Relationship of fiber preparation and characteristics to performance of medium-density hardboards

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Abstract

Techniques of characterizing and processing wood fibers were investigated as a means of evaluating the effects of raw material manipulation on strength properties and dimensional movement of hardboard. Four species of wood, two hardwoods and two softwoods, were refined to four drainage rates. In addition to drainage rate, the resulting fiber was characterized by fiber length, Bauer-McNett screen fractionation, and scanning electron microscopy. Wet-formed, medium-density hardboards were prepared from the pulps and evaluated for static bending, internal bond, tensile strength parallel to the surface, and dimensional movement between 50 and 90 percent relative humidity (RH) and between 50 percent RH and water soak. Relationships between wood species, fiber characteristics, and hardboard performance were examined. There was considerable variation in response of strength properties and dimension change to changes in fiber drainage rate. No single drainage rate was found that would provide maximum strength and minimum dimension change for all four wood species.

Dimensional movement as relative humidity (RH) changes is a fact of life with hardboard, as with all wood and wood-base products. It is equally well known that heat treatment after hot-pressing will improve the strength, water resistance, and dimensional stability of hardboard. On the negative side, excessive heat treatment will make the product very brittle. The changes occurring in hardboard as a result of heat treatment have been described by Back and Klinga (2, 3, 7).

Adding other materials to hardboard fiber is another way to increase dimensional stability. Some high-density hardboards are “tempered” by adding various oils to the surface of pressed board, followed by a thermal treatment. Such treatment reduces water absorption, improves the strength properties, but makes the boards more brittle. Klinga and Tarkow (8) described the effect of acetylation of hardboard on its dimensional stability. Increased stability can also be achieved by using specifically formulated phenolic resin (5). Alternate procedures include the following: a) adding more resin to the fiber-mat surface or increasing the total resin content (19), or b) combining phenolic and thermoplastic resins (18). Glass fibers bonded to the hardboard surface will also increase stiffness and stability (18). With the exception of tempering, none of the other approaches listed above have been adopted by the hardboard industry because of cost or processing problems.

The effects of various wood characteristics and processing variables on hardboard performance have also been studied. Nelson (14) studied the properties of eight wood species and of pulps made from these species to determine their effects on medium-density, dry-formed hardboard performance. McMillin (11, 12) studied the interrelationships between gross wood characteristics, fiber morphology, and the physical properties of wet-formed hardboards made from loblolly pine. Wangaard (20) reported that wood from tropical species was inherently more stable than wood from U.S. species of the same specific gravity. A study conducted at the Forest Products Laboratory (FPL) found hardboards made from mixed tropical hardwoods to be more dimensionally stable than comparable hardboards made from domestic woods (13). Steinmetz and Fahey (19) found that wood species and the type of refiner used to process the fiber caused the greatest change in linear and thickness movement. Short, Woodson, and Lyon (17)...

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also reported that refining controls fiber size and shape and subsequently controls stability. Norberg and Back (15) have also shown that refining alters the fibers and affects the quality of board that can be produced.

Dimensional movement of hardboard appears to be controlled primarily by the raw material. Manipulation of the raw material or fiber processing might help minimize dimensional changes of hardboard with minimum cost to the manufacturer. Study objectives were 1) to better characterize the wood fibers intended for hardboard manufacture and 2) to attempt to control dimensional movement by raw material manipulation and/or fiber processing techniques.

Experimental materials

Four species, two hardwoods and two softwoods, were selected on the basis of wood fiber length and volumetric shrinkage from a green to an oven-dry condition (6, 23). Hardwoods were sweetgum (*Liquidambar styraciflua* L.) (1.7-mm fiber length, 15.8% volumetric shrinkage) and aspen (*Populus tremuloides* Michx.) (1.0-mm fiber length, 11.5% shrinkage). Softwoods were eastern white pine (*Pinus strobus* L.) (3.0-mm fiber length, 8.2% shrinkage) and southern yellow pine (*Pinus* spp.) (4.4-mm fiber length, 12.2% shrinkage).

Resin used in manufacturing all hardboards was a commercially available, high molecular weight liquid phenol-formaldehyde resin specifically developed for the manufacture of wet-process hardboard. A commercial acid-sensitive wax emulsion was also used for better moisture resistance and dimensional stability of the hardboards.

Procedure

Chip preparation

Three of the wood species arrived as roundwood and had to be peeled before chipping. Southern yellow pine was obtained as veneer cores. All four species were chipped separately in a commercial-sized four-knife chipper. The chips were screened, with fines and oversized materials discarded, before being placed in polyethylene-lined barrels and stored at 40°F until needed for fiberizing.

Fiber preparation

Chips were first fiberized in an 18-inch, single-disk pressurized refiner equipped with coarse plates. The chips were steamed for 10 minutes at 302°F, refined at the same temperature, blown from the refiner, and dropped into a polyethylene-lined barrel. Plate gap was vaned to produce fiber with approximately 15- and 25-second drainage rates. A 12-inch-diameter, single-disk atmospheric refiner equipped with fiberizing plates had to be used to obtain fiber with 50- and 75-second drainage rates. Heated dilution water was added to the fiber during atmospheric refining. This excess water was pressed from the fiber before it was fluffed and placed in polyethylene-lined barrels.

Fiber characterization

Four criteria were used to characterize the fibers. These tests were drainage rate, Bauer-McNett screen analysis, average measured fiber length, and fiber appearance using scanning electron microscopy.

Drainage rate is the time, in seconds, required for the water in a 10-liter fiber suspension (128 g per 10 L) to pass through a screen and draw 10 liters of air through the fiber mat formed on the screen (21).

The Bauer-McNett screen analysis is designed to measure the weighted average length of fiber by screen classification (22). A 10-gram (ovendry) sample of fiber is diluted with water and passed through a series of progressively finer mesh screens (20, 35, 65, and 150 mesh). The fiber retained on each screen is oven-dried and weighed. By substituting the weights into an appropriate mathematical formula, a weighted average fiber length can be calculated.

Average measured fiber length was determined by microscopically measuring the length of 200 to 400 individual fibers. A sample of fibers was dyed red and placed on a glass microscope slide, magnified, and projected onto a table for measurement. Actual measurement was accomplished by using two sensors (multiple electret microphones) placed along the table’s x and y axis, a stylus or cursor, and associated electronics (16). Output from the electronic equipment was transmitted to a computer, where the average fiber length and other statistics were calculated.

A sample from each of the pulps was examined and photographed at magnifications of 200 and 2000 times using a scanning electron microscope.

Hardboard manufacture

Enough fiber to make a 3/8- by 20- by 20-inch board with 45 pcf density was placed in a container and diluted with soft, cold water. While stirring the pulp slurry, 3 percent phenolic resin and 3/4 percent wax emulsion (percentage of ovendry fiber) were added and allowed to mix thoroughly before adding 1 percent alum and enough sulfuric acid to lower the slurry pH to between 3.5 and 4.0. Stirring was discontinued and the slurry poured into a 20- by 20-inch forming box, where the water was drained away and a fiber mat formed.

All fiber mats were pressed for about 1 minute at 100 psi in an unheated hydraulic press to compact the fiber and expel excess water. Final compaction and drying occurred with the mat held at 3/8-inch thickness in a 20- by 20-inch steam-heated platen press at 375°F for 50 minutes. All hardboards were subsequently heat treated for 1 hour in a 320°F convection oven.

Hardboard evaluation

Evaluations of static bending, tensile strength perpendicular to surface, and tensile strength parallel to surface were made after the hardboards were conditioned for 30 days at 50 percent RH and 73°F, using test procedures specified in ASTM Standard D 1037-72a (1). The only exception was dimensional stability, which was determined on 1/2- by 6-inch specimens conditioned for 30 days at 50 percent RH and 73°F, followed by exposure to one of the following conditions: 1) 90 percent RH and 80°F for 30 days, 2) immersion in water for 30 days, and 3) drying in an oven at 220°F for 72 hours. Length, thickness, and weight changes were determined before and after exposure to each condition.
Statistical analysis

A two-sample t-test, which did not pool variances, was used to test equality of measured fiber lengths. An analysis of variance was performed for each strength and dimension change test result to determine if any statistically significant differences between drainage rates were present. After establishing that several significant differences were present, Duncan's multiple range test was used to identify which drainage rates were significantly different.

Results and discussion

What happened to the fibers during refining?

A test had to be arbitrarily selected to monitor the amount of refining being performed on the fiber. Drainage, or freeness, of the pulp is commonly used in the fiber industry to guide machine operators during fiber preparation. Drainage rate was selected as a criterion here because it has been used for many years at FPL and elsewhere, the equipment necessary to run the test was available, and it is a fairly quick and easy evaluation to make. But is drainage rate the best way to characterize hardboard fiber? The test yields a number, in seconds, but reveals nothing more about the fiber.

Bauer-McNett screen classification is another well-established procedure that reveals more information about the fiber. The classification process divides the fibers by screen size, and it is possible to compare the percentages of each fraction against other fiber samples. Figure 1 shows that with increased refining, the coarse fraction decreased and the finest fraction increased, indicating that fiber bundles or fibers were being reduced to smaller particles. This was found for all species and was consistent with Clark (4), who reported that the main effect of refining was a reduction in fiber length and the production of debris. The percentages of fiber fractions can be substituted into a formula (22) to calculate a fiber length index number (presented at bottom of Fig. 1), which can be compared against drainage rate time.

Figure 1. – Bauer-McNett screen fractionation of aspen, sweetgum, white pine, and southern yellow pine fibers.
Microscopic measurement of individual fibers will provide an accurate determination of what happened to the fibers during refining, if enough are measured (Fig. 2). Many of the changes that occurred in fiber length as a result of refining were not statistically significant (letters in Fig. 2). With both softwoods, average fiber length was shortened with more refining. Average fiber length of aspen and sweetgum increased as draining rate increased from 15 to 25 seconds, but then decreased as refining continued. This phenomenon only occurred with the hardwoods, and the likely cause was the destruction of large vessel elements during refining. At a 15-second drainage rate many vessel elements were intact and measured along with the fibers. However, under the more severe refining conditions needed to produce a 25-second drainage rate, the vessel elements were converted into small pieces of debris, which were not measured. The longer fibers were essentially unchanged during refining from 15 to 25 seconds, which had the net effect of increasing average fiber length of the hardwoods. This characterization procedure yielded accurate information after many tedious measurements.

The three criteria for characterizing fibers are complementary. Drainage rate revealed that something had happened to the fiber with additional refining, which caused it to have greater water holding capacity. Bauer-McNett screen fractionation revealed that less coarse and more fine particles were generated as refining progressed. Fiber length index decreased as refining increased, and measured fiber length confirmed this. All procedures appear to measure the same parameters, but express them differently.

It was necessary to turn to scanning electron microscopy to see more definitively what was happening to the fiber as it underwent additional refining. Fibers were probably being broken, as illustrated by shorter measured fiber lengths. But what about the increase in fine material indicated by Bauer-McNett? Was all of this material small pieces of broken fiber or was some material being removed from the fiber surface?

All fiber furnishes were examined at three magnifications—200X, 1000X, and 2000X. Fibers subjected to the least amount of refining had many entire fibers and some fiber bundles present. Both hardwoods also had vessel elements present. As refining progressed, more broken fiber ends and fiber fragments became evident. Some of the fragments could be identified as broken cross sections, and others appeared to be fragments of the fiber walls (9, 10). It also appeared as though the fiber surface was being cleaned or polished by additional refining. At a 15-second drainage rate, many fibers have small pieces of material clinging to or peeling away from the fiber wall. This surface debris was probably fragments of the middle lamella or primary cell wall torn loose during fiber separation. With additional refining these materials appear to have been removed from the fibers, giving a much cleaner and smoother appearing surface.

Changes taking place on the fiber surface can be better observed at the higher magnifications. The cleaning or smoothing action to the fiber surface as a result of additional refining is better observed. It also becomes evident that additional refining was doing more damage to the fiber than just shortening length. Fiber walls were deteriorating as illustrated by missing pits, and many cracks and tears were becoming evident, especially in the southern yellow pine. Absent from every photograph was the fibrillation commonly found when refining chemical pulps for papermaking (10). Since the hardboard fibers were produced at high temperatures, fiber separation occurred in the middle lamella. This was evident on micrographs of all fibers by the presence of middle lamella corner ridges and shrinkage folds. Retention of the middle lamella-primary wall will prevent fibrillation of hardboard fiber with additional refining.

What happened to hardboard strength properties within a species?

Refining the fiber to slower drainage rates generally improved hardboard strength properties (Figs. 3 to 6). However, the effect of drainage rate on strength properties was not consistent from species to species, and to a much lesser extent, it was not consistent within a species.

For each species group, the strength properties were analyzed using an analyses of variance to deter-
mine if any significant differences existed. Results of this analysis showed that for each species group, statistically significant differences did exist between all strength properties except density and tensile strength perpendicular to the surface for sweetgum hardboards. (Dimension and weight changes will be discussed separately.) Given that statistically significant differences exist between strength properties, another statistical analysis, Duncan's multiple range test, was used to identify which strength properties were not significantly different within a species group. In Figures 3 through 6, means with the same letter within a species group are not significantly different at the 0.05 level.

The analyses revealed that significant hardboard density variations existed within all species, except sweetgum. As the fibers were refined to slower drainage rates, density increased for hardboards manufactured under identical forming and hot-pressing conditions. Apparently, the shorter fiber lengths and finer particles packed together more tightly, producing a higher density hardboard. Fearing this significant density variation might have affected the relationships between static bending properties, the modulus of rupture (MOR) and modulus of elasticity (MOE) values were divided by hardboard density. This manipulation did not change the results for an analysis of variance on static bending properties within a species.

Aspen hardboards became stronger as drainage rate increased from 15 to 22 to 50 seconds, and these increases were statistically significant. When refining was continued to a 76-second drainage rate, MOR and MOE increased slightly, but tensile strength parallel to surface and internal bond declined. No significant differences were found between the strength properties of 50- and 76-second drainage rate hardboards; therefore nothing more was gained by additional refining.

Sweetgum followed essentially the same pattern as aspen, with the notable exception of internal bond. All strength properties increased to reach their maximums at a 52-second drainage rate. When refining was continued to 76 seconds, all strength properties declined. Except for internal bond, strength increases for fiber refined to a 52-second drainage rate were statistically significant. Refining the fiber to a 76-second drainage rate resulted in no significant change in MOR, but did result in a significant reduction in MOE and tensile strength parallel to the surface. The differences in internal bond appear to be large and somewhat erratic (Fig. 6), but statistically they are not significantly different.

The strength properties of white pine responded most erratically in relation to different drainage rates. In general, the strongest hardboards were made from fiber having a 26-second drainage rate. Statistical analysis showed that refining white pine to a drainage rate slower than 26 seconds resulted in no significant change in most strength properties, or resulted in a significant reduction in tensile strength perpendicular to the surface (Fig. 6). More variation in strength properties existed within white pine than observed in any other species. Most of the variation can probably be attributed to problems encountered in manufacturing white pine hardboards. All of the hardboards made from 16-second drainage rate fiber were suitable for evaluation, but starting with the 26-second drainage rate hardboards, internal blows were revealed when the hardboards were cut into test specimens. Blows were never evident on any of the board exteriors. More refining only aggravated the problem. The slower drain-
Figure 5. – Tensile strength parallel to surface versus drainage rate. Means with the same letter are not statistically significant at the 0.05 level. Comparison of letters must be restricted to within a species. Numbers in parentheses are standard deviations.

Figure 6. – Tensile strength perpendicular to surface (IB) versus drainage rate. Means with the same letter are not statistically significant at the 0.05 level. Comparison of letters must be restricted to within a species. Numbers in parentheses are standard deviations.

age rate caused greater moisture retention and slower moisture diffusion during hot-pressing, resulting in internal blows. Subsequently, the number of sound test specimens that could be cut from the hardboards was diminished. Fewer test specimens and perhaps other undetected problems contributed to greater property variation.

Southern yellow pine was similar, but not identical, to the two hardwoods’ performances. Strength properties increased as fiber drainage rate became slower, except MOE, which declined slightly (Fig. 4). However, the statistical analysis indicated that strength properties of 77-second drainage rate hardboards were not significantly greater than those obtained for 52-second drainage rate hardboards. Once again, refining fiber to a drainage rate greater than 52 seconds resulted in a nonsignificant change in strength properties.

What happened to dimension change within a species?

Linear, thickness, and weight changes between 50 percent RH and 90 percent RH, and between 50 percent RH and water soak conditions were altered by a change in fiber drainage rate (Figs. 7 to 10). Unfortunately, the relationships between linear, thickness, and weight changes and drainage rate were much more variable than observed with strength properties and drainage rates. As an example, linear movement between 50 percent RH and 90 percent RH for aspen and white pine became greater as the drainage rate increased (Fig. 7). Sweetgum exhibited less linear movement under the same circumstances. and southern yellow pine remained fairly stable. Thickness and weight change was inconsistent within a species, as opposed to an overall increase or decrease in movement resulting from an increasing fiber drainage rate.

Within a species, many of the means were significantly different (Figs. 7 to 10), emphasizing the fact that changes in fiber drainage rate resulted in some significant changes in dimension and weight changes. This should not be surprising, as several authors had previously reported relationships between refining and dimension changes (15, 17, 19). It is also likely that the long pressing and heat-treating cycle had the greatest influence on dimension and weight changes, perhaps influencing one species more than another.

Several attempts were made to uncover possible relationships between raw material properties and dimension and weight changes. There was no apparent relationship between wood species or wood volumetric shrinkage and linear movement. There was, however, an apparent relationship between percent volumetric wood shrinkage and thickness change between 50 and 90 percent RH, and also between 50 percent RH and water soak. This relationship should be fairly easy to understand, since hardboard is generally considered to have a random fiber orientation in the x-y plane. A wood that underwent maximum shrinkage from a green condition and was further compressed during hot-pressing has the potential of large expansion upon moisture absorption, primarily in the thickness direction. Additional movement in the linear dimension should not occur in a randomly oriented board and was not detected.
Comparison of strength and dimension changes between wood species at the same drainage rate

Differences in hardboard properties are evident between species at the same drainage rate (Figs. 3 to 10). For each drainage rate grouping, the strength and dimension changes were analyzed using an analysis of variance to determine if any significant differences existed between species. The results of this analysis showed that for each drainage rate grouping many statistically significant differences existed between species and the properties. Given the existence of statistically significant differences between species, another statistical analysis, Duncan's multiple range test, was used to identify which species were significantly different within a drainage rate grouping. These results are presented in Table 1 and should be used in conjunction with Figures 3 through 10 to interpret the observed strength and dimensional change properties.

There were only four instances in which no significant differences existed between species within a drainage rate grouping. All of these occurred in static bending, within the 15- and 25-second drainage rate groupings. All of the other properties had significant differences between species. It should be noted that the effect of species on strength properties or dimensional change was not consistent within or between drainage rate groupings. An example of within-group variation can be found in the 25-second drainage rate grouping for MOE and tensile strength perpendicular to the surface (IB). Aspen and southern yellow pine are not statistically significant at the 15-second drainage rate for tensile strength parallel to the surface but are significantly different in the remaining three drainage rate groupings.

Several overall observations can be made from Table 1. There appear to be more significant differences between bending property means at the 15- and 25-second drainage rates than at the 50- to 75-second drainage rates. There are few significant differences in the tensile strength parallel to the surface means. Only one species was significantly different from the others in the 15-, 25-, and 75-second drainage rate groupings, but it was never the same species. There was much more of a species effect on tensile strength parallel to the surface in the 50-second drainage rate groupings.

Species obviously had an effect on the linear change of hardboard for both specimen exposure conditions. More significant differences occurred between species in the 15- and 25-second drainage rate groupings, with decreasing species effect as the drainage rate slowed. Species had its greatest effect on thickness change for all drainage rate groupings, for both specimen exposure conditions. Thickness swell was very much dependent on species and indirectly on the volumetric shrinkage from a green to oven-dry condition of the original woody material.

Is there an optimum drainage rate?

It is impossible to pick a single drainage rate that would provide optimum strength and dimensional stability for all four wood species. An optimum drainage rate will depend upon which property a manufacturer would like to optimize. For example, if a manufacturer...
was using aspen and wanted to make hardboard with maximum stiffness, he would refine the fiber to a 50- or 76-second drainage rate. Other strength properties would also benefit from such a move. However, linear and thickness change between 50 and 90 percent RH is much greater than the change obtained with 15- and 25-second drainage fiber, which is undesirable. Refining to a higher drainage rate also has some economic disadvantages: increased energy costs of additional refining, and a slower draining pulp, which would slow down the forming line. Final cost of the hardboard produced would be increased.

Figure 9. – Linear change (50% RH to water soak) versus drainage rate. Means with the same letter are not statistically significant at the 0.05 level. Comparison of letters must be restricted to within a species. Numbers in parentheses are standard deviations.

Figure 10. – Thickness change (50% RH to water soak) versus drainage rate. Means with the same letter are not statistically significant at the 0.05 level. Comparison of letters must be restricted to within a species. Numbers in parentheses are standard deviations.

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<th>TABLE 1. – Duncan's multiple range test grouping*</th>
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*Same letters indicate means are not significantly different. Comparison of letters must be restricted to a single property within a drainage rate.
Conclusions

Three of the criteria used to characterize fibers were complementary. Drainage rate, Bauer-McNett fiber length index, and measured fiber length described the same parameters but expressed them differently. Drainage rate was found to be the quickest and easiest fiber characterization test to perform. This procedure, however, should be complemented by others for more precise fiber description.

Scanning electron microscopy illustrates the fiber modifications measured by the other procedures. Quality, blister-free hardboards could not be made from white pine fiber processed to a drainage rate in excess of 25 seconds.

Refining the fibers to slower drainage rates generally improved hardboard strength properties. The relationship, however, was not consistent from species to species, and was even found to be inconsistent within a single species.

Linear, thickness, and weight changes between 50 and 90 percent RH were related to a change in fiber drainage rate. Unfortunately, the relationships were much more variable than observed between strength properties and drainage rates.

Thickness change appears to have been influenced by volumetric shrinkage of the wood used. None of the other hardboard properties were related to wood shrinkage or average fiber length of the wood.

There was significant board-to-board variation, which was accounted for in the statistical analyses. A single drainage rate could not be selected that would provide maximum strength and minimum dimensional change for all four wood species.

Literature cited