Strength properties of optimally designed rectangular composite wood joists

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Abstract

Mechanical and physical properties of composite wood panels were determined and used to design rectangular joists, each consisting of two outer layers (flanges) to carry tension and compressive stresses and a center region (web) to carry shear load. By controlling density, flake alignment, and particle type in the flanges and webs, joists were designed to duplicate properties of solid-sawn wood joists or to provide the maximum stiffness-to-weight ratio. The designed joists were fabricated using a three-component forming process. Flange and web mat height differential was controlled by choosing appropriate flake and fiber mixtures for the web. Actual stiffness of the joists as measured in bending tests was between 60 and 95 percent of design values and strength was 53 to 82 percent of design values. Differences between the measured and design properties were attributed to poorly controlled placement of flange material, density distribution, and flake alignment in the composite structure.

The reconstituted wood industry, which supplies particleboard for furniture core stock, has expanded into the structural panel market. The natural evolution of the production of underlayment to the production of mobile home flooring and decking has been followed by the development of flakeboard panels for roofs, walls, and floors of light-frame construction. Technological improvements in flaking, gluing, pressing, and particle orientation are now being directed toward fabrication of composite joists and beams. Reconstituted material is being used commercially as web members in componentized I-joists (8) and flat joists (7) with either veneer or solid lumber flanges. A reconstituted joist that is rectangular, uniform in density, and constructed entirely of strands made from waste veneer, has recently been introduced into the marketplace (10).

The performance of reconstituted products made entirely from flakes compares favorably to that of solid lumber or peeled veneer when proper fabrication techniques are combined with basic engineering design (4,6). Geimer and Lehmann (5) showed the feasibility of producing an I-beam entirely from reconstituted wood. Although the flange and web were constructed of different flake or particle types, the density of this product was relatively uniform throughout its cross section.

This study investigates the fabrication of rectangular composite joists with different types of flakes or fibers using the same structural concepts embodied in I-shaped sections. The two outer layers (flanges), which carry tension and compressive stress, are connected by a central region (web), which predominately carries shear loads. By varying the density, alignment, and type of material in the flanges and web, the properties of certain flake geometries are used to full advantage and wood resources are used economically.

Research plan

The objectives of this study were to experimentally evaluate the strength and stiffness properties of composite wood joists whose flange and web components were designed and fabricated to provide a) optimum stiffness-to-weight ratios; and b) bending stiffness equivalent to that of solid-sawn lumber. In addition, we explored forming and pressing techniques suitable for the manufacture of composite wood joists.

Three flake types differing in geometry were used as flange material for the joists. A mixture of ring flakes and fiber was used for the web. All material was Douglas-fir. Preliminary studies provided the basic relationships between board properties and the variables of particle geometry, flake alignment, and board specific gravity (SG) needed to design the joists.

The 1.5-inch-thick by 102-inch-long joists were constructed in pairs (Fig. 1) by simultaneously depositing both flange and web material on the caul. The joists were tested for bending properties using three-point loading and sub
sequently segmented to provide strength test specimens for the individual web and flange components.

**Design**

Design of the composite joists considered flange tension and compression properties, web shear properties, flake alignment, and restrictions on mat height and specific gravity. The composite joists were optimized in two ways: 1) by maximizing bending stiffness-to-weight ratio; or 2) by matching the properties of the joists to the properties of Douglas-fir solid-sawn lumber.

**Constraints and criteria**

**Fabrication characteristics**

**Joist size and specific gravity.** – Design was limited to two joist sizes – 1.5 by 9.25 inches and 1.5 by 11.25 inches – corresponding to nominal 2 by 10 and 2 by 12 lumber.

For design purposes, SG (based on oven-dry (OD) board weight) was limited to a maximum of 0.90, with the assumption that higher values would result in "blows" during pressing. SG was assumed to be constant throughout the web or flange areas. In reality, there was a narrow zone where SG changed between flange and web. In addition, a density gradient existed in the thickness plane as is the case with most conventionally pressed boards.

**Flanges.** – Three Douglas-fir flake types, all 0.02 inch thick, were used as flange material: 1) 0.5- by 7-inch flakes produced on a Turner lathe flaker; 2) 0.5- by 3-inch flakes cut on a disk flaker; and 3) random-width by 1-inch-long flakes cut on a ring flaker. Individual joists contained only one flange flake type.

The joist flanges were to be fabricated with a high degree of flake alignment. Sonic velocity ratios and bending modulus of elasticity (MOE) ratios indicated 70 percent alignment was possible for Turner and disk flakes and 50 percent alignment could be obtained for ring flakes (MOE ratios of approximately 10:1 and 5:1, respectively (3)). Although the flakes of most commercial oriented strandboards (OSBs) are aligned to a lesser degree (approximately 33%, corresponding to an MOE ratio of 3:1), laboratory experience suggests that the 70 percent alignment level is feasible (2).

Weds. – Bulk density of the web was controlled by varying a mixture of nonoriented Douglas-fir ring flakes and fibers. The difference between web mat height and flange mat height was limited to 2 inches. This restriction was initially imposed to keep the web and flange areas discrete during both forming and pressing operations when different materials were used in these layers. Mat height is a function of board or “design” density and material bulk density. For a 1.5-inch-thick board, the relationship between web and flange mat height is defined as:

\[ WD/WB \times 1.5 = (FD/FB \times 1.5) \pm 2 \]  

where:

\[ WD = \text{web design density} \]
\[ WB = \text{web bulk density} \]
\[ FD = \text{flange design density} \]
\[ FB = \text{flange bulk density} \]

and the allowable maximum difference between web and flange mat height is 2 inches.

Web bulk density parameters can be determined by transforming Equation [1]:

\[ WB = \frac{WD}{[(FD/FB) \pm 1.333]} \]  

Bulk densities were obtained by forming the materials into a vibrating 12-by 12-inch box to a depth of 12 inches. The motion simulated vibration that occurs on the forming line. Bulk density for flange flakes and selected mixtures of web materials is given in Tables 1 and 2, respectively.

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**TABLE 1.** – Mechanical and physical properties of flanges.

<table>
<thead>
<tr>
<th>Flake type</th>
<th>Furnish bulk density</th>
<th>Target alignment</th>
<th>Board OD-SG</th>
<th>Bending MOE</th>
<th>Tension MOE Strength</th>
<th>Compression MOE Strength</th>
<th>Interlaminar shear Modulus Strength</th>
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<tbody>
<tr>
<td></td>
<td>(pcf)</td>
<td>(%)</td>
<td></td>
<td>(psi)</td>
<td>(psi) (× 10^3)</td>
<td>(psi) (× 10^3)</td>
<td>(psi) (× 10^3)</td>
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<td>1.270</td>
<td>7.500</td>
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<td>4.920</td>
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**TABLE 2.** – Web design properties.

<table>
<thead>
<tr>
<th>Fiber content</th>
<th>Furnish bulk density</th>
<th>Web SG</th>
<th>Flange shear strength</th>
<th>Interlaminar shear Modulus Strength</th>
</tr>
</thead>
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<tr>
<td>(%)</td>
<td>(pcf)</td>
<td></td>
<td>(psi)</td>
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</tr>
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<td>1.050</td>
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<td>75</td>
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<td>100</td>
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<td>0.637</td>
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</table>

---

*From Geimer (2,3).
TABLE 3. – Regression constants and values for relationship of flange tension properties to specific gravity.\(^a\)

<table>
<thead>
<tr>
<th>Flake type</th>
<th>MOE (or maximum strength) = A(SG)(^b)</th>
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</thead>
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<tr>
<td></td>
<td>Regression constants</td>
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<td>Turner</td>
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<td>Disk</td>
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<tr>
<td>Ring</td>
<td>1.89</td>
</tr>
</tbody>
</table>

\(^a\)MOE (or maximum strength) = A(SG)\(^b\)

Estimated design properties

**Flange tension and compression properties.** – Table 1 relates the average mechanical properties of flange material to SG and flake alignment for all three flake types. Basic design data for the disk-cut flakes were available from published reports (2,3). Panels measuring 0.5 by 24 by 28 inches were manufactured and tested to obtain design data for the Turner and ring-cut flakes. The limited number of panels and test specimens does not provide a statistically valid estimate of properties, but serves as the basis for illustrating the design steps. Note that although the bending, tension, and compression moduli were comparable within a flake type, bending strength was higher than either tension or compression strength. This was attributed to the high degree of “yielding” material on the compression face of the bending specimen. Data on shear properties were useful in determining shear-related restrictions for a few homogeneous joists made entirely from flange material.

Tension modulus was used to approximate the axial stiffness of the flange material in a sectioned joist. The data in Table 1 were used to estimate the change in tensile stiffness and strength with SG. Regression constants developed from these data are given in Table 3. Average measured strength values from Table 1 were reduced by a factor of 3.30 to allow for 5th percentile adjustment (1.38) (coefficient of variation was assumed to be < 15% to estimate 5th percentile, with 75% tolerance on a normal population), load duration (1.61, safety factor (1.3), and size effects (1.15) (1). These factors are all derived for solid-wood members and are used here to illustrate the design technique.

**Shear properties.** – Test panels were made using various mixtures of nonoriented ring flakes and fibers at several SG levels to obtain shear design data. Shear properties are given in Table 2. Strength and stiffness decreased with decreasing SG and increasing fiber content.

Design criteria called for using the lowest density material that met shear strength requirements as well as differential mat height criteria. Using an empirical relation determined previously for ring flakes (3) in conjunction with a similarly derived relation for the fiber data in Table 2, rail shear strength for the fiber-flake mixture was estimated to vary with SG as follows:

\[
\text{Rail shear strength} = \left[\frac{4.684(SG) - 1.604}{100}\right] \frac{\text{percent flake}}{100} + \left[\frac{3.770(SG) - 1.130}{100}\right] \frac{\text{percent fiber}}{100}
\]

Values calculated from Equation [3] were divided by 3.30 to allow for 5th percentile adjustment, load duration, safety, and size (1). No reduction in shear was required for checks, shakes, or splits of composite joists as would be the case for lumber. Shear strength was assumed to have a value of zero at an SG of 0.34 and to increase linearly with SG as reflected in Equation [3].

**Required strength and stiffness values**

**Joist deflection.** – Deflection was limited to the span length (L) divided by 360 (L/360) determined using a live load. Shear deflection was found to contribute less than 6 percent of total deflection and thus was not considered significant in the design process.

As shown previously (6), the moment of inertia (I) of the central or web portion contributes less than 10 percent to the I value of the joist when the web is less than 70 percent of the joist depth. In our study, no flexural strength was attributed to the web for two reasons: 1) joists were designed using a relatively low stiffness material for the web; and 2) the web material was usually less than 70 percent of the joist depth. This assumption produced a small, but conservative, design error.

**Design equations.** – The sectioned joists were designed to the maximum allowable values for flange modulus (E), flexural strength (F\(_b\)), compression perpendicular to alignment (F\(_c\)) (bearing compression), and in-plane shear (F\(_v\)). The following equations provide the relationship between joist geometric properties, applied loading, and span. For deflection (stiffness) control:

\[
EI_f > 4.69w_1L^3
\]  

[4]

For flexural stress:

\[
F_b > wL^2d/(16I_f)
\]  

[5]

For compression perpendicular to alignment (bearing):

\[
F_c > wL/2b x
\]  

[6]

For in-plane shear:

\[
F_v > 3wL/4bd
\]  

[7]

where:

- \(b\) = width of joist cross section (1.5 in.)
- \(d\) = depth of joist cross section (9.25 or 11.25 in.)
- \(I_f\) = moment of inertia of joist flange around an axis through the center of the joist, parallel to the narrow face
- \(w\) = force per unit length, live and dead load
- \(w_1\) = force per unit length, live load only
- \(x\) = bearing length on support (assumed to be 2 in.)

**Optimization**

Optimal joist design called for determining maximum
stiffness-to-weight ratios for two joist depths: 9.25 and 11.25 inches. We also designed joists to match the flexural stiffness of No. 2 Douglas-fir 9.25-inch joists. In addition, several homogeneous joists were made from each of the three flake types.

**Maximum stiffness-to-weight ratios**

The objective was to optimize the bending stiffness-to-weight ratios of the joists within the structural and fabrication design constraints. Bending stiffness rather than strength was optimized because stiffness is usually the controlling factor for long-span joists. Our analysis showed that all joist designs were optimized when flange SG was maximized at 0.90. In theory, maximum density is not optimum for a flange component of a joist in certain situations. For example, maximum density would not be optimal if the web SG exceeds that of the flange. This condition is plausible for very short shear-critical joists. Maximum density may also not be optimal when stiffness does not increase proportionately with density. Considering that the flange is at 0.90 SG, the optimization becomes an iterative procedure: the depth of the flange is chosen, the minimum web density providing the needed shear capacity is computed, and the stiffness-to-weight ratio of the joist is calculated. Through several iterations, this optimization routine would select flange depths that satisfy the criterion of interest (in our analysis, maximum stiffness-to-weight ratio). At each iteration, the appropriate strength and stiffness criteria (Eqs. [4] to [7]) need to be checked to assure adequacy for the particular design. Further development of the optimization process is described by Laufenberg (6).

Figure 2 shows stiffness-to-weight ratio compared to flange depth for three flange SG levels of the 9.25-inch joist. Data describing the joists at the optimized points in these curves are given in Table 4. At a flange SG of 0.90, optimized joist SG was similar for all flake types; the SG averaged 0.72 or nearly 1.5 times that of Douglas-fir lumber (SG 0.5). Turner flakes had design stiffness-\( (EI) \) to-weight ratios that were double that of the ring flakes. Maximum design flange modulus (\( E \)) (at 70% alignment and 0.90 SG) of Turner flakes was \(3.6 \times 10^6 \text{ psi} \), or twice that of Douglas-fir lumber (\(1.7 \times 10^6 \text{ psi} \)) (9). However, the ring flake material had only 88 percent of the modulus of Douglas-fir lumber according to these calculations.

All the joists were originally designed for long spans; 20 feet for nominal 2- by 10-inch joists and 24 feet for nominal 2- by 12-inch joists. However, the processing equipment limited the joists to a maximum trimmed length of 8.5 feet. Structural testing of the joists was thus scheduled for a 90-inch span, and web density was increased in most cases to account for the increase in shear stresses accompanying this span.

In practice, the density of the flange might be a limiting factor, not only in fabrication but also in use; for example, fastenings may be difficult to install. For joists optimized for stiffness-to-weight ratio, we arbitrarily decided to target flange SG to 0.75. This specification was adhered to in designing both nominal 2- by 10-inch and 2- by 12-inch joists in addition to joists made with homogeneous flakes. Flange SG of joists designed with properties of solid-sawn lumber was 0.90. Final design data for all joists are given in Table 5.

**Equivalent Douglas-fir lumber design**

Initial analysis showed that flexural stiffness, not flexural strength, controlled flange design. Design specifications for the joists with properties equivalent to those of Douglas-fir lumber were optimized with maximum flange density, as was the case with the maximum stiffness-to-

![Figure 2](image-url)
weight joists. However, for the lumber-equivalent joists, we chose to fabricate the flanges to the maximum design SG of 0.90. Flange depths were chosen to obtain a predicted bending MOE of \(1.7 \times 10^6\) psi, the value for No. 2 Douglas-fir specified by the National Forest Products Association (9). Joists optimized previously for stiffness-to-weight ratio with the ring flakes at 0.90 SG were below the MOE design value for Douglas-fir (Table 4). Thus, joists made with this flange furnish were designed to obtain an MOE of \(1.1 \times 10^6\) psi, equivalent to the MOE of Englemann spruce (9).

Because the design stiffness value is fixed, the web shear strength necessary to obtain this MOE is also constant. For joists made with Turner and disk flakes, the minimum design value for rail shear strength was calculated to be 68 psi; this value was obtained after applying duration of load, 5th percentile adjustment, and margin of safety factors. For the joists made with ring flakes, the minimum design value for web shear strength was 42 psi. Minimum web density and fiber proportion necessary to provide shear strength and to meet the design restrictions for mat height are given in Table 5. Based on our experience in fabricating the joists made with the other flake types, we changed the original web design specification for joists made with Turner flakes from 70 percent fiber to 30 percent fiber. The web SG was not lowered accordingly.

<table>
<thead>
<tr>
<th>Flake type</th>
<th>Design specifications</th>
<th>Measured properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turner</td>
<td>0.69 0.75 3.125 0.55 3.0 70 3,100</td>
<td>9,500 890 0.643 2,167 7,760 670</td>
</tr>
<tr>
<td>Disk</td>
<td>0.65 0.75 2.875 0.49 3.5 20 2,000</td>
<td>8,840 610 0.627 1,675 6,372 530</td>
</tr>
<tr>
<td>Ring</td>
<td>0.63 0.75 2.750 0.44 3.75 10 1,300</td>
<td>6,110 410 0.609 910 3,247 290</td>
</tr>
</tbody>
</table>

**Fabrication**

The procedure for fabricating the composite joists involved blending the flakes with adhesive, forming the joist, and pressing the mats.

**Blending**

With the exception of the Turner flakes, all furnish was spray-blended with 5 percent phenolic adhesive; 7 percent phenolic resin was applied to the Turner flakes. Flakes were blended with adhesive in a 6-foot-diameter by g-foot-long rotating drum blender. The adhesive was applied through four air-atomized spray heads. Target moisture content after blending was 10 percent based on oven-dry furnish. Addition of a small amount of ring flakes to the web fiber furnish (30% ring flakes for joists made with Turner flake flanges) vastly improved handling characteristics and prevented the material from balling up in the blender.

**Forming**

Joists were fabricated in pairs (Fig. 1) allowing for 2.5 inches of trim on the long edges and a sawkerf through the central flange portion. A forming machine was used to fabricate those joists with flanges made from disk or ring flakes (Fig. 3). A splitting device installed on the forming machine served to separate the material into the appropriate volumes prescribed for the two outer areas (single flange with trim) and the single inner area (double flange with trim).
Uneven distribution of material across the width of the flange areas, caused by crowding the furnish into narrower paths in the forming machine, was smoothed out by the reciprocating action of the alignment plates. The web material was manually felted through a screen placed adjacent to the flake aligner. The screen was blocked off over the flange areas. No more than 0.5 inch of flange flake material was deposited in a single pass, to allow manual formation to keep pace with the machine. Much less web material was needed to maintain a level mat than we had anticipated. Utilization of the web furnish was hampered by a slight tendency for the flange material to slough down into the web area and a strong tendency for the fibrous web material to adhere to the edge of the flange material. We therefore decided to reduce the fibrous material in the web portion of joists made with Turner flake flanges from 70 to 30 percent. After a few joists had been made, we decided to replace the unused fins in the web portion of the alignment machine with curved wooden blocks. The vibrating action of the alignment machine consolidated the mat and kept the fibers in the web section at a height equal to that of the flange material. Final mat height varied with joist design and ranged between 12 and 14 inches.

A special forming device was designed for felting the 7-inch-long Turner flakes. The device consisted of a finned box with a tapered exit chute on one end. Flakes manually dropped into the vibrating box were partially aligned by the fins; the flakes were further aligned when the entire assembly was tipped and the flakes were moved by gravity through the narrower exit channel. To form the double-joist panel, 1.5-inch-thick spacers, cut to design width of the webs, were positioned on the caul plate in the web sections. Flange material was then laid down as the mat moved underneath the vibrating former (Fig. 4). When the flange material had been built up to the top of the lumber spacers, the spacers were removed and the voids filled with web material. The web material was manually felted through a screen as described. The 1.5-inch spacers were then placed on top of the web material, and the entire operation was repeated.

Pressing

The formed mats were pulled into the 5-by 9-foot press and pressed for approximately 25 minutes at 375°F. The press was closed in approximately 1 minute by using board pressure of 800 psi. Up to 14 minutes were required to arrive at a core temperature of 220°F. Additional moisture sprayed on the faces of the mat (Fig. 3) helped to reduce total pressing time to 20 minutes. No major delaminations occurred in any of the joists made with fiber-flake webs. The low density web areas proved to be efficient channels for releasing moisture. However, small separations occurred in the flanges of joists made with the Turner flakes. We suspect that some of these separations may have been due to degradation of the wood caused by exposure to high temperatures for long periods. However, chemical analysis of these sections showed no differences in cellulose or hemicellulose contents as compared to that of other nonaffected areas. The homogeneous joists fabricated with the Turner flakes, the equivalent solidsawn joists made with 0.90-SG Turner flake flanges, and the homogeneous joists made from disk flakes were all cooled to a core temperature below 212°F while still in the press.

Results

After the joists were pressed, they were cut to nominal dimensions (Fig. 5) and equilibrated to 80°F, 65 percent relative humidity. All the joists were tested to destruction using three-point loading on a 90-inch span. Results are shown in Table 5.

Effective bending properties of both the nominal 2-by 10-inch and 2- by 12-inch joists designed for optimum stiffness to weight were essentially comparable within flake types. Bending MOE of these joists was between 61 and 84 percent of design values, and bending strength ranged from 53 to 82 percent of design values. Optimized (stiffness-to-weight ratio) joists fabricated with the long
Turner flakes were characterized by MOE values of over $2 \times 10^6$ psi and MOR values well over 7,000 psi. Strength and stiffness decreased with decreasing flange flake length.

The MOE and MOR values of the optimized (stiffness-to-weight ratio) joists made with ring flakes were approximately half those of joists constructed with the Turner flakes. Stiffness-to-weight values of fabricated joists can be compared to stiffness-to-weight values of nominal 2-by 10-inch and 2-by 12-inch Douglas-fir lumber joists (671 and $993 \times 10^6$ in.³, respectively) (9). Optimized joists made with Turner flakes were characterized by ratios of 670 and $880 \times 10^6$ in.³, indicating that stiff wood composite joists can be designed without incurring large weight penalties.

One would expect that the ultimate strength of a joist designed for optimum performance would be randomly determined by either tension, compression, and/or shear failures. However, the joists were not likely to fail in shear because the web density of the joists was in most cases dictated by mat height restrictions and because the joists were consequently built to higher density levels than needed to provide design shear strengths. Shear failure was evident only in the two Turner flake joists optimized for maximum stiffness to weight. These joists withstood rather large loads.

Although the disk- and ring-flake joists designed for equivalency to solid-sawn lumber performed well, the low bending properties of joists constructed with Turner flakes are attributed to the narrow flange depth. Local variation in the 0.95-inch-deep flange caused one joist to fail in compression.

Following large-scale testing, the joists were cut and individual portions of the flange areas were subjected to bending, tension, and compression tests. Data from these tests (Table 6) did not indicate any major reductions in resin blending efficiency or poor bonding caused by long press times that would reduce joist performance. Bending values of the segmented joist flanges (accounting for any density differences) were comparable to those determined for the design boards (Table 1). No distinct pattern was observed in tension values of design boards compared to that of segmented joists. However, values of compression MOE were generally lower and those of compression strength higher for the samples from segmented joists compared to those properties measured for the design boards.

![Figure 5. Joists trimmed to nominal dimensions.](image)

![Figure 6. Density gradients (depth) of three-component joists. A. Joists designed equivalent to solid-sawn lumber. B. Joists optimized for stiffness-to-weight ratio.](image)

<table>
<thead>
<tr>
<th>Flake type and design parameters</th>
<th>SG</th>
<th>Bending MOE (× 10³ psi)</th>
<th>MOR (psi)</th>
<th>Tension MOE (× 10³ psi)</th>
<th>Strength (psi)</th>
<th>Compression MOE (× 10³ psi)</th>
<th>Strength (psi)</th>
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<tbody>
<tr>
<td>Turner flake</td>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Optimum stiffness-to-weight ratio</td>
<td>0.75</td>
<td>0.659</td>
<td>1,056</td>
<td>6,180</td>
<td>1,173</td>
<td>3,750</td>
<td>788</td>
</tr>
<tr>
<td>Equivalent to solid-sawn lumber</td>
<td>0.90</td>
<td>0.730</td>
<td>938</td>
<td>4,980</td>
<td>1,012</td>
<td>2,300</td>
<td>637</td>
</tr>
<tr>
<td>Homogeneous flakes</td>
<td>0.75</td>
<td>0.742</td>
<td>1,192</td>
<td>7,697</td>
<td>1,241</td>
<td>3,997</td>
<td>937</td>
</tr>
</tbody>
</table>
Reduced flange density caused by movement of the flange material to the web area during forming and pressing accounted for reduction in bending properties of the three-layer joists designed as equivalent to solid-sawn lumber (Fig. 6A). This movement or shifting of the materials from the flange area to the web area had less effect on bending properties in those joists with deep flanges (Fig. 6B). Alignment of the flange flakes was not measured. Lateral flake movement and an intermixing of flange and web material would reduce effective flake alignment.

Concluding remarks

Reconstituted wood joists (8-ft.-long nominal 2- by 10-in. and 2- by 12-in. lumber) were designed either to yield maximum stiffness-to-weight values or to match the performance of similarly sized solid-sawn lumber components. The optimization analysis was based on the properties of test specimens cut from small laboratory boards. Flake type, density, flake alignment, and depth were considered in designing the flanges to carry the tension and compression loads. Optimization included an assessment of web density for fiber-flake mixtures to provide adequate shear strength and to achieve the proper match between web and flange bulk mat heights.

Fabrication techniques were devised to permit adjacent deposition of two furnishes differing greatly in bulk density. Mixing flakes with the fibrous web material improved the handling characteristics of this furnish. Although long press times were necessary, no steam delaminations occurred in the three-component joists. The low density web zones acted effectively as channels for moisture release.

The bending MOE of all the joists fabricated in this study ranged between 60 and 95 percent of design values. The material properties of segmented joists were similar to the properties used in the design process. During forming and pressing, movement of flange material into the web area of joists fabricated with dense narrow flanges attributed to the reduced performance of these joists. By using long flakes for the flanges, we were able to fabricate stiff composite wood joists without incurring excessive weight.

Literature cited