STRENGTH AND PROCESSING PROPERTIES OF WET-FORMED HARDBOARDS FROM RECYCLED CORRUGATED CONTAINERS AND COMMERCIAL HARDBOARD FIBERS

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ABSTRACT

Recycled paper fiber recovered from our municipal solid waste stream could potentially be used in structural hardboard products. This study compares strength properties and processing variables of wet-formed high-density hardboard panels made from recycled old corrugated container (OCC) fibers and virgin hardboard fibers using continuous pressure during drying. The results show that panels made from OCC fibers had 3 times the strength and 2 times the stiffness of panels made from virgin hardboard fibers. For commercial hardboard, panels made from OCC fibers had 2.5 and 2 times the strength of standard and tempered hardboards, respectively, and for the American National Standards Institute (ANSI)/American Hardboard Association (AHA) standards, panels made from OCC had 5 and 3 times the strength of standard and tempered hardboards, respectively. Linear expansions for OCC fiber panels were similar to commercial standards, but expansions of panels made from hardboard fibers were about half those of commercial panels and panels made to ANSI/AHA standards. Mats formed with OCC fibers were slower draining, higher in initial consistency, and thinner than mats formed with hardboard fibers. The results indicate that fibers from OCC have strong potential for use in structural hardboard products.

In 1995, the U.S. Environmental Protection Agency (9) estimated there were 74 × 10^6 metric tons (82 × 10^6 short tons) classified as paper and paperboard in the municipal solid waste stream. Approximately 40 percent of this material was recycled, yet nearly (44 × 10^6 metric tons (49 × 10^6 short tons) were still landfilled. One opportunity to further use wastepaper is in industrial structural hardboard products. Hardboards do not have the same strict requirements for fiber cleanliness as paper products, but there are tough requirements for structural performance. If a portion of these waste fibers could be recycled into structural hardboards, then some of our natural resources would be saved while at the same time reducing landfill pressures.

Research efforts to recycle paperboard fibers into hardboards are not new. Steinmetz (6) investigated fibers from wax-coated corrugated containers as a partial or total replacement for virgin hardboard fibers in wet-process hardboards. He found that adding increasing amounts of fibers from wax-coated corrugated containers up to 100 percent increased bending strength 10 percent and stiffness 4 percent but decreased drainage rates 110 percent. Kruse (4) reported equivalent hardboard properties from a commercial trial where 20 percent recycled old corrugated container (OCC) fibers were added to virgin hardboard fibers. Adding OCC fibers reduced drainage rates and caused fractures in the mat during wet-pressing. Kruse concluded that OCC fibers could be added to the manufacturing system with minor adjustments to the process equipment. Yao (10) explored the properties of hardboards made from 100 percent municipal solid waste paper fibers. He investigated the effects of binder type, heat treatment, wax treatment, and using one screen compared with using two screens. He found that hardboards met or exceeded the commercial requirements for tensile strength, modulus of rupture, internal bond, and thickness swell. He

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TABLE 1. -Drainage rates, thicknesses, and consistencies of mats formed and pressed from hardboard and OCC fibers.

	Hardboard fibers	OCC fibers
Drain rate (mm/sec. (in/sec.))	22.6 (0.89)	6.7 (0.26)
Formed thickness (mm (in.))	44.3 (1.74)	19.1 (0.75)
Formed consistency (%)	11.7	16.5
Wet-pressed thickness (mm (in.))	15.6 (0.61)	6.5 (0.26)
Wet-pressed consistency (%)	48.9	47
Dry-pressed thickness (mm (in.))	2.92 (0.114)	2.69 (0.106)
Dry-pressed consistency (%)	100	100

also found that properties improved if screens were used on both sides rather than one side of the panel during drying.

When considering the use of recycled fibers in structural products, it is important to remember that the morphology of commercial hardboard fibers is different from that of fibers in recycled pulp. Press cycles may need to be modified to accommodate fiber differences. In the previously mentioned studies, the drying press cycle included a period of time when the pressure was reduced to vent steam. Gunderson (3), however, reported an increase in paper strength when constant pressure was maintained throughout the drying cycle (press-dried) compared to using intermittent pressure. Fiber-pulp yield has also been shown to strongly influence paper properties. McGovern et al. (5) showed that tensile strength and modulus of elasticity (MOE) increased as pulp yield decreased in press-dried paper made from hardwood fiber.

In this study, we determined how high-yield commercial hardboard fibers and low-yield OCC fibers affected tensile strength, tensile MOE, sonic MOE, and linear expansion when wet-formed and press-dried with constant pressure. Tensile and linear expansion properties of these experimental panels were compared with commercial data for standard and tempered hardboards. Drainage rates, mat consistencies, and mat thicknesses were determined for comparisons of processing variables.

EXPERIMENTAL PROCEDURES

FIBERS

Two types of fiber were used in this study, a high-yield virgin wet-forming hardboard fiber and a low-yield recycled OCC fiber. The hardboard fibers were obtained from Georgia-Pacific Corporation (Duluth, Minn.). They were not dried after processing and had a consistency (dry fiber weight/total water and fiber weight) of 45.9 percent. The fibers were a mixture of 90 percent hardwood (primarily aspen) and 10 percent softwood. The OCC fibers were hydropulped at the USDA Forest Service, Forest Products Laboratory (FPL), in Madison, Wis., from preshredded corrugated containers. An atmospheric refiner, set with a refiner gap of 0.26 mm (0.010 in.), was used to fiberize the OCC fibers. The OCC pulp had a freeness (8) of 623 mL and a Kajaani (Model FS-100, Kajaani, Electronics Inc., Finland) average fiber length of 2.09 mm (0.082 in.).

Typically, fibers in new corrugated containers have been chemically pulped to remove lignin from the fibers. Removing lignin lowers the fiber yield but results in more flexible, conformable, and bondable fibers compared with high-yield fibers. Recycled OCC fibers retain most of these properties.

FORMING AND PRESSING

A total of 12 wet-formed panels were formed, 6 with each type of fiber. The target thickness was 2.54 mm (0.1 in.) with a specific gravity of 1.0.

Fibers were mixed in water for 3 minutes at a consistency of 0.83 percent. Phenol-formaldehyde resin (GP 2378, Georgia-Pacific Corporation) was added to the water at 1.5 percent (based on dry fiber weight), and the slurry was mixed for 3 minutes. The pH of the slurry was reduced to between 4.5 and 5.0 with dilute sulfuric acid and then mixed for another 3 minutes.

The slurry was poured into a 510- by 510-mm (20- by 20-in.) forming box with additional water added to bring the slurry height to 380 mm (15 in.) or 0.72 percent consistency. The fiber mats were formed on a bronze screen, 2.0- by 2.35-wires/mm (52- by 60-wires/in.) pattern, by draining the water with a vacuum of 75 kPa gage pressure (22.2 inHg). Drain time was measured from the time the drain valve opened until the water level reached 50 mm (2 in.) above the forming screen. The thickness and weight of the formed mats were measured.

A screen similar to the forming screen was placed on top of the mat, then aluminum cauls 3.12 mm (0.125 in.) thick were placed on both the top and bottom. The total package, caul-screen-mat-screen-caul, was cold-pressed for 1 minute at 1.72 MPa (250 psi) to consolidate and dewater the mat. After pressing, the thickness and weight of the mat were measured.

The fiber mats were pressed with screens on top and bottom in a steam-heated press maintained at 170 ± 2°C (338 ± 3.6°F). The press closing rate was approximately 120 mm/minute (4.7 in./min.). Once the press closed, pressure increased from 0.70 MPa (100 psi) to 1.72 MPa (250 psi) within 6 seconds and was maintained for 10 minutes to ensure that the panels were dry. Optimizing press time was beyond the scope of this study. The dry panel thickness and weight were measured. **Table 1** lists all forming, wet-pressing, and dry-pressing data for the two types of fiber.

TESTING

SONIC MOE

The hardboard panels were conditioned at 22°C (72°F) and 50 percent relative humidity (RH) for 4 days before measuring sonic MOE. Panel thicknesses and weights were measured after conditioning.

A Metriguard stress wave timer (Model 239A, Pullman, Wash.) was used to measure stress wave times across the diagonals of each panel. The sonic MOE (E) was calculated using the following formula:

$$E = (V^2)\,(d)\,(c)\,(1/g)$$

where:

E = sonic MOE (GPa (psi))
V = velocity (m/sec. (in/sec.))
d = density (kg/m^3 (pci))
c = conversion factor (N/kg (1))
g = gravitational constant (m/sec.^{2} (in./sec.^{2}))

TENSILE AND LINEAR EXPANSION TESTS

Tensile strength, tensile MOE, and linear expansion were determined using American Society for Testing and Materials (ASTM) Test Method D1037 (2). Two tensile and two linear expansion specimens, each oriented perpendicular to one another, were cut from each panel.

Linear expansions were measured at equilibrium conditions going from 26.5°C (80°F) and 30 percent RH to 26.5°C (80°F) and 90 percent RH.

RESULTS AND DISCUSSION

PROCESS

Drainage rate. — Drainage rates of the two fiber types were significantly different as expected. Hardboard fibers drained more than 3 times faster than the OCC fibers **(Table 1).** Hardboard fibers, often present in fiber bundles, are high-yield lignin encased. Lignin stiffens the fiber structure. These stiffer fibers and fiber bundles form a low-density fiber network that allows water to flow easily through it. By contrast, the recycled OCC fibers are low yield or essentially lignin-free, which makes them more flexible and conform more easily into a denser fiber network. The denser fiber network restricts the flow of water. The differences in fiber-network compactions are evident in mat thickness where mats with hardboard fibers were 2.3 times thicker than those formed with OCC fibers **(Table 1, Fig. 1).**

Mat drainage rates are good indicators for adjusting wet-pressing rates, particularly when different fibers are being pressed. If the drainage rate for the mat decreases, but the wet-pressing rate of the press remains the same, there is potential for internal damage to the mat from high internal hydraulic pressure. Kruse (4) noted this problem when OCC fibers were added to hardboard fibers. Similar problems occur in the paper industry where slow draining pulps exhibit internal sheet tearing, called crushing, from excessively fast pressing rates. The slower the drainage rate, the slower the wet-pressing rate should be to prevent internal mat damage. For this study, we decreased the press-closure rate to accommodate the slower water flow through the OCC fiber network.

The slower drainage rates and the reduced wet-pressing rates for OCC fiber will lengthen production schedules compared with those for hardboard fibers and will need to be considered when designing a new or re-engineering an existing production line.

Mat thickness and consistency. —The effects of hardboard fibers and recycled OCC fibers on mat thicknesses and consistencies are listed in **Table 1** and shown in **Figure 1.** Hardboard fibers formed mats 2.3 times thicker than OCC fibers, 44 mm (1.7 in.) compared with 19 mm (0.75 in.), respectively. The thicker mats held 5,390 mL of water (11.7% consistency) compared with 3,610 mL water (16.5% consistency) by the OCC fiber mats.

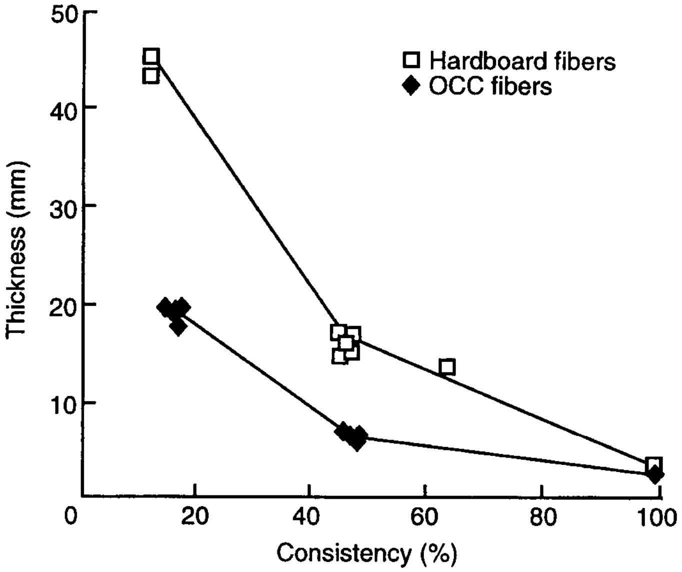

Figure 1. —Thickness compared with consistency of mats of hardboard and OCC fibers after forming, wet-pressing, and dry-pressing into hardboard panels.

After wet-pressing, the hardboard fiber mats were thinner, but still 2.4 times thicker than the OCC fiber mats, 16 mm (0.62 in.) compared with 6.6 mm (0.26 in.), respectively. The hardboard fiber mats were thicker because hardboard fibers are stiffer and contain more fiber bundles, thus producing a network of “simply supported beams,” which results in greater spring-back compared with the more conformable and flexible OCC fibers. Residual water in the mats after wet-pressing was similar for both fiber types where consistencies were between 47 and 49 percent.

After hot-pressing, hardboard fiber panel final thickness was 2.92 mm (0.114 in.) and OCC fiber panel final thickness was 2.69 mm (0.106 in.). The OCC fibers produced denser panels because the fibers were more flexible and conformable than hardboard fibers. This can be seen in **Figure 2a** where OCC fibers are collapsed and conformed to adjacent fibers to form a dense fiber network. **Figure 2b** shows that some hardboard fibers did not collapse (fibers with open lumens) under pressure and the fibers appear to have formed a less dense fiber network.

Overall thickness, from formed mat to dry panel, decreased by a factor of 15 for the hardwood fibers and by a factor of 7 for the OCC fibers. Mat thicknesses for both fiber types decreased by a factor of 3 from the initially formed to the wet-pressed mat thickness. From wet-pressed mat to dry panel, mat thickness decreased by a factor of 5.5 for the hardboard fiber and by a factor of 2.5 for the OCC fibers. Thickness change information has implications for various process and design parameters. For example, if OCC fibers were used instead of hardboard fibers to make panels, the open distance between press platens could be decreased and then several more platens could be added without altering the dimensions of the overall press frame. Adding more platens has the potential for increasing production. Overall thickness change information is also useful when considering the design of complex three-dimensional shapes. For complex shapes, fiber consolidation is not always vertical, thus requiring that mating molds be designed to accommodate initial, wet-pressed, and final mat thicknesses.

The consistencies are provided for estimating the rates of water flow through the process and calculating energy requirements for drying.

PROPERTIES

Density plays an important role influencing both mechanical and physical properties of hardboards, and exact com-

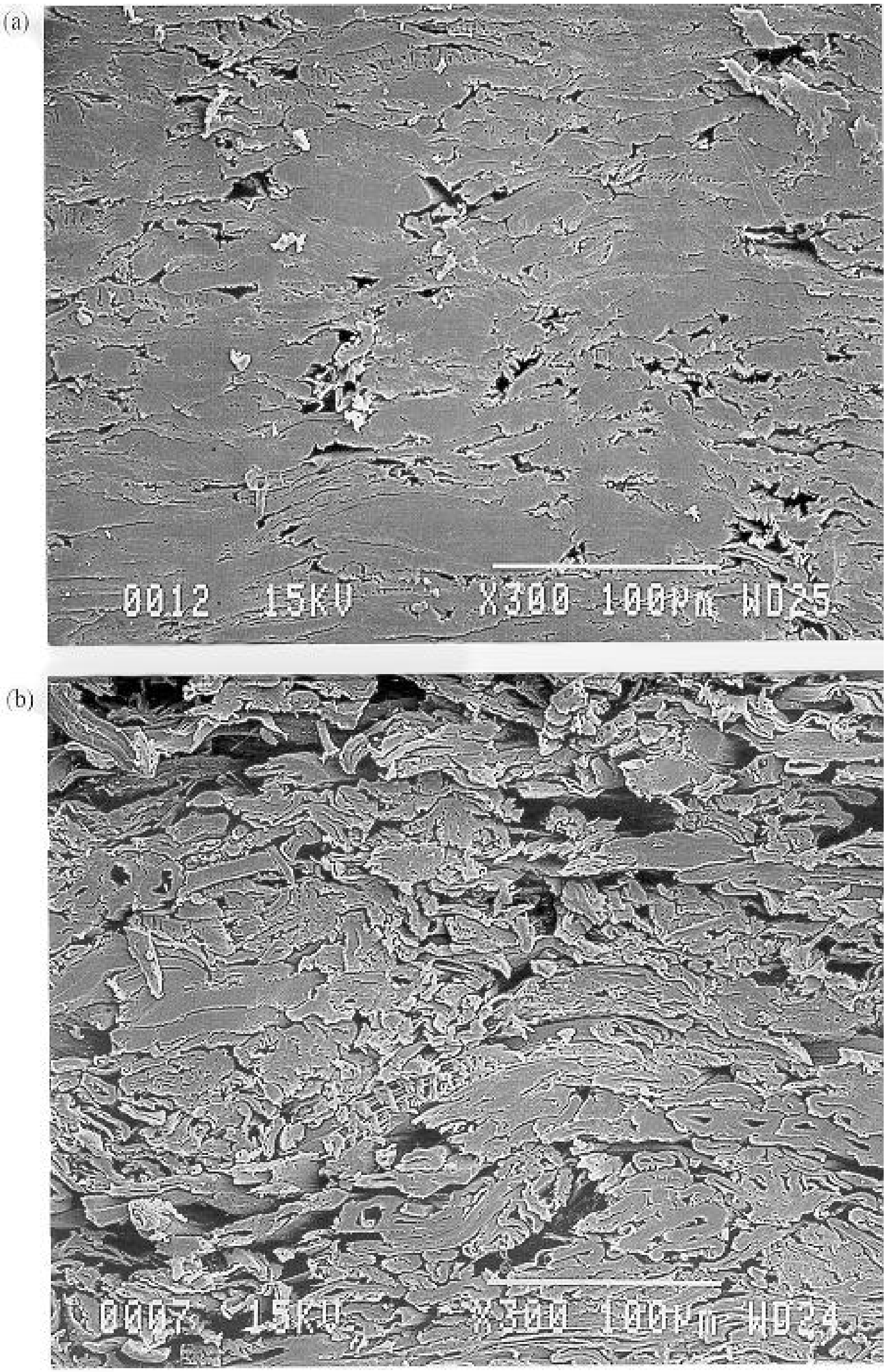

Figure 2. —Scanning electron micrographs of edges of panels made from recycled OCC fibers (a) and commercial hardboard fibers (b).

parisons should be on an equal density basis. In this study, however, we chose to use the same processing conditions rather than to vary the process to achieve equal board densities. By using the same processing conditions, we were able to gain insights on fundamental fiber characteristics and processing differences. The same process conditions produced hardboards with slightly different densities but significantly different properties.

Tensile properties. — Tensile strength and MOE values clearly indicate that panels made from OCC fibers were stronger and stiffer than panels made from hardboard fibers **(Table 2).** The hardboard panels made from OCC fibers were only 16 percent denser than panels made from hardboard fibers but produced significantly stronger and stiffer panels. Panel strengths and MOEs were 26.3 MPa and 4.3 GPa for hardboard fibers and 74.7 MPa and 9.5 GPa for the OCC fibers, which were increases by factors of 2.8 and 2.2, respectively. Tensile strengths and MOEs are shown in **Figures 3** and **4,** respectively. One reason panels made from OCC fibers exhibited improved strength properties was because the fibers were more conformable **(Fig. 2a),** thus creating more fiber-to-fiber contact and increasing the potential for adhesive, hemicellulose, and lignin bonding.

Sonic MOE. — Sonic MOE was measured and correlated with tensile MOE. Results are listed in **Table 2,** and the correlation is shown in **Figure 5.** The regression slope is 1.07 for a Y-intercept set at zero with $r^2 = 0.97$. This high level of correlation indicates that sonic MOE could be used as a nondestructive, first approximation for tensile stiffness.

Linear expansion. — Linear expansion was higher for panels with OCC fibers than for hardboard fiber panels (0.27% and 0.19%, respectively). The difference is due in part to fiber morphology and density. The OCC fibers have been chemically modified and are more hydrophilic than the high-yield hardboard fibers; thus they expanded more when exposed to high relative humidity. Density also affects linear expansion. The panels made from OCC fibers are more dense with higher interfiber bonding, which means expansion of each fiber is more cumulative toward an overall dimension change.

Comparisons with commercial data and standards. — Tensile strengths of panels made with hardboard fibers were greater than minimum ANSI/AHA standards (1) for standard and tempered hardboards, equal to commercial data (7, p. 222-226) and less than commercial data for tempered hardboards **(Table 2, Fig. 3).** The OCC fiber panels, however, had approximately 2.5 and 2 times the tensile strength of commercial standard and tempered hardboard data, respectively. Compared with ANSI/AHA standard hardboards, the OCC fiber panels were 5 and 3 times stronger than standard and tempered hardboards, respectively. The OCC fiber panels were twice as strong as tempered hardboards.

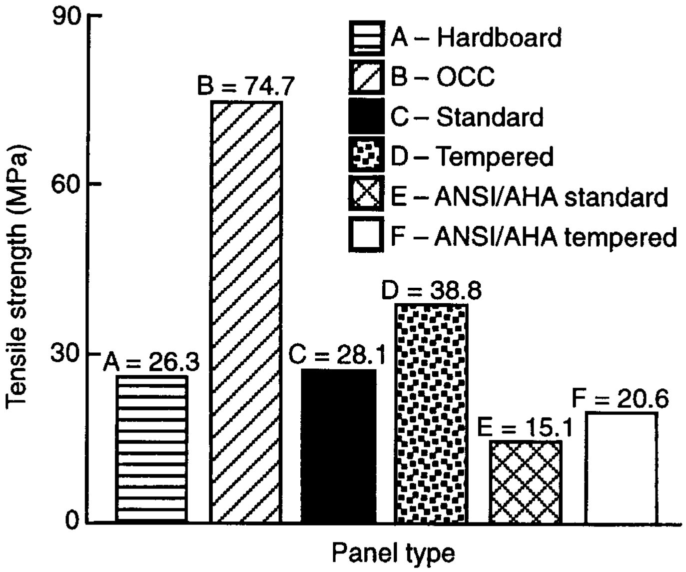

Figure 3. — Tensile strengths of experimental and commercial hardboard panels and minimum ANWAHA standards for hardboards.

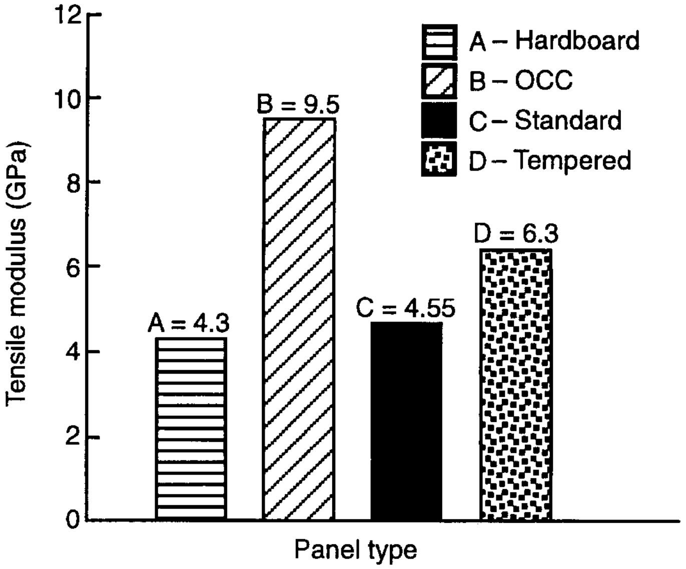

Figure 4. —Tensile MOEs of experimental and commercial hardboard panels.

Tensile MOEs for panels made from hardboard fibers were equal to commercial data for standard hardboards and one-third less than tempered hardboards. Tensile MOEs for panels from OCC fibers, however, were twice that of commercial standard hardboards and 1.5 times commercial tempered hardboards **(Table 2, Fig. 4).**

As mentioned previously, increased OCC fiber panel strengths and MOEs could be attributed to increased fiber-to-fiber contact of the lower yield fibers and continuous pressure during drying. McGovern et al. (5) reported similar tensile strengths and MOEs for press-dried paper made from high- and low-yield fibers.

Linear expansions of panels made from hardboard fibers were approximately 40 percent less than commercial tempered hardboards **(Table 2),** but panels made from OCC fibers equaled expansion of commercial tempered hardboards. The double-screen arrangement (top and bottom of mat) may have had an effect that reduced linear expansion of panels with hardboard fibers. As reported by Yao (10), water absorption decreased in panels made from municipal wastepaper fibers when panels were pressed with double screens.

None of the panels in this study contained waxes, nor were they tempered with oil and heat to improve their strength and resistance to water adsorption and dimensional change.

CONCLUSIONS

Hardboard panels made from OCC fibers exhibit superior strength and stiffness compared with panels made from virgin hardboard fibers and commercial standard and tempered hardboards. The authors understand that density influences properties and comparisons should be made at equal densities; however, the intent of this study was to examine properties at similar process parameters. The properties from the panels made from OCC fiber show the potential of recycled fibers to produce superior panels at reduced hot-pressing pressures. Future work will include comparisons at equal densities.

Continuous pressure during drying may influence bonding for OCC fibers more than hardboard fibers and may be the primary reason why OCC fibers produced panels with superior strength and stiffness. More work needs to be done to examine the effects of constant pressure compared with conventional breathing press cycles with different fiber types.

Low-yield OCC fibers form denser wet-fiber mats than do high-yield hardboard fibers. The denser OCC mat reduces initial drainage rates and water removal rates during pressing. Hardboard processing procedures, particularly wet-pressing, need to be modified to accommodate the slower drainage and water removal rates of OCC fibers. Increased production capacity may be possible due to the thinner OCC mats by allowing more openings per press frame in a multiple-opening press.

Fiber type has an effect on consistencies and wet-formed thicknesses. The forming effects of any fiber type must be characterized and are critical when designing three-dimensional structural panels as they relate to initial mold configuration, mold pressing configuration, and processing variables.

OCC fibers should be considered as a potential source of fiber for structural

TABLE 2. — Physical and mechanical properties of experimental and commercial wet-formed panels.

	Density	Tensile strength	Tensile MOE	Sonic MOE	Linear expansion 30% to 90% RH
	(kg/m^3 (pcf))	(MPa (× 10^3 psi))	- - - - - - - - - (Gpa (× 10^6 psi)) - - - - - - - - -		(%)
Hardboard	935 (58.4)	26.3 (3.81)	4.3 (0.62)	4.4 (0.638)	0.19
OCC	1,080 (67.4)	74.7 (10.8)	9.5 (1.37)	8.6 (1.25)	0.27
Commercial standard[a]	880 (54.9)	28.1 (4.07)	4.6 (0.66)	NA	NA
Commercial tempered[a]	950 (59.3)	38.8 (5.64)	6.3 (0.91)	NA	0.29
ANSI/AHA standard[b]	- -[d]	15.1 (2.20)	- -	- -	- -
ANSI/AHA tempered[c]	- -	20.6 (3.00)	- -	- -	- -

[a] From Suchsland and Woodson (7, p. 222-226); wet-formed 3.18 mm (1/8 in.) thick.
[b] From ANSI/AHA (1); wet-formed 3.18 mm (1/8 in.) thick.
[c] From ANSI/AHA (1); wet-formed 6.36 mm (1/4 in.) thick.
[d] - - = value not specified.

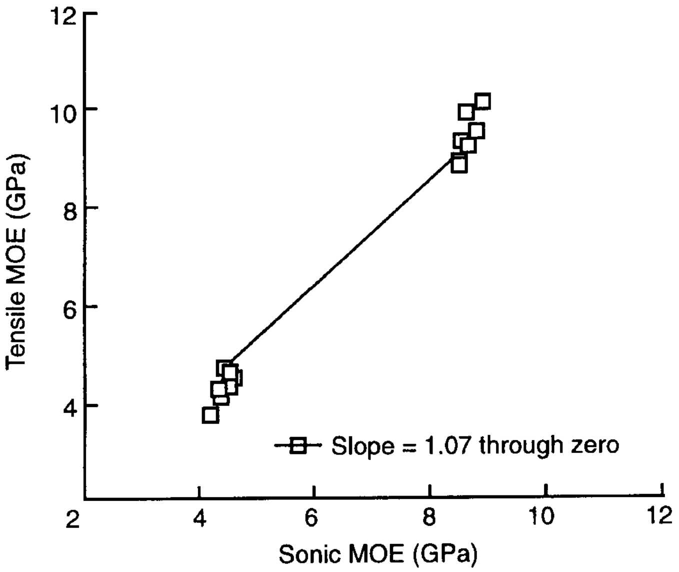

Figure 5. —Correlation of sonic MOE with tensile MOE.

hardboard products. More work needs to be done to determine if other recycled paper and paperboard fibers have similar tensile properties as OCC fibers. With improved closed water systems adapted from the paper industry, wet-formed hardboard panels made from pulp-type fibers may provide sufficiently improved performance properties to warrant change from dry-forming for some applications.

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