Influence of Fiber Alignment
On Stiffness and Dimensional Stability
Of High-Density Dry-Formed Hardboard

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Abstract
The effects of aligning fibers and of their placement within the fiber mat on strength, elastic modulus, and dimensional stability of high-density, dry-formed hardboard were investigated. This approach was taken to produce hardboards with increased strength for use as structural components. Four sets of oriented fiber configurations and one set of random-formed control boards 3/16 inch thick were prepared from aspen and from Douglas-fir. For a given species, homogeneous, highly oriented fiber boards showed the greatest improvement in strength, elastic modulus, and dimensional stability. These properties varied in direct proportion to the percent of the total fibers in the one direction. Some loss in cross-direction strength and in stability accompanied these fiber-direction improvements. With the highly oriented boards, the elastic modulus was in the range of that of many clear lumber species. The linear movement in the fiber direction was also comparable to that for wood in the grain direction. The bending strength and stiffness were the only properties that benefited significantly from concentrating the oriented fibers on the surface of the mat. Tensile strength and both tensile modulus of elasticity and bending modulus of elasticity were improved by orienting alternate layers of fibers perpendicular to the preceding layer but not to the extent of the other oriented boards. The dimensional stability, however, was comparable to that for random-formed control boards in either fiber or cross-fiber direction.

Experimental Procedure
Fiber Preparation and Refining
Quaking aspen (Populus tremuloides Michx.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) France) fibers were prepared in a MacMillan Fiberizer in which wood bolts are passed over rapidly rotating drums fitted with metal needles that reduce the wood to a coarse fiber. The fiber from this process is particularly suited for orientation because of its relative straightness. Exploratory experiments were conducted with fibers prepared by other processes including pressurized refiners, but these fibers were more difficult to orient (Fig. 1).

Eight percent by weight, based on the fiber, of a 30-percent solution of an alkaline-catalyzed phenol-formaldehyde resin of the type commonly used for dry formed hardboard was sprayed on the fiber in a rotating drum, and the resulting fiber mat was then pressed into 3/16-inch-thick hardboard. The linear movement of the fibers in the direction of pressing was also comparable to that for wood in the grain direction. The bending strength and stiffness were the only properties that benefited significantly from concentrating the oriented fibers on the surface of the mat. Tensile strength and both tensile modulus of elasticity and bending modulus of elasticity were improved by orienting alternate layers of fibers perpendicular to the preceding layer but not to the extent of the other oriented boards. The dimensional stability, however, was comparable to that for random-formed control boards in either fiber or cross-fiber direction.

W O O D-F I B E R- B A S E H A R D B O A R D, a well-known product, has been used for years. However, its use for structural members has been limited. With the growing shortage of high-quality knotfree timber and related products, the need for improved wood fiber-base structural products that are uniformly strong and that can be better engineered for the particular end use becomes apparent.

Although chemical binders have been employed successfully to improve many of the properties, they have not provided certain properties, especially stiffness and linear stability, comparable to those of many wood products. The dry-formed process now makes it possible to produce thick fiber-base members economically.

It has been shown that a fiber is stronger and more dimensionally stable in the longitudinal direction than in the cross-fiber direction. To take advantage of these inherent characteristics, this work was undertaken to establish the benefits of forming hardboard with the majority of the fibers in one direction.

References
drum. The fiber-resin mixture was allowed to air-dry to about 8 percent moisture content. This was followed by one pass through a 12-inch-diameter disk mill equipped with pyramid-type plates to disperse the large cluster of fiber bundles formed during resin treatment and drying.

**Boardmaking.** – A method devised at the Forest Products Laboratory by the authors was used to orient the fibers and form the mat. The separated fibers were deposited by air conveyance from a height of 18 inches or more onto a vibrating corrugated plate with flutes 11/32 inch wide. These oriented fibers were then transferred to a flat caul plate, and the process repeated until the desired mat thickness was obtained. The mats were then pressed between platens of a hot press at a platen temperature of 385°F for 5 minutes using “stops” to control board thickness. The boards were given a further heat treatment in a circulating-air oven at 200°F for 3 hours.

Boards, 12 inches by 12 inches by 3/16 inch, were fabricated with the following configurations (Fig. 2).

**Highly oriented, homogeneous** (A). – Most of the fibers were aligned in the same general direction (90 percent orientation).

**Partially oriented, homogeneous** (B). – One-half of the fibers by weight were oriented, and distributed throughout the thickness of the mat in 17 equal-weight layers alternating oriented and random-formed layers (70 percent orientation).

**Partially oriented, surface** (C). – One-half of the fibers by weight were oriented and divided equally on the two surfaces of the mat with the middle half of the mat consisting of randomly formed fibers (70 percent orientation).

**Alternate layers oriented** (D). – Nineteen equal-weight oriented layers of fiber were formed with the fibers in the adjacent layer perpendicular to those in the preceding layer (50 percent orientation).

**Random oriented** (E). – Control boards with all fibers randomly oriented as in conventional hardboard (50 percent orientation).

Three boards of each configuration and of each species were fabricated.

**Evaluation**

Specimens were cut from the boards for evaluating the following properties:

- **Tensile strength**—three each direction, 8 inches by 1 inch by 3/16 inch (without a reduced center section)
- **Modulus of rupture**—five each direction, 6 inches by 2 inches by 3/16 inch (with 4-1/2-in. span, center loading)
- **Internal bond strength**—three 2 inches by 2 inches by 3/16 inch
- Linear and thickness stability and water absorption—six each direction, 6 inches by 1/2 inch by 3/16 inch.

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3Orientation values indicated were based on the ratio of linear dimensional movement in the cross-fiber direction to the movement in the fiber direction of the hoards.
All strength and modulus of elasticity values were determined according to ASTM D 1037-72a. To eliminate errors in measurement due to compressing or crushing the linear dimensional stability specimens, stainless steel balls, 1/8 inch in diameter, were embedded with epoxy glue in the ends of each specimen. The specimens were initially conditioned to equilibrium for 30 days at 50 percent relative humidity (RH) and 72°F. Two specimens of each configuration in each direction were then exposed to each of the following conditions: 80 percent RH, 90 percent RH, and immersion (water soak) for 30 days (all at 80°F). Length, thickness, and weight were recorded before and after each of these exposures.

Discussion of Results

Presentation of Data

A summary of the strength data for the high-density hardboards is presented in Table 1; the dimensional

![Figure 2. Configurations showing fiber orientations for hardboards.](image)

Table 1. EFFECT OF FIBER CONFIGURATION AND SPECIES ON THE STRENGTH PROPERTIES OF HIGH-DENSITY HARDBOARDS.

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Static bending</th>
<th>Tension</th>
<th>Internal bond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Modulus of rupture in test directions</td>
<td>Modulus of elasticity in test direction</td>
<td>Maximum stress in test direction</td>
</tr>
<tr>
<td></td>
<td>(-) (psi)</td>
<td>(+) (psi) x 1,000</td>
<td>(-) (psi)</td>
</tr>
<tr>
<td>Homogeneous, highly oriented</td>
<td>11,860</td>
<td>4,450</td>
<td>1,675 425</td>
</tr>
<tr>
<td>Homogeneous, partially oriented</td>
<td>9,520</td>
<td>6,350</td>
<td>1,260 645</td>
</tr>
<tr>
<td>Partially surface oriented</td>
<td>10,110</td>
<td>4,970</td>
<td>1,450 435</td>
</tr>
<tr>
<td>Alternate layers oriented</td>
<td>6,980</td>
<td>9,660</td>
<td>1,155 805</td>
</tr>
<tr>
<td>Random (control)</td>
<td>8,100</td>
<td>7,950</td>
<td>920 075</td>
</tr>
</tbody>
</table>

| Homogeneous, highly oriented| 8,200          | 4,020           | 1,000 385  | 8,070 3,490   |
| Homogeneous, partially oriented| 7,120         | 4,430           | 810 415   | 6,300 3,410   |
| Partially surface oriented  | 7,170          | 4,080           | 915 325   | 4,650 3,220   |
| Alternate layers oriented   | 5,230          | 5,750           | 615 600   | 4,440 4,260   |
| Random (control)            | 5,430          | 6,270           | 555 600   | 3,880 4,450   |

Notes:

1. Values adjusted to specific gravity of 1.0 actual value x (1.0/actual specific gravity).
2. See Figure 2 for schematic illustrations.
3. (-), fiber direction; (+), cross-fiber direction.
Table 2. - EFFECT OF QUANTITY AND LOCATION OF ORIENTED FIBERS ON THE DIMENSIONAL MOVEMENT\(^1\) AND WATER ABSORPTION OF HIGH-DENSITY HARDBOARD.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Specific gravity (gm/cc)</th>
<th>Percent length change(^2) in test direction(^3) from 50 percent RH to:</th>
<th>Percent thickness change(^2) in test direction(^3) from 50 percent RH to:</th>
<th>Percent weight change(^2) in test direction(^3) from 50 percent RH to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>80 percent RH</td>
<td>90 percent RH</td>
<td>Water soaked</td>
</tr>
<tr>
<td>Homogeneous, highly oriented</td>
<td>0.88</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Homogeneous, partially oriented</td>
<td>0.93</td>
<td>(-)</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Partially surface oriented</td>
<td>0.91</td>
<td>(-)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Alternate layers oriented</td>
<td>0.92</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Random (control)</td>
<td>0.93</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Homogeneous, highly oriented</td>
<td>0.93</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Homogeneous, partially oriented</td>
<td>0.93</td>
<td>(-)</td>
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<tr>
<td>Partially surface oriented</td>
<td>0.93</td>
<td>(-)</td>
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</tr>
<tr>
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<td>0.93</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Random (control)</td>
<td>0.93</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
</tbody>
</table>

\(^1\)Equilibrium conditioned at each relative humidity (RH) and water soak (W.S.), 30 days.
\(^2\)Based on dimension or weight at 50 percent RH.
\(^3\)(-), fiber direction; (+), cross-fiber direction.

stability data for the boards are presented in Table 2. Comparisons of the effects of aligning the fibers and varying the configurations are illustrated in Figures 3 through 6 for certain properties.

Because of variations in specific gravities of the different boards, all of the strength values were adjusted by multiplying the test value by the factor

\[
\left( \frac{1.0}{\text{actual specific gravity}} \right)^3
\]

to permit a better comparison between configurations. The moisture content at time of test was approximately 6 percent for all specimens (equilibrium moisture content at 50 percent RH, 72°F).

Degree of Fiber Orientation

The properties of the hardboards were shown to improve in the fiber direction when the number of fibers with their length in this direction increased. The highly oriented aspen board was 89 percent stiffer in the direction of fiber alignment than was the random-formed control board. Improvements of 75 percent in tensile strength and 47 percent in bending strength were also noted. This highly oriented board showed a very significant reduction in linear movement in the fiber direction. It moved only 0.05 percent for a change in moisture conditions from 50 percent RH to water soaked, which was less than one-third the movement of its control board. Similar improvements were noted with the Douglas-fir boards. The homogeneous partially oriented boards were also more improved in these properties than were the control boards, but the improvement in the fiber direction was not as much as that for the highly oriented boards with greater fiber alignment.

Figure 3. - Relationship of modulus of elasticity (tensile) to quantity and location of oriented fibers of aspen and of Douglas-fir high-density hardboards. (A, highly oriented; B, partially oriented-one-half of fibers by weight were oriented; C, partially oriented, oriented fibers concentrated on surface layers, randomly oriented in center half; D, alternate layers oriented, fibers in adjacent layers perpendicular to preceding layer; and E, randomly oriented control board.)
The internal bond strength did not change appreciably. Thickness swelling and water absorption were slightly greater for the highly oriented boards.

With the greater amount of fiber alignment, the properties as expected decreased in the cross-fiber direction. The highly oriented aspen board, for example, had a 36 percent lower tensile modulus of elasticity in the cross-fiber direction than did the random-formed board. The highly oriented aspen board had an adjusted tensile modulus of almost 2 million psi which is in the high range of that for most clear wood species. The 1.5 million psi for the Douglas-fir hardboards was also in the range of common species used in structural lumber. These hardboard values were compared at a specific gravity of 1.0, higher than that for most common structural lumber species.

The ratios of cross-direction linear movement to fiber-direction linear movement of 10:1 for the Aspen and 6:1 for the Douglas-fir boards is similar to that reported for wood. This ratio should be indicative of the degree of fiber orientation that has been achieved. The ratios for strength and stiffness were not as great, which indicates that this particular phenolic resin binder may not be adequate for developing the inherent strength of the fiber.

The aspen boards were generally stronger and more stable than were the Douglas-fir boards. Although the
fibers were prepared in the same manner, the Douglas-fir fibers were shorter and coarser than were the aspen fibers, which may account for some of the differences noted in board properties (Fig. 1).

Surface Versus Homogeneous Orientation

This comparison was made by examining the board properties obtained with configuration “C” with only surface fibers oriented and “B” with partial homogeneous orientation (Fig. 2). In both, about 70 percent fiber orientation was achieved. Only the bending properties were consistently improved by placing the oriented fibers on the surface. As much as a 15-percent increase in bending modulus was noted. In the aspen boards tensile strength and modulus were higher for the surface-oriented boards, but the opposite was true with the Douglas-fir boards.

The internal bond strength was significantly higher for the aspen surface-oriented boards, but there was little difference between the two configurations for the Douglas-fir.

Very little difference was noted in dimensional movement between the two configurations especially in the fiber direction. In the cross-fiber direction, however, surface orientation gave better linear stability than did the homogeneous partially oriented configuration especially at the elevated moisture condition. Both of these partially oriented configurations had better properties in the fiber direction than did the random-formed boards.

Layers Oriented with the Major Fiber Direction Perpendicular in Adjacent Layers

Improved tensile properties were obtained by constructing boards of alternate-oriented fiber layers with the fibers perpendicular to those in adjacent layers. Bending stiffness, for example, in the principal direction of the top and bottom layers of oriented fibers was 15 to 20 percent higher, and strength was 10 percent higher. This was accomplished without a loss in cross-direction properties.

Linear dimensional stability, thickness swelling, and water absorption were comparable to the control configuration.

Conclusions

Wood fibers can be formed in various configurations to produce hardboards that will meet diverse specific engineered end-use requirements with strengths and stiffnesses in the range of solid wood. The greatest increase in properties for a direction is obtained by orienting most of the fibers in this particular direction with the increase proportional to the percent of the total fibers aligned in the direction. When comparing the two partially oriented configurations, concentrating the aligned fibers on the two surfaces improves the bending stiffness in that direction but does not significantly affect the other properties.