trees were removed, and so on.

### Sample collection and analysis

153 trees were sampled including 17 loblolly pine and 136 pitch pine X loblolly pine hybrids. Trees of the same family were planted in rows of four, and each family was replicated a minimum four times throughout the stand. The hybrid pines sampled included trees from 16 different crosses released at four different levels based on the FTG value: C = FTG <2, L = FTG 2 to 4, M = FTG 4 to 6, H = FTG >6. Twelve-mm increment cores were removed at breast height from the selected standing trees throughout the study site during the summer of 2006. Cores were placed in plastic bags labeled with the tree identification number. The cores were then frozen to reduce damage and moisture loss. Prior to analysis, the samples were placed into a conditioning chamber with a temperature of 20 °C and relative humidity of 65 percent, resulting in equilibrium moisture content (EMC) of 12 percent.

The cores were then mounted in wood holders attached with common wood glue. The holders were then sawn with a dual blade saw to create 1.5 mm thick strips from the cores, with the height of the sample being 12 mm, exposing the cross sectional surface of the sample. The samples were then returned to the conditioning chamber to allow the MC to become consistent once again.

The unextracted samples were scanned by x-ray densitometry using Quintek Measurement Systems, Inc. (Knoxville, Tennessee), QMS Tree Ring Analyzer. All density measurements were on a dry weight per green volume basis. The data were then averaged into individual growth rings. The percentage latewood, latewood density, ring density and core density average were all calculated.

### Data analysis

Data were analyzed using SAS® 9.1.3 (SAS Institute, Cary, North Carolina), using the general linear model procedure. Mean separations were examined using Fisher's least significant difference method. The data were analyzed for mean differences between loblolly pine and the pitch pine X loblolly pine for all years, and the last 10 years of growth. For the hybrid familys both for the complete core and for the last 10 years, and finally for the effect of the crown touching thinning that was performed on the hybrid pines. All values provided are significant at the 0.05 alpha level.

*Table 1. — Mean whole core wood density, wood density in the last 10 years, and latewood percent in the last 10 years for specific crosses of pitch pine X loblolly pine at age 25 growing in the Virginia Piedmont.*

| Cross | N | Mean wood density | Mean wood density last 10 years | Percentage latewood last 10 years |
|---|---|---|---|---|
| | | ----------($kg/m^3$)---------- | | |
| 66OP | 4 | 555 | 601 | 69 |
| 57X15 A | 4 | 549 | 590 | 55 |
| 62X19 | 11 | 541 | 597 | 57 |
| 62X26 | 10 | 534 | 568 | 53 |
| 62X22 | 7 | 531 | 560 | 51 |
| 78X22 | 11 | 527 | 575 | 56 |
| 51X15 A | 7 | 526 | 558 | 52 |
| 78X11 to 1 | 11 | 520 | 561 | 53 |
| 77X11 to 1 | 7 | 508 | 550 | 52 |
| 52X15 A | 7 | 504 | 532 | 49 |
| 62X11 to 1 | 6 | 504 | 544 | 49 |
| 62X15 A | 7 | 504 | 534 | 46 |
| 59X7 to 56 | 8 | 499 | 533 | 47 |
| 55XWind | 4 | 494 | 530 | 48 |
| 81X7 to 56 | 11 | 485 | 517 | 44 |
| 51X23 | 10 | 483 | 506 | 43 |
| Fisher | $LSD_{0.05}$ | 44 | 54 | 10 |

## Results and discussion

### Species differences

The mean density of the pitch pine X loblolly pine hybrids (516 $kg/m^3$) was significantly higher than the density of the loblolly pine (495 $kg/m^3$) at this site ($p = 0.0458$). The mean density for loblolly falls within the range of published values for the species (Panshin and De Zeeuw 1980).

Similarly, the last 10 years of growth for the two species showed significant difference, where the hybrid pine had a mean density of 553 $kg/m^3$, while the loblolly had a density of 526 $kg/m^3$ ($p = 0.0428$). There was not a significant difference between the latewood percentages for the wood produced by either species for either time period. The higher density of the hybrids compared to the pure loblolly pine may be due to the location of the study site. Density of loblolly pine in northern portions of the range tends to be lower than those found in the southern portion of the range (Koch 1972). This study is located in the upper Piedmont of Virginia, where density of loblolly pine tends to be lower than the species average across the South (Clark et al. 2006b, Koch 1972). The higher percentage of extractives likely occurring in the hybrid from the pitch pine component may also contribute to the greater density observed (Koch 1972).

### Differences among crosses

In this study there where 16 pitch pine X loblolly pine crosses with at least 3 trees sampled in each cross. These crosses were examined to determine if there was a significant difference in wood density. There was a significant difference in the wood density (core average, unextracted) of the 16 hybrid crosses ($p = 0.0071$, ANOVA). Wood densities of individual crosses ranged from 483 $kg/m^3$ to 555 $kg/m^3$ (**Table 1**). The percentage of latewood ranged from 43 percent to 69 percent (**Table 1**). The cross with the highest density (66OP) had the highest percentage latewood, and the cross with the lowest density (51X23) had the lowest percentage of latewood. There was a strong correlation between latewood percentage and wood density ($r = 0.825$).

The density of the wood produced in the last 10 years was greater than the wood density of the whole core in all crosses. Cross 66OP had the highest density (601 $kg/m^3$) and cross 51X23 had the lowest density (506 $kg/m^3$). The range in wood density in the last 10 years was greater than that of the whole core.

### Thinning differences

Wood densities ranged from 525 $kg/m^3$ to 470 $kg/m^3$ among the 4 levels of thinning intensity (**Table 2**). Several trees had to be removed from the analysis because of mortality of surrounding trees leading to a change of FTG rating. Wood density of the trees released on all sides, and thus presumably growing the fastest, had significantly lower wood densities than those receiving a lesser degree of thinning (**Table 2**). The percentage of latewood and latewood density were also significantly lower in the trees released on all sides.

These results are similar to results from other studies that have generally shown little impact of silvicultural treatment on wood density of loblolly pine (Clark and Edwards 1999, Clark and Saucier 1989). However, the current study and others have shown that wood properties can be negatively affected in the fastest growing trees in the southern pines. Clark et al. (2006b) found that both cross section weighted specific gravity (SG) and latewood percentage were lower following complete weed control treatments that increase tree growth dramatically and for extended periods of time. Repeated fertilization that maintains rapid growth rates in loblolly pine also causes a significant decrease in SG of loblolly pine, whereas there is little impact following a single fertilizer application that increases growth for a limited time (Clark et al. 2004). In the present study only when the trees were completely released on all sides and growth rates were fastest was there a decrease in wood density and latewood percentage. This level of release is not widely utilized in pine plantations in the United States. These results suggests that silvicultural treatments normally used in pine plantations will likely not have a large impact on wood properties

## Summary and conclusion

Hybrid pines were originally bred to have the rapid growth rate of loblolly pine, and the cold hardiness of pitch pine. This study indicates that the density of the hybrid pines is greater than that of regular loblolly pine. The greater density means that there would likely be an adequate stiffness to produce structural components from the wood produced by the hybrid trees (Panshin and De Zeeuw 1980). Differences in individual hybrid families, while significant, do not vary as greatly as indicated by published densities for loblolly pine (Belonger et al. 1997).

Thinning responses for the pitch pine X loblolly pine where varied with the trees falling into the low thinning group having the highest density, but not significantly different from the medium and control thinning rates. The high thinning release resulted in a significantly lower density likely caused by both the increased production of earlywood, and the reduced density of the latewood being produced, resulting in lower average ring densities.

*Table 2. — Impact of thinning intensity as measured by FTG rating on wood density and percent latewood in pitch pine X loblolly pine hybrids at age 25 when grown in the Virginia Piedmont.*

| Thinning intensity | FTG | Wood density | Latewood percentage | Latewood density | Sample size |
|---|---|---|---|---|---|
| | | (kg/m$^3$) | | (kg/m$^3$) | |
| L | 2 to 4 | 525 A[a] | 46 A[a] | 790 A[a] | 68 |
| M | 4 to 6 | 521 A | 45 A | 800 A | 24 |
| C | <2 | 505 A | 42 A | 794 A | 14 |
| H | >6 | 470 B | 35 B | 747 B | 10 |

[a]Values within a column with the same letter are not significantly different at $\alpha = 0.05$.

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# Antioxidative activity of water extracts from leaf, male flower, raw cortex and fruit of *Eucommia ulmoides* Oliv.

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Run-Cang Sun

**Abstract**

The antioxidative activity of water extracts from leaf, male flower, raw cortex and fruit of *Eucommia ulmoides* Oliv. was characterized by free-radical scavenging, reducing power, $Fe^{2+}$ chelating ability, and antioxidant activity in linoleic acid emulsion assays. The water extract of leaves showed a marked antioxidant activity. The free-radical scavenging, reducing power, antioxidant activity in linoleic acid emulsion of the extract from the male flower were found to be less than leaf extract but stronger than that of raw cortex and fruit. The results showed that extract from the male flower and the leaf of *Eucommia ulmoides* Oliv. could possibly be promoted as a natural antioxidant.

Over the past 20 years the importance of active oxygen and free radicals as exacerbating factors in human cellular injury and the aging process has attracted increasing attention (Ames et al. 1993, Halliwell 1996). In addition, these factors are considered to induce lipid peroxidation causing the deterioration of foods (Duthie 1993). Free radicals can easily damage the structural and functional components of the cells such as lipids, proteins, carbohydrates, DNA, and RNA. They are generally by-products of various endogenous processes that can be stimulated by external factors such as air pollution, irradiation, smoking, stress, and toxins present in food and/or drinking water. The data have shown that oxidative stress arises from an imbalance of oxidant/antioxidant ratio in the human body and contributes to the etiology of many chronic diseases of high prevalence (Arts et al. 2001, Simonetti et al. 1997), such as brain dysfunction (Aruoma 1994), cancer, and cardiovascular diseases (Hertog et al. 1995, Lampe 1999). Antioxidants can interfere with the oxidation process by scavenging free radicals, chelating catalytic metals and by acting as oxygen scavengers (Frankel and Meyer 2000, Shahidi and Wanasundara 1992). In addition, antioxidants effectively retard the onset of lipid oxidation in food products (Harris et al. 1992, Wagner et al. 1993). Commercial antioxidant supplements or natural antioxidants have been used in order to reduce oxidative damage in the human body (Cutler 1991). However, the possible toxicity of synthetic chemicals used as antioxidants has long been questioned (Imaida et al. 1983, Namiki 1990). In recent years, there has been a global trend toward the use of natural phytochemicals present in natural resources, such as fruits, vegetables, oilseeds, and herbs, as antioxidants and functional foods (Farr 1997, Kitts et al. 2000, Wang et al. 1997). Natural antioxidants can be used in the food industry, and there is evidence that these substances may exert their antioxidant effects within the human body (Rice-Evans et al. 1995, Van Poppel and Van den Berg 1997).

*E. ulmoides* (*Eucommia ulmoides* Oliv.) tea (the aqueous extract of leaves) is commonly used in China and Japan for treatment of hypertension and is thought to be a functional health food (Nakazawa 1997). *E. ulmoides* tea may reduce

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cholesterol and a condition know as " fatty liver" (Nakasa et al. 1995) and also has been reported to reduce blood pressure (Nakazawa 1997). *E. ulmoides* (leaf) tea had a suppressing effect on mutagenicity and chromosome aberration following mutagen treatment (Nakamura et al. 1997, Sasaki et al. 1996). *E. ulmoides* leaf extracts exhibited inhibitory effects on oxidative damage in biomolecules such as deoxyribose and DNA as induced by Fenton reaction (Hsieh and Yen 2000) and it possesses inhibitory effects on the oxidative modification of LDL induced by $Cu^{2+}$ (Yen and Hsieh 2002).

The water extract from *E. ulmoides* may scavenge free radical and reactive oxygen species (ROS). The scavenging activity of the extract on ROS was correlated to its protocatechuic acid content (Yen and Hsieh 2000). In addition, the extract also possesses antioxidant activity toward various lipid peroxidation models and the inhibitory activity follows the order of leaves > roasted cortex > raw cortex (Yen and Hsieh 1998). In China, the fruit, male flower, leaf and cortex of *E. ulmoides* all have been used toward functional health food or Chinese traditional medicine. Thus, the objectives of this work were to investigate the antioxidant activity, including: 1) radical-scavenging effect, 2) reducing power, 3) $Fe^{2+}$ chelating ability, and 4) antioxidant activity in linoleic acid emulsion of the fruit, male flower, leaf and cortex of *E. ulmoides*. The results obtained would be compared with butylated hydroxytoluene (BHT) and ascorbic acid. The total content of polyphenolic compounds was also determined.

## Materials and methods

### Materials

*E. ulmoides* (*Eucommia ulmoides* Oliv.), including leaves, raw cortex, fruit and male flowers, was collected in 2005 from garden of the Northwest Agricultural and Forestry University, Yangling, China. 1,1-Diphenyl-2-picrylhydrazyl (DPPH) and Folin-Ciocalteu's phenol reagent were purchased from Sigma Chemical Co. (St. Louis, Missouri). [4,4-[3-(2-pyridinyl-1,2,4-triazine-5,6-diyl) bisbenzenesulfonic acid] (ferrozine) and linoleic acid were purchased from Fluka Chemie (Buchs, Switzerland). All other chemicals were of analytical grade.

### Preparation of water extracts of *E. ulmoides*

Each sample of the air-dried and ground leaf, raw cortex, fruit and male flower of *E. ulmoides* (20 g, 20 mesh) was extracted with distilled water (200 mL) at 60 °C for 60 minutes twice, respectively. The two extracts were combined, filtered and evaporated to dryness in a vacuum at 50 °C to give brown and yellow residues. The yields of extracts from leaves, raw cortex, male flower and fruit of *E. ulmoides* were 5.26, 2.63, 6.84, and 2.03 percent (percent of the dry starting material), respectively.

### Radical-scavenging activity

The effect of *E. ulmoides* on the DPPH radical was estimated according to the method of Norie et al. (2003) with some modification. A solution of samples in ethanol (2 mL) was added to 1 mL of 500 μM DPPH solution. After the mixture had been shaken, the reaction solution was allowed to stand for 20 minutes at room temperature in the dark. The absorbance of the mixture was measured at 517 nm. Solvent (1 mL) containing 500 μM DPPH mixed with 2 mL alcohol was used as the control. The radical-scavenging activity of the samples was calculated according to the following formula:

DPPH radical scavenging activity (%) = 100
– (absorbance of sample/absorbance of control) × 100.

### $Fe^{2+}$ chelating ability

The $Fe^{2+}$ chelating ability was determined according to the method of Decker and Welch (1990) and Hsieh and Yen (2000) with some modification. A sample (1 mg/mL distilled water, 5 mL) was incubated with a solution of 0.1 mL of 2 mM $FeCl_2$ at room temperature for 10 minutes. The reaction was started by the addition of 0.2 mL of 5 mM ferrozine solution and the reaction mixture was shaken and left to stand for 10 minutes at room temperature. After incubation, the absorbance of the solution was measured at 562 nm, and 5 mL distilled water mixing with a solution of 0.1 mL of 2 mM $FeCl_2$ and 0.2 mL of 5 mM ferrozine solution was used as a control. The lower absorbance of the reaction mixture indicated a higher $Fe^{2+}$-chelating ability. The capability to chelate the ferrous iron was calculated using the following equation:

Chelating effect (%) = 100
– (absorbance of sample/absorbance of control) × 100.

### Reducing power

The determination of the reducing power was conducted according to the method developed by Oyaizu (1986) for the reducing power test. The solution of *E. ulmoides* extract 2.5 mL) was spiked with 2.5 mL of phosphate buffer (0.2 M, pH 6.6) and 2.5 mL of 1 percent potassium ferricyanide. The mixture was then placed in a 50 °C water bath for 20 minutes After cooling rapidly, 2.5 mL of 10 percent trichloroacetic acid was added and centrifuged at 3,000 rpm for 10 minutes The supernatant (2.5 mL) was then mixed with 2.5 mL of distilled water and 0.5 mL of 0.1 percent ferric chloride. The absorbance at 700 nm was recorded for the reaction for 10 minutes. Increased absorbance of the reaction mixture indicated an increase of the reducing power.

### Antioxidant activity in linoleic acid emulsion

An antioxidant activity of *E. ulmoides* was determined according to the thiocyanate method (Mitsuda et al.1996). Each sample (0.5 mg) in 0.5 mL of distilled water was mixed with linoleic acid emulsion (2.5 mL, 0.02 M, pH 7.0). The linoleic acid emulsion was prepared by mixing 0.2840 g of linoleic acid, 0.2804 g of Tween 20 as emulsifier, and 50 mL of phosphate buffer; and then the mixture was homogenized. The reaction mixture was incubated at 37 °C. Aliquots of 0.1 mL were taken at different intervals during incubation. The degree of oxidation was measured according to the thiocyanate method by sequentially adding ethanol (4.7 mL, 75%), and ammonium thiocyanate (0.1ml, 30%), sample solution (0.1ml), and ferrous chloride (0.1 mL, 0.02 M in 3.5 percent HCl). After the mixture stood for 3 minutes, the peroxide value was determined by reading the absorbance at 500 nm. A control was performed with linoleic acid but without samples. The inhibition effect was calculated according to the following formula:

Inhibition effect (%) = 100
– (absorbance of sample/absorbance of control) × 100.

### Total polyphenolics

Total polyphenolics were estimated according to a protocol similar to that of Slinkard and Singleton (1977). 1 mL sample solution was mixed with 5 mL of distilled water and 0.5 mL of 1 N Folin-Ciocalteu's phenol reagent. The mixture was

*Table 1. — The phenolics and antioxidative effect of different parts of* E. ulmoides.[a]

| Part | Yield (%) | Total polyphenol (mg/g) | $IC_{50}$ (mg/mL) DPPH | Chelating effect (%) | Inhibition effect (%) |
|---|---|---|---|---|---|
| Cortex | 13.2 | 62.39 ± 4.48 b | 0.955 ± 0.037 e | 21.81 ± 1.74 a | 28.69 ± 1.85 b |
| Leaf | 26.3 | 112.79 ± 7.18 a | 0.274 ± 0.010 c | 69.73 ± 2.12 c | 58.58 ± 2.46 b |
| Male flower | 34.2 | 58.96 ± 1.63 b | 0.596 ± 0.003 d | Negligible d | 39.82 ± 4.89 c |
| Fruit | 10.2 | 34.63 ± 0.98 c | >1 f | 49.84 ± 3.32 b | 2.60 ± 1.88 a |
| BHT | -- | -- | 0.090 ± 0.001 b | Negligible d | 92.83 ± 5.62 e |
| Ascorbic acid | -- | -- | 0.015 ± 0.000 a | 67.70 ± 2.43 c | 30.48 ± 2.98 b |

[a]The values are the mean ± SD ($n$ = 3). Significant differences at $p < 0.05$ are indicated with different letters within a column. The concentration of samples was 1 mg/mL in the measurement of chelating effect and inhibition effect on peroxidation of linoleic acid. The inhibition effect (%) was measured after incubation for 70 hours.

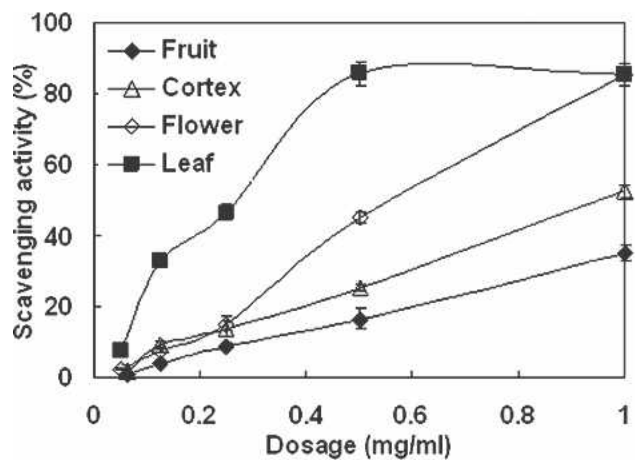


*Figure 1. — DPPH scavenging activity of the extracts from different parts of* E. ulmoides *(The values are the mean ± SD,* n *= 3. Dosage represents the concentration of extracts).*

allowed to react for 5 minutes and 1 mL of 5 percent $Na_2CO_3$ was added. Thereafter, it was thoroughly mixed and placed in the dark for 1 hour and the absorbance was measured at 725 nm with the spectrophotometer. A gallic acid standard curve was obtained for the calculation of polyphenolic content. The amount of phenolics was expressed as gallic acid equivalent (GAE) in milligrams per gram dry plant extract.

### Statistical analysis

All results were obtained from three independent experiments and expressed as mean ± SD. After significant ANOVA, differences between treatment ($p < 0.05$) were determined by Duncan's multiple range test.

## Results and discussion

### Free-radical scavenging activity

In cells, free radicals are continuously produced either as by-products of metabolism or deliberately as in phagocytes (Cheeseman and Slater 1993). The model of scavenging DPPH radical is especially useful in evaluating chain-breaking activity in the propagation phase of lipid (and protein) oxidation (Manzocco et al. 1998). The effect of antioxidants on DPPH radical scavenging was thought to be a result of their hydrogen donating ability (Gulcin et al. 2004). **Figure 1** shows the dose-response curves for DPPH radical scavenging activity of the aqueous extracts of *E. ulmoides* leaf, cortex, male flower and fruit, and the $IC_{50}$ is presented in **Table 1**. The DPPH scavenging activity of the aqueous extracts of *E. ulmoides* increased with increasing amount of the extract. Extract from the leaf showed a significant ($p < 0.05$) stronger DPPH scavenging activity ((that is a lower $IC_{50}$ at 0.274 ± 0.010 mg/mL) than other extracts, and its polyphenolic content (112.79 ± 7.18 mg/g) was also significant higher than other extracts. Although the polyphenolic content of the extract of male flower was not significantly different from that of cortex, its DPPH scavenging effect ($IC_{50}$ = 0.596 ± 0.003 mg/mL) was significantly stronger than that of cortex ($IC_{50}$ = 0.955 ± 0.037 mg/mL). The order of DPPH scavenging activity was ascorbic acid > BHT > leaf > male flower > cortex > fruit.

### Metal chelating effect

Metal chelating capacity is claimed as one of the antioxidant activity mechanisms (Diplock (1996, Yildirim et al. 2001), since it reduces the concentration of the catalyzing transition metal in lipid peroxidation (Hsu et al. 2003). It has been reported that chelating agents, which complex with metal by σ-bonds, are effective as secondary antioxidants because they reduce the redox potential, thereby stabilizing the oxidized form of the metal ion (Gordon 1990). Ferrozine can quantitatively form complexes with $Fe^{2+}$. In the presence of extract of *E. ulmoides*, the complex formation is disrupted with the result that the red color of the complex is decreased. As shown in **Table 1**, leaf extract and ascorbic acid exhibit significantly higher metal chelating effect than other extracts and BHT. In the concentration of 1 mg/mL, their metal chelating effects were 69.73 ± 2.12 percent and 67.70 ± 2.43 percent respectively. The extracts from fruit and cortex also demonstrated a certain ability to chelate metal ion. However, BHT and extract from male flower shows very poor (negligible) ferrous chelating ability. The decreasing order of the metal chelating effect was leaf > ascorbic acid > fruit > cortex > male flower and BHT.

### Reducing power

The reducing capacity of a compound may serve as an indicator of its potential antioxidant activity (Meir et al. 1995). In the reducing power assay, the antioxidant activity of samples was measured by their ability to reduce the $Fe^{3+}$/ferricyanide complex by forming ferrous products. **Figure 2** shows the reductive power of *E. ulmoides* compared with BHT and ascorbic acid. Similar to the antioxidant activity, the reducing power of *E. ulmoides* increases with increasing dosage. All the extracts of the *E. ulmoides* showed a certain extent of reducing power. However, the reducing powers of BHT and ascorbic acid were found to be significantly more pronounced than that of *E. ulmoides*. Among the plant parts tested, the leaf extract and male flower extract exhibited greater reducing power than that of cortex and fruit, which is partly related to their different polyphenolic contents. The order of reducing power in *E. ulmoides* extracts at the amount of 2 mg/mL, compared with positive controls, was BHT > ascorbic acid > leaf > male flower > cortex > fruit. This order was similar to that of free radical scavenging effect but different from the metal chelating effect.

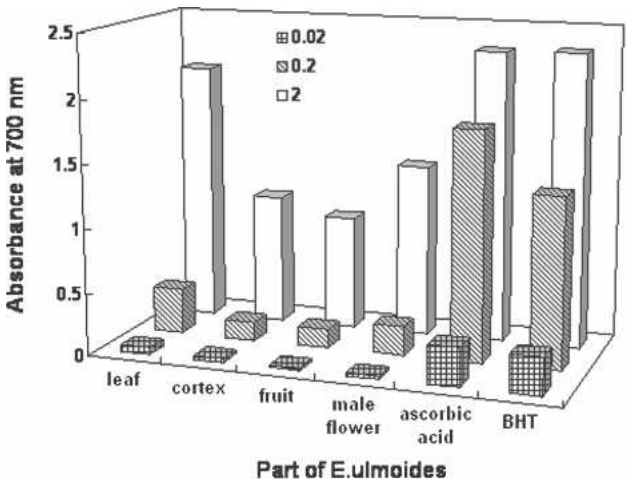


*Figure 2. — Reducing power of the extracts from different part of* E. ulmoides. *Increased absorbance of the reaction mixture indicated an increase of the reducing power. The numbers (0.02, 0.2 and 2) are the values of the concentration (mg/ml) of extracts or chemicals.*

## Antioxidant activity in linoleic acid emulsion

For evaluation of the antioxidant activity of *E. ulmoides*, the inhibition effect on the peroxidation of linoleic acid was investigated. As shown in **Table 1**, leaf extract could inhibit 59 percent peroxidation of linoleic acid; however, male flower extract, cortex extract and ascorbic acid only could suppress 40 percent, 29 percent and 30 percent of linoleic acid lipid peroxidation, respectively. Moreover, fruit extract showed very poor capacity to inhibit peroxidation of linoleic acid. The antioxidant activity of BHT was significantly higher than that any of all the plant extracts. The decreasing order of antioxidant activity in linoleic acid emulsion was BHT > leaf > male flower > ascorbic acid > cortex > fruit. This order was also close to that of free radical scavenging effect and reducing power, but different from that of metal chelating effect.

## Total polyphenolic compounds

Polyphenolic compounds and flavonoids are the most active antioxidants derived from plants (Aruoma 1997). The antioxidant activity of water extract from *E. ulmoides* leaves and cortex was correlated to their polyphenol content (gallic acid equivalent, GAE) (Yen and Hsieh 1998), especially to their protocatechuic acid content (Yen and Hsieh 2000). To explain whether the polyphenolic compounds were the main antioxidant compounds in extracts of male flower and fruit, the total polyphenolics compounds content (gallic acid equivalent, GAE) of all the four extracts was determined by using the Folin-Ciocalteu method. As shown in **Table 1**, leaf extract contained much more polyphenolic compounds than other extracts, and extracts of male flower and cortex contained a similar amount of polyphenolics. The antioxidant activity of the fruit extract was significantly lower than the other three extracts except for the metal chelating effect. Moreover, its polyphenolic compounds content was also significant less than other extracts. Although the polyphenolics content of the extract of male flower and cortex was similar, the antioxidant activity of male flower extract was significantly higher than that of cortex extract except for the metal ion chelating effect. From this it could be assumed that not only the content but also properties of polyphenolic compounds contribute to different activities in different extracts.

## Conclusions

The above results indicate that the water extract from the leaf of *E. ulmoides* shows a stronger antioxidant activity than those from the other plant parts. It seems the reason for this difference just is that the polyphenolic content in the water extract from the leaf is much higher than in those from other parts. On the other hand, although there was no significant difference in the content of polyphenolics, the water extract from the male flower also showed significantly higher reducing power, DPPH scavenging effect and lipid peroxidation of inhibition than those from the cortex. This phenomenon suggests that the properties of polyphenolic compounds in the male flower and cortex were different in their chemical composition and structure. It also could be assumed from the results that not only the content but also properties of polyphenolic compounds contribute to different activities in different extracts. A further study, therefore, is necessary to discover the bioactive compounds in the male flower of *E. ulmoides,* which is currently under investigation in our laboratory.

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# Evaluating selected demographic factors related to consumer preferences for furniture from commercial and from underutilized species

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Matthew Bumgardner*

**Abstract**

This technical note describes consumer preferences within selected demographic categories in two major Pacific Northwest markets for six domestic wood species. These woods were considered for construction of four furniture pieces. Chi-square tests were performed to determine species preferences based on gender, age, and income. Age and income were statistically significant (with a stronger effect for age); gender was not significant. Older respondents preferred oak while younger respondents preferred spruce. Cherry was preferred by respondents in higher income categories and oak by respondents in lower income categories. Maple was preferred by younger male respondents, while birch was preferred by lower income males. Lastly, red alder was found to have lower preference among females in higher income categories. Such information is useful for considering the role that species choice can play in the development of customized products by the domestic furniture industry.

Manufacture of custom products is often cited as a strategy for domestic firms to compete against the commodity-like offerings produced in foreign locations (Schuler and Buehlmann 2003). Offering a specific piece of furniture produced from several different species is a possible element of customization. For wood products manufacturers to accurately identify target markets, information is needed regarding the demographic segments that favor specific products. In market segmentation, an overall group of consumers is divided into similar groups having homogenous needs (Sinclair 1992). These groups can vary with respect to purchasing power, wants, geographic locations, buying attitudes, and buying practices (Kotler 1991).

Two ways to achieve market segmentation include divisions based on consumer demographics and on geography (Smith and Olah 2000). We followed this approach in our current study, where markets for furniture of various species used in household furniture were segmented based on the demographic factors of age, gender, and income. These factors have been found to be related to preferences for a variety of wood products (Nicholls and Stiefel 2007), and perceptions associated with certain wood species have been influenced by gender (Blomgren 1965, Bumgardner and Bowe 2002).

Both eastern and western U.S. hardwoods are commercially important in furniture production. Among eastern hardwoods, furniture and cabinet markets are now favoring fine-grained species such as black cherry (*Prunus serotina* Ehrh.) and maple (*Acer* spp.), while using less lumber from coarse-grained species like oak (*Quercus*, spp.). This in part has been reflected by generally declining oak lumber prices as well as a weaker presence (i.e., percentage of groups shown) at national furniture markets (Luppold and Bumgardner 2005). Although red and white oak are still used in many secondary wood prod-

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ucts, there is potential for using other species in office furniture (Smith et al. 2005).

Among western hardwoods, red alder (*Alnus rubra* Bong.) has become a major species used to produce a variety of furniture products. In Washington state, the average volume of red alder harvested annually was 212 MMBF between 1992 and 2002 (Larsen and Nguyen 2004). Lower grades of red alder, including "knotty" red alder, have become increasingly popular and represent a means of capturing premium prices for less valuable material. Paper birch (*Betula papyrifera* Marsh.) in Alaska has been used to a limited extent within niche markets such as flooring, cabinetry, and craft products. In a competitive industry, western and eastern species are able to serve niches within broader markets, and it is therefore important to accurately characterize consumer preferences for these species.

Specific information about preferences of demographic groups for given products should help wood products manufacturers better utilize the species available to them, particularly as part of a customization strategy. The focus of this study is to evaluate how age, gender, and income influence consumer preferences for species use in household furniture products. Gender was of specific interest, given the influence of this factor to species perceptions as noted in previous studies. This work is based on a broader study which also considered the effects of pricing and species information on consumer preferences for wood use in furniture (Bumgardner et al. 2007). For this technical note we identify possible demographic segments to target for marketing various wood species. Our research questions included:

How do species preferences vary among specific demographic groups based on gender, age, and income?

For a given age category, how do male and female respondents differ?

For a given income category, how do male and female respondents differ?

## Methods

### Data collection

Data were collected at two Pacific Northwest home shows (Seattle, Washington, and Portland, Oregon) in late 2004 and early 2005. A total of 1,125 respondents participated. No screening of respondents was done other than a minimum age of 18 years. An incentive was offered to participants who provided responses.

Respondents visiting the booth indicated which of six species samples they preferred for each of four furniture pieces. The six species included cherry, maple, oak, spruce (*Picea glauca* (Moench) Voss), birch, and alder. An artist's rendition of the furniture pieces included only line drawings, so that responses would not be biased by attributes such as color, texture, or grain patterns. Scale was indicated by including common household items as part of the drawings. The question used for evaluation was, "If you were to purchase this [*furniture piece name*] for your home, which wood sample would you prefer?" Defect-free wood samples having a clear coat finish were used (in combination with the pictures) as proxies for actual furniture pieces (samples were 8 inches long by 5 inches wide). The clearwood samples used were chosen to be representative of each species, and represented a wide range of color, from birch and maple (light) to cherry (darker).

Collected demographic information included respondent age, gender, household income, and home ownership. The home ownership rate in the sample was nearly 90 percent. A limitation of this study was that the data collection was nonrandom and regional, taking place at Pacific Northwest locations only. Past research has shown that respondents at events such as these tend to be older and wealthier than the population at large (Nicholls et al. 2004).

### Furniture piece and species selection

Four furniture pieces were evaluated in this study: an entertainment center, a dresser, a hutch, and a desk. These pieces were chosen to represent a broad cross section of furniture styles and sizes, and are among the most commonly purchased products according to a national survey of household furniture manufacturers (Meyer et al. 1992). When choosing favorite species for a given furniture piece, respondents viewed 6 clearwood samples mentioned previously (each of a different species). The species evaluated in this study represent both commercially important species and underutilized species from eastern and western U.S. regions. This group of species allowed for regional comparisons, while also including several species generally considered underutilized, that could have considerable market potential (Donovan et al. 2003).

### Data analysis

All statistical analyses were based on chi-square tests of two-way tables. We used tests for independence to determine if gender, age, or income affected overall species preferences. Similar tests were done to determine if there were differences in preferences between male and female respondents based on age and income. While in the previous study the furniture pieces were analyzed separately, the data were pooled for the present analysis. Here, all furniture pieces were considered together, so each respondent posted four species preference responses. The data also were pooled across four separate treatments, with the sample split nearly equally between respondents presented with low or high priced furniture pieces, with species information present or absent. Each treatment group had a similar demographic composition.

Segmentation factors included three age categories: 18 to 40 years (29% of the sample), 41 to 50 years (31% of the sample), and 51 years or older (39% of the sample). We also considered three levels of annual household income: $50K or less (25% of the sample), $51K to $100K (50% of the sample), and greater than $100K (25% of the sample). Gender was also considered, and respondents were 55 percent females and 45 percent males. As part of the analyses, chi-square statistics, Cramer V statistics, and cell chi-square values were calculated.

## Results and discussion

**Table 1** presents overall results for species preferences by gender, age, and income for this sample of attendees at Pacific Northwest home shows. There was a significant age effect, with a moderate strength of association (as measured by Cramer's V statistic). Spruce was preferred by younger consumers, and oak was preferred by older consumers. The income effect also was significant, but the strength of association was weaker. Cherry was preferred by higher income consumers and oak by lower income consumers. These results indicate that the age effect is stronger than the income effect for species preference, and that oak's niche is with older, lower income consumers. Cherry's position as a status wood also was

*Table 1. — Overall results for species preferences in household furniture construction by gender, age, and income.*

| Category | $\chi^2_{(df)}$ | Sig. | N[a] | Cramer V | Level | Cell results[b] | Cell values |
|---|---|---|---|---|---|---|---|
| gender | $6.58_{(5)}$ | 0.25 | 4300 | -- | -- | -- | -- |
| age | $139.53_{(10)}$ | <0.01 | 4396 | 0.13 | 18 to 40 years | oak (−) | 49.5 |
| | | | | | | spruce (+) | 25.0 |
| | | | | | 41 to 50 years | -- | -- |
| | | | | | 51 + years | oak (+) | 25.4 |
| | | | | | | spruce (−) | 18.0 |
| income | $36.27_{(10)}$ | <0.01 | 3996 | 0.07 | $50K or less | cherry (−) | 10.3 |
| | | | | | | oak (+) | 6.1 |
| | | | | | $51K to $100K | -- | -- |
| | | | | | >$100K | cherry (+) | 6.6 |

[a]This reflects number of respondents 4x, as each respondent evaluated four furniture pieces.
[b](+) = higher than expected frequency in the cell; (−) = lower than expected frequency.

*Table 2. — Results for species preferences (in household furniture construction) for gender by age.*

| Category | $\chi^2_{(df)}$ | Sig. | N[a] | Cramer V | Level | Cell results[b] | Cell values |
|---|---|---|---|---|---|---|---|
| male | $63.80_{(10)}$ | <0.01 | 1921 | 0.13 | 18 to 40 years | oak (−) | 17.2 |
| | | | | | | spruce (+) | 5.6 |
| | | | | | | maple (+) | 5.5 |
| | | | | | 41 to 50 years | -- | -- |
| | | | | | 51 + years | oak (+) | 17.1 |
| | | | | | | spruce (−) | 6.9 |
| female | $89.35_{(10)}$ | <0.01 | 2363 | 0.14 | 18 to 40 years | oak (−) | 29.6 |
| | | | | | | spruce (+) | 19.5 |
| | | | | | 41 to 50 years | -- | -- |
| | | | | | 51 + years | spruce (−) | 10.7 |
| | | | | | | oak (+) | 8.2 |

[a]This reflects number of respondents 4x, as each respondent evaluated four furniture pieces.
[b](+) = higher than expected frequency in the cell; (−) = lower than expected frequency.

*Table 3. — Results for species preferences (in household furniture construction) for gender by income.*

| Category | $\chi^2_{(df)}$ | Sig. | N[a] | Cramer V | Level | Cell results[b] | Cell values |
|---|---|---|---|---|---|---|---|
| male | $22.46_{(10)}$ | 0.01 | 1825 | 0.08 | $50K or less | cherry (−) | 3.3 |
| | | | | | | oak (+) | 2.6 |
| | | | | | | birch (+) | 2.4 |
| | | | | | $51K to $100K | -- | -- |
| | | | | | > $100K | oak (−) | 4.6 |
| | | | | | | cherry (+) | 3.9 |
| female | $33.05_{(10)}$ | <0.01 | 2083 | 0.09 | $50K or less | cherry (−) | 7.6 |
| | | | | | | oak (+) | 4.1 |
| | | | | | $51K to $100K | -- | -- |
| | | | | | > $100K | cherry (+) | 6.1 |
| | | | | | | red alder (−) | 3.1 |

[a]This reflects number of respondents 4x, as each respondent evaluated four furniture pieces.
[b](+) = higher than expected frequency in the cell; (−) = lower than expected frequency.

confirmed by this study. Gender was not significant overall, suggesting that previous findings of differences by gender in the *perceptions* associated with species do not necessarily translate into actual species *preference.* However, a few gender differences were noted when considering age and income. Nicholls and Roos (2006) also found no gender differences in preferences for red alder cabinets stained to different shades, although only one species was investigated.

**Table 2** shows results for species preferences for gender by age, and **Table 3** shows results for gender by income. Not surprisingly, given no overall gender effect, similar trends for age and income held for both males and females. However there were a few notable exceptions. Maple was preferred by younger males, which along with a preference for spruce could indicate a general preference for lighter colored woods by younger males. Birch, along with oak, was preferred by lower income males. Lastly, alder had a lower preference among higher income females, suggesting a lack of status position for this species.

Demographic differences in species preferences for the four furniture pieces we considered can be summarized as follows. Age and income both were statistically significant, with a stronger effect for age. The income effect was quite weak, and statistical significance likely was influenced by the large sample size.

Gender was not statistically significant.

Spruce was more preferred by younger respondents and less preferred by older respondents.

Oak was more popular among older respondents and less popular among younger respondents.

Oak also was more preferred by lower income respondents.

Cherry was more preferred by higher income respondents and less preferred by lower income respondents.

Red alder was less popular among higher income female respondents.

Maple was preferred by younger male respondents; birch was preferred by lower income male respondents.

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# Effect of post-treatment steaming on the bending properties of southern pine treated with copper naphthenate

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**Abstract**

The effect of steaming after treatment was evaluated for southern pine treated with a waterborne copper naphthenate formulation. Little practical effect on the mechanical properties was noted. Steaming for 2 hours had a greater effect than a 30-minutes steam period. No difference in modulus of elasticity and modulus of rupture, work to proportional limit, work to maximum load, or fiber stress at proportional limit between samples steamed following treatment and those only treated was shown. Differences between untreated and treated samples were ascribed to treatment rather than steaming. This treatment effect is common with waterborne preservative treatments.

Preservative treatments or treating regimens should not have a deleterious effect on wood properties. Many studies (Barnes and Winandy 1986) have been conducted on the effect of various treatments on the mechanical properties of wood. For example, research by Winandy and others (Barnes and Winandy 1989, Barnes et al. 1990, Winandy and Barnes 1991, Winandy et al. 1992) recommended drying temperature limitations for CCA-treated wood, which were adopted by Standards organizations. Other work has shown ACQ and other treatments do not cause significant reductions in mechanical properties (Barnes and Winandy 1986, Barnes et al. 1993). A 2005 paper presented to the American Wood-Preservers' Association (AWPA) showed no practical deleterious effects of waterborne copper naphthenate treatment on the bending properties of southern pine (Barnes et al. 2005).

Post-treatment conditioning cycles have varying effects on the resultant strength of wood depending on species, treatment, and type of conditioning. Losses in modulus of rupture (MOR) from 8 to 33 percent have been reported depending on the steaming time, temperature, and preservative retention (Barnes 1985). This paper reports on the testing of southern pine treated with waterborne copper naphthenate and subsequently steamed after treatment.

## Methods and materials

### Materials

All-sapwood, defect-free southern pine samples were cut from commercial dimension stock into samples measuring 1.5 by 1.5 inch in cross section by 24-in long (38 by 38 by 610 mm). Samples were randomly assigned to four treatment groups of 30 samples each such that each group would have a similar density range, ring count, and earlywood/latewood ratio. The groups tested were water-treated, water-treated steamed (30 min), copper naphthenate (CN)-treated, and CN-treated steamed (30 min). Since AWPA Standard T1–06 section 8.1.6.2 for southern pine allows steaming for up to 2 hours (AWPA 2007), an additional treated group containing only 12 replicates was steamed for 2 hours in order to get some idea of the effect of the longer steaming period.

### Treatment

Treating solutions were prepared from a waterborne concentrate of copper naphthenate by water dilution. The formulation was CuNap-5 W™ (Merichem Co.) which meets the AWPA P5–07 specifications (#21) for CuN-W, meaning it contained monoethanolamine as the cosolvent (AWPA 2007). The concentrate contained a nominal 5 percent Cu, but did not contain any additives such as water repellants, moldicides, or

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colorants. All samples were treated using a full-cell cycle consisting of 30 minute vacuum at 25 in Hg. The cylinder was filled while under vacuum and pressure applied for 30 minutes at 145 to 150 psig. The samples were removed, wiped of excess solution, and weighed. Post-treatment steaming for 30 minutes or 2 hours was accomplished by injecting live steam into the treating cylinder at atmospheric pressure. Temperature typically rose to 105 to 110 °C in the cylinder and approximately three liters of condensate were collected during a 30-minute steaming period. Samples were allowed to condition at 68 °F, 65 percent relative humidity before testing.

## Testing and analysis

Samples were tested in static bending with center-point loading according to D143 (ASTM International 2006). Moisture content (MC) and specific gravity (SG) were determined on small samples cut from near the break of the bending samples. Average MC was 10.6±1.4 percent. SG (od wt, volume at test) averaged 0.56±0.06. Modulus of elasticity (MOE), modulus of rupture (MOR), work-to-maximum load ($W_{ml}$), work-to-proportional limit (elastic resilience, $W_{pl}$), and fiber stress at proportional limit ($S_{pl}$) were computed. The data were analyzed by covariate analysis using SG, MC, and preservative retention as covariates. Least square mean separation techniques were used to separate the means (SAS Institute 2001).

*Table 1. — Descriptive statistics for unadjusted bending property values.*

| Value | $W_{ML}$ | $W_{PL}$ | $FS_{PL}$ | MOR | MOE |
|---|---|---|---|---|---|
| | ----- (in-lbf/in$^3$) ----- | | --------------- (psi) --------------- | | |
| | | *Water treated, unsteamed [UT]* | | | |
| Mean | 12.2 | 1.14 | 4,384 | 9,204 | 983,803 |
| SD | 4.9 | 0.47 | 1,252 | 1,364 | 194,503 |
| COV | 40% | 41% | 29% | 15% | 20% |
| | | *Water treated, steamed 30 minutes [UT-S30]* | | | |
| Mean | 12.7 | 1.12 | 4,557 | 9,322 | 1,075,176 |
| SD | 4.0 | 0.38 | 1,474 | 2,024 | 418,502 |
| COV | 32% | 34% | 32% | 22% | 39% |
| | | *Treated, unsteamed [TRT]* | | | |
| Mean | 11.4 | 0.88 | 3,729 | 8,340 | 927,408 |
| SD | 4.4 | 0.29 | 931 | 1,227 | 232,868 |
| COV | 38% | 33% | 25% | 15% | 25% |
| | | *Treated, steamed 30 minutes [TRT-S30]* | | | |
| Mean | 11.8 | 0.98 | 3,850 | 7,950 | 871,376 |
| SD | 4.9 | 0.28 | 869 | 1,175 | 210,314 |
| COV | 41% | 29% | 23% | 15% | 24% |
| | | *Treated, steamed 2 hrs [TRT-S120]* | | | |
| Mean | 9.96 | 0.77 | 3,225 | 7,179 | 819,079 |
| SD | 3.64 | 0.33 | 960 | 935 | 188,030 |
| COV | 37% | 43% | 30% | 13% | 23% |

## Results and discussion

Raw data means are shown in **Table 1**. Adjusted means and mean comparisons from the covariate statistical analysis are given in **Table 2**.

Compared to the untreated adjusted value, no significant impact of steaming for either 30 minutes or 2 hours on the MOE for the treated stock was noted. These data are compared in **Figure 1**.

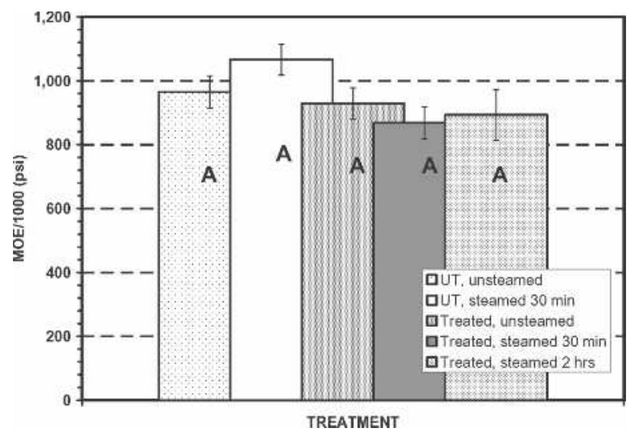


*Figure 1. — Comparison of MOE values (bars without a common letter are significantly different one from another at* p *= 0.05).*

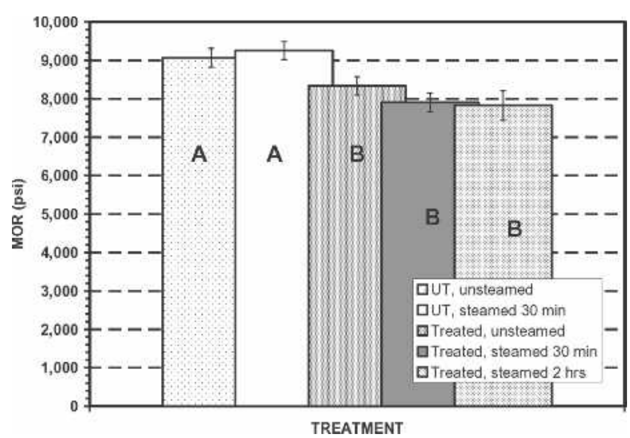


*Figure 2. — Comparison of MOR values (bars without a common letter are significantly different one from another at* p *= 0.05).*

*Table 2. — Least-square adjusted mean values for bending properties.[1]*

| Treatment | MOR | MOE | $FS_{PL}$ | $W_{PL}$ | $W_{ML}$ |
|---|---|---|---|---|---|
| | --------------------------- | (psi) | --------------------------- | ------- (in-lbf/in$^3$) | -------- |
| Untreated | 9,067 A | 964,814 A | 4,388 A | 1.14 A | 12.1 A |
| Untreated, steamed 30 minutes | 9,250 A | 1,065,908 A | 4,530 A | 1.11 A | 12.6 A |
| Treated | 8,336 B | 929,126 A | 3,712 B | 0.87 B | 11.3 A |
| Treated, steamed 30 minutes | 7,904 B | 868,164 A | 3,814 A | 0.96 AB | 11.7 A |
| Treated, steamed 120 minutes | 7,825 B | 893,190 A | 3,539 B | 0.85 B | 10.9 A |

[1]Means not followed by a common letter are significantly different one from another at $p = 0.05$.

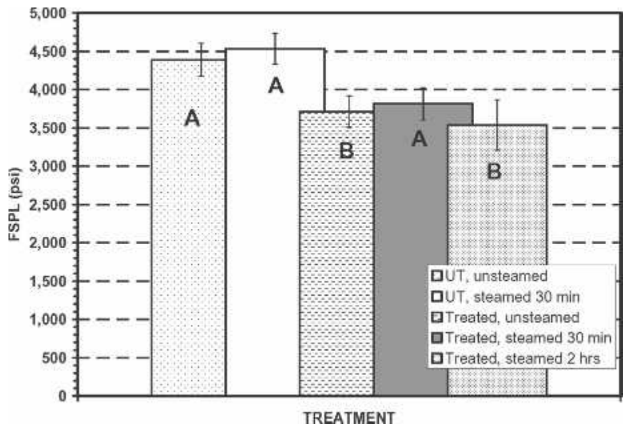


*Figure 3. — Fiber stress values for the various treatment groups (bars without a common letter are significantly different one from another at* p *= 0.05).*

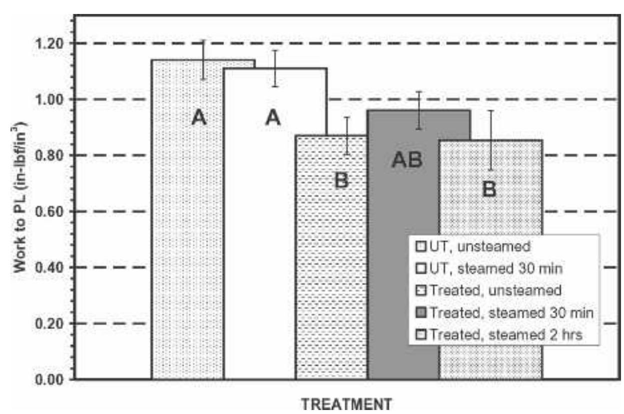


*Figure 4. — Work-to-proportional limit for the various treatment groups (bars without a common letter are significantly different one from another at* p *= 0.05).*

There was no significant difference in the adjusted untreated MOR means whether steamed or not (**Fig. 2**). Treated and treated-steamed (30 min and 2 h) values were lower than the untreated means. This difference is interpreted as being a treatment effect common with other waterborne preservative systems. A similar result was obtained for fiber stress (**Fig. 3**) except that the steamed (30 min) value was statistically equivalent to the untreated values.

A similar result was found for the work-to-proportional limit values (**Fig. 4**), but the treated and steamed for 30 minutes values were not different from the control steamed and unsteamed values. For work-to-maximum load, no significant differences were found for the adjusted treatment mean values (**Fig. 5**). Again, the differences seen in the work values are attributed to a treatment effect.

## Summary and conclusions

This study has shown the effect of post-treatment steaming on the mechanical properties of southern pine tested in bending to have little practical effect on the treated wood for

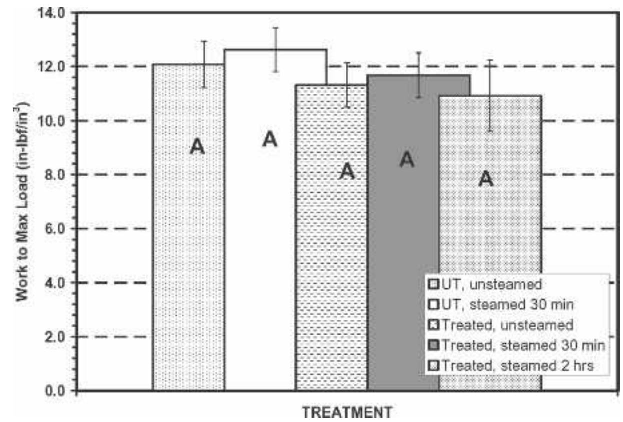


*Figure 5. — Comparison of work-to-maximum load for the treatment groups (bars without a common letter are significantly different one from another at* p *= 0.05).*

steaming periods for up to 30 minutes. Limited strength loss was apparent with steaming after 2 hours. Some care should be taken in judging the extended steaming period data as this experimental group was composed of only 12 samples. Any differences between treated and untreated wood are attributed to a treatment effect. These results suggest that southern pine treated with waterborne copper naphthenate can be successfully steamed after treatment with limited concern for loss in bending properties.

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Technical Note

# The standardization puzzle: An issue management approach to understand corporate responsibility standards for the forest products industry

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**Abstract**

There are increasing discussions regarding creation of global corporate social responsibility (CSR) standards. One important approach to understanding CSR is issue management. We adopted an issue identification approach to examine the issues faced by the forest products industries in the United States and India. Interviews were conducted with a range of key informants regarding social responsibility issues in the forest products industry in both countries. Our results show that there are marked differences in the issues with which key informants think forest products companies should be concerned. The results suggest that even though overarching CSR guidelines are globally relevant, any CSR standard for global forest products companies must maintain context-specific components.

*"Government wants the industry to maintain water emission levels to be better than the drinking water provided by Delhi water board for human intake. . . . Is that possible?"*

*— A paper manufacturer in India*

*"We should focus on consolidation . . . why the paper needs to go to China, recycled there and then come here in some form. We need facilities that can use recycled paper."*

*— A U.S. government employee*

These two statements provide no final conclusion regarding the environmental orientation of forest products companies in the United States and India, yet they are indicative of the difference in environmental thinking across varying socio-economic contexts. In an era when global standards in various fields are being heavily discussed, there remains a significant push to develop context-specific standards. For example, at a recent Sustainability Summit: Asia, held in New Delhi, the Secretary in the Ministry of Environment and Forests, Government of India announced that India is developing its own certification system instead of adopting that of the Forest Stewardship Council. Similarly, the role of socio-economic context in fields such as corporate social responsibility (CSR) is well documented in that CSR perception and implementation varies among different cultural contexts (Burton et al. 2000). We draw on the issue management approach to identify differences in the issues surrounding forest products companies in the United States and India. Based on such differences, this paper argues that while general guidelines are necessary to provide a global framework to CSR, any standard in the global forest products industry must capture the context-driven spirit of CSR.

## Some perspectives on global CSR

Despite numerous definitions, CSR simply refers to balancing economic, social, and environmental responsibilities of companies. Panapanaan et al. (2003) note that 42 percent of Finnish managers reported that CSR is a recurring concept that is not being embraced by developing countries, something similar to how CSR was treated in Finland 40 or 50 years

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ago. A similar proportion of managers reported that pursuing CSR is not a problem in Finland, but it is a problem in developing countries. On the consumer side, U.S. consumers highly value corporate economic responsibilities while French and German consumers are most concerned about businesses conforming to legal and ethical standards (Maignan 2001). Vidal and Kozak (2007) suggest that context plays a significant role in the corporate responsibility perception of forest product companies.

The editor-in-chief of *Science*, Donald Kennedy (2007), argues that sustainability carries strong social, economic, and cultural attributes and that different societies are likely to address sustainability in their own ways. In order to achieve the global objective of sustainability, there is a logical need for CSR at a global level. There is a global consensus about some of the overarching CSR themes, such as, economic bottom-line, employee treatment, community development, and other stakeholders' engagement. However, there are several underpinning variations that require that particular social paradigms and expectations from business are considered in any CSR evaluation mechanism.

## CSR guidelines and standards

Cramer (2005) notes that for global companies CSR does not stop at national borders. She argues that the pressing question for companies is how to translate CSR principles into practice? To facilitate the understanding of global-level CSR, she distinguishes between standards and guidelines: *"A standard implies that companies can and should achieve a uniform output, while a guideline provides a set of guiding principles."*

There are efforts to establish both the guidelines and standards for implementing CSR at a global level. For example, the Global Reporting Initiative (GRI 2007) suggests general guidelines for companies to follow, whereas organizations such as AccountAbility (AccountAbility 2007) and Social Accountability International (SAI 2007) provide specific standards that companies can adopt in order to audit their social performance. The International Organization for Standardization (ISO) is involved in developing CSR standards. The certification developed by Social Accountability, SA 8000, is widely used and covers aspects of human rights protection at the work place. Accountability has developed what is called the AA 1000 series. Both AA certification series and the SA 8000 certification claim global applicability across all industry sectors.

On the other hand, the most commonly accepted document developed by GRI, the sustainability reporting guidelines (G-3), consists of reporting principles, reporting guidance, and standard disclosures (including performance indicators). Performance indicators are categorized as core and additional. Core indicators are to be of interest to most stakeholders and are expected to be generally included. Additional indicators represent emerging practice or topics that may be relevant to only some organizations (GRI 2007). In addition to the guidelines, the GRI documents also include sector supplements. These sector supplements provide flexibility to GRI documents and also manifest GRI's recognition of the fact that a rigid set of indicators may fail to capture aspects of sustainability performance that are unique and crucial to a given industry sector. Indicators contained in sector supplements are considered core, further bolstering the idea that sustainability or for that matter the concept of corporate responsibility is a context-driven proposition. In addition to these universal principles, as Pearson and Seyfang (2001) note that there are about 100 different standards that can be distinguished based on their geographical, sectoral, and workforce coverage. Lavery (2002) suggests that companies must choose guidelines and standards that reflect their business, culture, and stakeholder needs and that help the company find "meaning" in its measurement results. In the similar vein, the International Institute for Sustainable Development prepared an issue paper regarding ISO CSR standardization. The paper highlights two challenges involved with social responsibility: understanding society's expectations and implementing activities to deliver on these expectations. "Standards can play an important role in promoting these two general objectives, although it is not certain that one standard can serve both equally" (IISD 2004).

The foregoing discussion suggests that societal expectations and context play an important role in determining the form of CSR plans and programs for a company and/or industry. Sethi (1979) warns that increasing societal expectational gaps will cause business to lose its legitimacy and will threaten its survival. Issue management helps in identifying such gaps and can be a useful approach in discussing the relevance of universal vs. contextual CSR standards.

## Objective

Based on the above discussion, this study has two objectives:

— Obtain an understanding of the issues that face the forest products industries in the United States and India,

— Assess the applicability of universal vs. contextual CSR standards in the global forest products industry.

## Theoretical background

Marx (1986) notes that many crucial problems facing modern managers are arising from major changes in the traditional relationship between business and society. Among others, a reason for recent interest in CSR is the new role of business in contemporary society and changing societal expectations from business. Carroll (1991), one of the most notable scholars in the field, observes that corporate social performance (CSP) has emerged as an inclusive and global concept to embrace CSR. Wood (1991) suggests a three component CSP model with principles of social responsibility, process of social responsiveness, and outcomes of corporate behavior. The social responsiveness component comprises environmental scanning, stakeholder management, and issues management.

*Table 1. — Number and types of interviewees in the United States and India.*

| Country | Total number of interviews | Interviewee types |
|---|---|---|
| U.S. | 10 | 2 government employees |
| | | 5 NGOs employees |
| | | 1 consultant to an industry association |
| | | 2 political office holders |
| India | 8 | 1 government employee |
| | | 2 NGOs employees |
| | | 1 CSR consultant to industry |
| | | 1 industry association member |
| | | 3 academicians |

*Table 2. — Economic issues as identified by the key informants that the forest products industry is facing in the United States and India.*

| Issues unique to the United States | Issues common to both countries | Issues unique to India |
|---|---|---|
| *Profitability related issues:* | *Profitability related issues:* | *Profitability related issues:* |
| Falling product prices | High transportation costs | High per unit cost of raw material |
| *Market based issues:* | Rising public relations (PR) costs—liaison with more stakeholders | *Market based issues:* |
| Shrinking markets and declining raw material availability | Rising natural gas prices | Price fluctuation in raw material |
| Lack of consolidated purchasing mechanism-leading to higher purchasing costs | High cost of environmental compliance | Lack of sustained raw material supply |
| *Policy and external issues:* | *Market based issues:* | Seasonal/cyclic nature of market |
| Structure of landownership | Uneven global playing field | *Financial issues:* |
| Federal tax structure | Rising imports | No financial support from banks for technology up-grades |
| Differing state laws | Cheap imports | *Production related issues:* |
| Too much regulation to comply with | *Financial issues:* | Lack of technically competent workers |
| Harvest shifting to smaller logs | Lack of capital for modernization | Low scale production |
| Pressure from environmental nongovernment organizations (ENGOs) | Shrinking land availability for forestry | Inadequate production |
| Longer plant growth time in the United States | | Varied production lines |
| | | *Policy and external issues:* |
| | | Skewed forest policy toward ecology |
| | | Poor implementation of forest policy |
| | | Poor infrastructure |
| | | Poor legal mechanism |
| | | Unorganized business climate |
| | | Fake government statistics regarding demand and production |
| | | Unfavorable policies for small business |
| | | Imposed certification needs |
| | | Lack of globally compatible cloning |

Mahon and Wartick (2003) maintain that within the broad area of social issues in management, there are three main streams, namely issues management, political arena management, and stakeholder management. They further weave issues management and stakeholder management since stakeholder management deals with methods that organizations can use to assess and deal with internal and external groups on a given issue. Accordingly, the issues management approach becomes fundamental to stakeholder management and to CSP. A concrete structure to issue management in CSR was provided by Wartick and Rude (1986) where they emphasized the identification, evaluation, and response to social issues that an organization considers important.

According to Ansoff (1975), the goal of issue identification is to see and predict expectational gaps as a result of changing societal expectations or beliefs. Even in the same socio-cultural context, issues can be specific to a particular industry sector (Bridges 2004). Forestry has a special place within societal beliefs and values. Accordingly, with increasing environmental awareness, social pressures on forestry companies have intensified (Nasi et al. 1997).

Issues that forest products companies (or managers) consider important may be very different than those considered by society at large. In this research we focus on perceptions of current issues surrounding forest products companies in the United States and India from the perspective of general society. Therefore, we exclude industry managers. What managers think of the issues, whether they consider them relevant or not, pressing or emerging, is an area that will be investigated in a subsequent project.

## Methodology

Ritchie (2003) maintains that qualitative research approaches are desirable for situations where information is collected from individuals that have specialized roles in society and where the nature of the subject coverage is likely to be complex. The field of CSR in the United States and Indian forest products industry has not been widely investigated and therefore we chose to conduct this exploratory study through a qualitative approach, using in-depth interviews. Patton (2002) maintains that depending on the purpose, more than one qualitative sampling strategy can be adopted. In this research we began with intensity sampling, in which information-rich cases that manifest the phenomenon intensely are selected. These information-rich cases were selected via internet searches and organizations' interest in CSR in the forest products industry. After several such cases were contacted, we relied on snowball sampling in which these information rich cases referred to other information rich cases. In total, 10 key informants from the United States and eight from India were interviewed (**Table 1**).

*Table 3. — Social issues as identified by the key informants that the forest products industry is facing in the United States and India.*

| Issues unique to the United States | Issues common to both countries | Issues unique to India |
|---|---|---|
| *Worker related issues:* | *Worker related issues:* | *Worker related issues:* |
| Lack of labor availability | Declining employment | Unfair wages for workers |
| Illegal immigrants | *Community relation issues:* | *Resource side issues:* |
| Inadequate health care provision | Lack of engagement with community | Lack of price assurance for growers |
| Unfair employee treatment | | No government land for plantation |
| *Community relation issues:* | | Lack of plantation orientation and funds among small farmers |
| More public scrutiny needed on environment and land management issues | | Lack of rural infrastructure |
| Problems of negative public image | | Confrontation among forest communities for wood use—as fuel vs. timber |
| *Policy and lifestyle issues:* | | Declining income and employment for agro foresters |
| Lack of pressures on timberland investment management organizations (TIMOs) | | *Socio-economic and structural issues:* |
| Urbanization leading to decreasing forestland | | Parallel market/illegal felling |
| | | Inequitable profit margins |
| | | Structural issues in forest department |
| | | *Other issues:* |
| | | Naxalite issues—in some areas unlawful groups control resources |
| | | Low quality products for consumers |
| | | Declining craftsmanship and artisan work |
| | | Lack of basic research support by industry |
| | | Falsifying on-site fires and insurance claims |
| | | Geographic concentration of industries—leads to problems for agro-foresters |

*Table 4. — Environmental issues as identified by the key informants that the forest products industry is facing in the United States and India.*

| Issues unique to the United States | Issues common to both countries | Issues unique to India |
|---|---|---|
| *Forestry related issues:* | *Manufacturing process related issues:* | *Forestry related issues:* |
| Increase in insects and diseases and wild fires in the U.S. West | High energy consumption | Multiple laws for tree felling |
| Lack of sustainable forestry practices | Lack of renewable resource use | *Manufacturing process and compliance issues:* |
| High mortality rate | Point and non-point pollution (air and water) | Lack of availability of clean technology |
| Endangered species | Waste management | Excessive water use at production stage |
| Overstock of unhealthy forests | Purchasing policies | Use of chemicals and chlorine |
| Fragmentation of forests | *Overarching issues:* | Illegal timber procurement |
| Plantation forestry: leading to monoculture | Global warming | Lack of compliance with environmental laws |
| "Special place" issue: no forestry activity allowed at some places | Declining bio-diversity | Lack of environmental orientation |
| *Manufacturing process and policies issues:* | Deforestation | Lack of moral commitment |
| Lack of recycling | Climate change | Lack of Eco-labeling |
| *Institutional issues:* | | Lack of responsibility for regenerating the resources |
| Too much legal interference | | *Institutional issues:* |
| | | Ineffective and insufficient monitoring |
| | | Unrealistic, too high and unattainable norms determined by government |

Face-to-face interviews were conducted using questions designed to draw out thoughts regarding the economic, social and environmental issues facing the forest products industry. Patton (2002) notes that a fundamental principle of qualitative interviewing is to provide a framework within which respondents can express their own understandings in their own terms. Accordingly, a semistructured interview protocol was prepared. The field of CSR is commonly accepted to have three domains: economic, social and environmental and as such, we asked the respondents which issues they feel surround these three domains of CSR in the forest products industry in their respective countries. Since interpretation of the issues mentioned was not involved in such direct questions, data were recorded via note-taking.

Maxwell (1996) maintains that qualitative studies have three types of purpose: description, interpretation, and theory. Accordingly, he suggests three potential threats to validity. This research aims at identification and description of issues and therefore, based on this purpose, the primary concern is to secure descriptive validity. Maxwell (1996) suggests making thorough notes and the use of member-checks to eliminate the threat to descriptive validity. Additionally, Maxwell (2005) suggests bias and reactivity as two threats to validity in qualitative research. Our research used direct questions and responses were straight forward in the three different CSR categories requiring little interpretation by the researchers. Therefore, these threats were minimized by the design and purpose of the study. Maxwell (2005) also suggests respondent validation as one of the important methods to eliminate threats to validity. All the issues and related explanations that respondents provided were noted and at the end of each interview, the researcher summarized the issues identified by the respondent in each of three components of CSR. Each interview took approximately 30 minutes. Interviews notes were categorized into the major groups comprising economic, social and environmental categories. For an easy comprehension and comparability between countries, we divided the data within subgroups (e.g., profitability related issues, etc.). These subgroups were created based on similarity of themes emerging from the issues identified by respondents in each of the CSR component categories.

## Results

Economic, social and environmental issues, as identified by experts in the United States and India, are shown in **Tables 2, 3,** and **4**. Due to the exploratory nature of the study, we did not include the identified issues based on frequency. Also, information rich respondents represent diverse fields and some of the issues might come out of their peculiar experiences and observations. Hence, even if an issue was identified by only one respondent, it is included. The majority of issues were mentioned by only one respondent but there are issues that were mentioned by the majority of respondents. For example, falling product price was mentioned by only one respondent in the United States, whereas uneven global playing field was mentioned by 9 out of 18 respondents.

Out of 104 total issues in all three categories, only 35 issues are common to both countries. As can be seen from the tables, most issues are unique to one country, though there is some overlap in each category. The social category showed the least overlap where of 26 total issues, only 2 are common. Beyond the responses shown in the tables, the flow of interviews elicited some notable differences. For example, creation of biorefineries was mentioned as a way to embrace CSR in the United States industry, yet industry providing for cheap housing for slum dwellers was suggested as one potential way for companies in India to be socially responsible. Such narratives obtained through interviews bolster the findings shown in the tables suggesting considerable differences between the countries.

## Discussion and conclusion

In all three categories, most issues are country-specific. The common issues largely fall in the environmental and economic categories and are global in nature. We assume that this results from a global mandate regarding overarching environmental issues. Many issues in India are related with either institutional inadequacy or non-compliance with stipulated regulation. The recurrent issue in the United States that emerged during interviews is too much interference by the courts. Although, the rising cost of environmental compliance is a common issue in both countries, in India much of this cost is involved in getting around the regulation rather than compliance. In the United States, cost is either associated with compliance or litigation as indicated by the following statement:

*"Even if there could be some regulations in developing countries regarding environment, labor safety, and fair wages, etc., yet the compliance is nonexistent. This leads to cost disadvantage for U.S. industry."*

*— Consultant to a U.S. industry association*

Further, there could be issues in both countries that respondents did not identify. For example, no respondent in India identified "unfair employee treatment" as a social issue, nor was "the lack of sustainable forestry practices" identified as an environmental issue. This only indicates that respondents identified issues based on locally existing social and environmental paradigms.

Apart from the issues that reflect global economic changes and commonly accepted environmental problems, most issues that forest products companies can address in order to be socially responsible in the United States and India are unique to their respective, domestic socio-economic structures. Such marked contrast suggests that any CSR standardization in the forest products industry is illogical. Such standardization may only aggravate misuse of standards in countries where regulatory frameworks are not well developed. Additionally, economic and social dependence on forestry and the forest products industry in the two countries is very different. In India, social issues are closely tied with the forest sector because of livelihood dependence of forest dwellers on forests. Accordingly, a significant component of Indian forest policy is devoted to securing sustainable use of nonwood forest products and forest-fiber based industries in India are at the margins of the industrial landscape. On the contrary, in the United States, it is a highly developed industrial sector with significant employment and economic contribution. Based on such differences, only general guidelines, such as the G-3 guidelines laid down by GRI can be used to provide a common guiding framework to forest products companies across the globe. However, depending on the socio-economic and regulatory framework in a given country, it is more feasible to leave specific CSR standards to be developed domestically. This leaves two alternatives for the forest products sector: 1) either develop country specific standards within the general GRI framework which makes cross county comparisons difficult or 2) develop a sector supplement within GRI provisions and leave room for dealing with country specific issues.

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I certify that the statements made by me are correct and complete.Carol Lewis, Executive Vice President and Treasurer

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Pacific Northwest Research Station, Portland, Oregon

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Interested applicants, or those desiring further information, should contact, by January 31, 2008, either Eini Lowell, Research Scientist, ESP Team at e-mail elowell@fs.fed.us (telephone (503) 808-2072); or Dennis Dykstra, Research Scientist, ESP Team at e-mail ddykstra@fs.fed.us (telephone (503) 808-3132), or write to USDA Forest Service, Pacific Northwest Research Station, Attention: Eini Lowell, PNW Research Station, 620 SW Main St. Suite 400, Portland, Oregon 97205.

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**April 15 – 17, 2008:** International BIOMASS '08 Conference & Trade Show, Minneapolis, Minnesota. Contact www.biomassconference.com.

**April 20 – 23, 2008:** 2008 World Adhesive Conference & Expo, Intercontinental Miami Hotel, Miami, Florida. Contact www.ascouncil.org/industry/wac/.

**April 28 – 30, 2008:** 2008 OSB World Symposium and Exhibition IV, Marriott Rivercenter Hotel, San Antonio, Texas. Contact janssens@osbguide.com.

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