Characterization of fiberboard pulp

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Abstract

Fiberboard pulps were prepared from four species of wood (aspen, eastern white pine, southern yellow pine, and sweetgum), each refined to four drainage rates. These fiberboard pulps were characterized in five ways: 1) drainage rate, 2) screen classification, 3) pulp composition, 4) fiber dimensions, and 5) scanning electron micrographs of fiber surfaces and walls. Refining fiberboard pulps results in a slower drainage rate because the number of fiber bundles and intact fibers decreases, while the number of whole fibers, broken fibers, and fiber fragments increases. Refining shortens fiber length, but has little influence on fiber diameter. During mild refining, debris is removed from the fiber surface, but more severe refining splits and fragments the fiber wall. Results are presented in 10 figures.

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 (4,12). The hardwoods were sweetgum (Liquidambar styraciflua L.) (1.7-mm fiber length, 30-µm fiber diameter, 15.8% volumetric shrinkage) and aspen (Populus tremuloides Michx.) (1.0-mm fiber length, 19-µm fiber diameter, 11.5% shrinkage). The softwoods were eastern white pine (Pinus strobus L.) (3.0-mm fiber length, 30-µm fiber diameter, 8.2% shrinkage) and southern yellow pine (Pinus spp.) (4.4-mm fiber length, 40-µm fiber diameter, 12.2% shrinkage).

Procedure

Chip preparation

Three of the wood species arrived as roundwood and were peeled before chipping. Southern yellow pine was obtained as veneer cores. All four species were chipped separately in a commercial-sized four-knife chipper. Chips were screened, and all materials less than 6 mm or greater than 32 mm were discarded, before being placed in polyethylene-lined barrels and stored at 36°C until needed for fiberizing.

Fiber preparation

The chips were first fiberized in a 46-cm, single-disk pressurized refiner equipped with waffle pattern plates. The chips were steamed for 10 minutes at 150°C, refined at the same temperature, blown from the refiner, and dropped into a polyethylene-lined barrel. Plate gap was varied to produce pulp with approximately 15- and 25-second drainage rates. In order to achieve the other two drainage rates, a 30-cm-diameter, single-disk atmospheric refiner equipped with flat me-

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Dium pattern plates was used to obtain pulps with 50- and 75- second drainage rates. Disk clearance was adjusted in the refiner, a small quantity of pulp was run, and the drainage rate was checked to see if the desired amount of refining was performed. If not, the refiner disk clearance was changed, a small quantity of pulp passed through, and the drainage rate was measured again. Once the proper disk clearance was attained, enough pulp was processed for boardmaking. 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**

We selected five procedures from the many possibilities available for characterizing fiberboard pulps, to determine: 1) pulp drainage rate, 2) screen fractionation of the pulps; 3) counts of fiber bundles, whole fibers, and broken fibers in the furnish, 4) measured fiber length and fiber diameter, and 5) scanning electron microscope images of the fibers and fiber surfaces.

1. Drainage rate, which determines how quickly water will drain from a pulp sample, was measured in an Asplund Drainage Tester. A pulp slurry was prepared by dispersing a 128-g (oven-dried (OD)) pulp sample in 10 L of water. This slurry was poured into the Asplund Drainage Tester, and the time (seconds) required for the 10 L of water to pass through a 21.6-cm-diameter screen and draw 10 L of air through the fiber mat formed on the screen was measured (9). A 10-g (OD) pulp sample was diluted with water and poured into the tank with the coarsest screen. As the pulp slurry flowed through the instrument, each progressively finer screen removed a portion of the pulp. Pulp retained on each screen was oven-dried, weighed, and a percentage of the total sample was calculated. These percentages were used to calculate a weighted average length of fiber (Table 1).

2. Wet-screen fractionation was conducted in a Bauer-McNett Classifier (11). This instrument consists of four narrow tanks whose outlets are covered by a progressively finer mesh screen (20-, 35-, 65-, and 150-mesh wire). A 10-g (OD) pulp sample was diluted with water and poured into the coarsest screen. As the pulp slurry flowed through the instrument, each progressively finer screen removed a portion of the pulp. Pulp retained on each screen was oven-dried, weighed, and a percentage of the total sample was calculated. These percentages were used to calculate a weighted average length of fiber (Table 1).

3. Pulp composition (fiber bundles, whole fibers, and broken fibers) was determined by staining a 5-g pulp sample with red dye and placing a subsample of the stained pulp on a glass microscope slide. Slide contents were examined with a projecting microscope by observing the images projected onto a smooth surface. Magnification was kept low so that an entire fiber could be seen in the projected field. A dot was also placed on the smooth surface, and as the slide was slowly scanned, any fiber or part of a fiber which touched the dot was observed. A visual judgment was made to classify the subject as a fiber bundle, whole fiber, or broken fiber. These individual observations were recorded, and the percentages of total counts were calculated. The total number of counts made for each pulp sample ranged from 150 to 800.

4. Fiber length and diameter was also determined microscopically by measuring the length and diameter of 200 to 400 individual fibers. The same microscopic slides used for pulp composition determinations were magnified and projected onto a table for measurement. Actual measurement was accomplished by using two sensors (multiple electret microphones) placed along the measuring table's x and y axis, a stylus or cursor to audibly mark fiber boundaries, and associated electronics to transform the audible inputs into x and y coordinates and place the information in memory (8). Information stored in memory was transmitted to a mainframe computer, where individual, maximum, minimum, and average fiber dimensions were calculated.
5. Fiber surfaces from each pulp were examined and photographed with a Cambridge Mark 2A1 scanning electron microscope. Magnifications were 200, 1,000, and 2,000 times normal.

Statistical analysis

Two statistical analyses were run on several fiber characteristics (fiber index, fiber length, and fiber diameter).

1. Regressions of fiber characteristics on drainage rate were run for all pulps. These gave mathematical models by least squares, predicting the change in fiber characteristics to a controlled change in drainage rate. They also gave estimates of error ($R^2$) between the observed and predicted fiber characteristics.

2. A two-sample t-test, which did not pool variances, was used to test equality of fiber characteristics.

Results and discussion

Drainage rate

Some criterion was needed to monitor the amount of refining during fiber preparation. The fiber industry routinely uses pulp freeness to guide machine operators during fiber preparation. Drainage rate was an obvious choice because it has been used for many years at the Forest Products Laboratory, and the evaluation is fairly quick and easy to make in a laboratory.

![Figure 1. Bauer-McNett screen fractionation of aspen, sweetgum, white pine, and southern yellow pine fibers.](image)

Unfortunately, this evaluation reveals little about the fiber to indicate what causes a change in drainage rate. The result is an empirical number, and according to Clark (3), many different fiber conditions could result in the same number. In general, it is agreed that refining generates broken fibers or debris. This means that when the drainage test is run without any fiber agitation during water drainage, a thick mat of fiber is formed on the screen; and consequently, debris is trapped in the mat resulting in slower water drainage rates. Refining can also split the fiber wall internally and externally, but if no debris is produced, Clark believes it does not slow water drainage in a tester.

Screen classification

Bauer-McNett screen classification (11) divided the pulp into fractions retained on five different screens. Figure 1 shows that with increased refining, as determined by drainage rate, the proportions retained on the coarser screens decline and increase on the finer mesh screens. This indicates fiber bundles are reduced to fibers during refining, which is consistent with the findings of Clark (3) who reported that the main effects of refining were reduction in fiber length and production of debris. However, it does not reveal whether individual fibers are being reduced along with the fiber bundles, or if changes are taking place within the intact fibers.

Fiber length index numbers were calculated for all pulps from the OD weights of particles retained on the different screens (Fig. 1). Fiber length index numbers were also plotted against drainage rates for the different species (Fig. 2), and the graphs for all species show that an increase in refining results in a lower fiber length index number. Linear regressions of fiber index versus drainage rate are statistically significant for all species.

![Figure 2. Fiber index versus drainage rate. Regression equations and coefficients of determinations are given for each species.](image)
four species. A two-sample t-test run on fiber index reveals that refining created statistically significant differences among the aspen and white pine pulps.

When screen classification results are combined with drainage rate, a better idea is obtained of what happens to the pulps during refining. We can infer that a slower drainage rate associated with additional refining is caused by the breakdown of larger into smaller particles.

**Pulp composition**

Fiber bundles, single fibers, and other debris were very visible when a pulp sample was examined under a projecting light microscope at low magnification (40 ×). The observer immediately gained a better understanding of the numbers generated by the drainage rate and screen fractionation tests. As the pulps were refined, drainage rate became slower and screen fractionation showed a higher percentage of fine materials passing the 150-mesh screen. Microscopic examination then revealed how more fine material was generated, leaving less coarse material in the pulp; fiber bundles were being broken apart and individual fibers were being broken into smaller pieces (Fig. 3). For aspen and white pine, the percentage of whole fibers counted remained nearly constant throughout the refining process. However, in sweetgum and southern yellow pine, whole fiber percentages were significantly reduced as a result of refining. The observer also saw broken ends on many individual fibers and pieces of fiber walls in the sample, illustrating what refining did to the fiber.

**Fiber measurements**

Fiber length generally decreases as a result of refining (Fig. 4). Only in the softwoods is the reduction of fiber length statistically significant, as shown by a regression analysis of fiber length on drainage rate. The average fiber length of both hardwoods (aspen and sweetgum) increased as the drainage rate was increased.
from 15 to 25 seconds, before decreasing as refining was continued. This phenomenon only occurred in the hardwoods and was probably caused by the destruction of large vessel elements during refining. At a 15-second drainage rate, many intact vessel elements were measured along with the fibers. After additional refining that reduced the drainage rate to 25 seconds, the vessel elements had been converted into small pieces of debris which were not measured. The longer fibers remained essentially unchanged. The net effect was an increase in the average measured fiber length of the hardwoods.

There is no consistent pattern of changes in fiber diameters in response to refining (Fig. 5). With additional refining, the diameter increased in aspen but decreased in the other three species. The regression of diameter on drainage rate was statistically significant.

Figure 6. – Scanning electron microscopy photographs of aspen fibers, refined to four drainage rates. A. 15 seconds, 200 ×; B. 22 seconds, 200 ×; C. 50 seconds, 1,000 ×; D. 76 seconds, 2,000 ×.

Figure 7. – Scanning electron microscopy photographs of sweetgum fibers, refined to four drainage rates. A. 15 seconds, 200 ×; B. 24 seconds, 200 ×; C. 52 seconds, 1,000 ×; D. 76 seconds, 2,000 ×.
only for southern yellow pine. Because the fiberboard fibers were high-yield fibers, they were not expected to respond to refining in the same manner as papermaking fibers (5,6). Refining of papermaking fibers may remove, outer cell wall layers and thus reduce diameter, or may permit the fiber to swell in water and increase diameter. Koran (5) reported that the only thing refining does to hardboard fibers is make them shorter. This was confirmed by our fiber length measurements and by measurements made previously.

**Scanning electron microscopy**

Scanning electron microscopy (SEM) illustrates in minute detail what happened to the fibers with additional refining. Previous measurements of drainage rate, fiber length, and pulp composition, showed that fiber bundles were separated and individual fibers broken. However, it was impossible to distinguish whether the increase in fine materials, as indicated by the Bauer-McNett screen classification, was due to fiber breakage or removal of material from the fiber surface. All pulp furnishes were examined at three magnifications—200×, 1,000×, and 2,000×. Many whole fibers (Figs. 6A, 6B, 7A, 7B, 8A, 8B, 9A, and 9B (pages 34 to 36)) and some fiber bundles (Figs. 6A, 7A, and 7B (page 34)) were present in the pulps subjected to the least amount of refining. Vessel elements, not visible on these photographs, were also present in the 15-second hardwood pulps. As refining progressed, more broken fiber ends and fiber fragments were evident (Figs. 6B, 7B, 8B, and 9B (pages 34 to 36)). These observations confirm those made during pulp composition, fiber length, and fiber diameter measurements. Some of the fragments could be identified as broken cross sections, and others appeared to be fragments of the fiber walls (5,6).

At the 15-second drainage rate, many fibers showed small pieces of material clinging to or peeling away from the fiber wall. This surface debris was probably parts of the cell wall partially torn loose during fiber separation. Apparently, with additional refining of the pulp these materials were removed, for the fiber surfaces appeared much cleaner and smoother. The debris contributed to the very fine particles that passed through the 150-mesh screen and appeared as “dust” under a light microscope.

Changes taking place on the fiber surface, especially the cleaning or smoothing action to the fiber surface (Figs. 6D, 7D, 8D, and 9D (pages 34 to 36)), were better observed at higher magnifications (1,000× and 2,000×). Under the SEM, it also became evident that additional refining was doing more damage to the fiber than just shortening length. Fiber wall deterioration is illustrated by missing pits in Figures 7C and 7D (page 34), and many cracks and tears were evident, especially in the southern yellow pine (Fig. 9D (page 36)). Absent from all photographs is the fibrillation commonly found when refining chemical pulps for papermaking (6). Since the hardboard fibers are produced at higher steam temperatures and pressures, fiber separation occurs in the middle lamella, yielding a lignin-rich fiber surface (2,6). This is evident on the photographs by the presence of middle lamella corner ridges and shrinkage folds on all fibers. Retention of the middle lamella primary wall presents a surface that is extremely resistant to secondary refining.
As reported by Short and Lyon (10), SEM examination of the various fiber surfaces reveals minimal differences between species. Observable differences are attributable to anatomical differences between species and to the changes taking place on and within the fiber surfaces as a result of additional refining.

**Summary**

Drainage rate measures how quickly a fiber mat can be formed from a pulp slurry. Results are sensitive to pulp variables which can be changed by refining the pulps. This test was used to monitor preparation of the pulps, and revealed that something happened to the fibers during refining.

By separating a pulp sample by screen mesh sizes, screen fractionation complemented the drainage rate test and indicated that the presence of less coarse and more fine materials in a pulp sample caused a longer drainage time.

Pulp composition was determined by examining a pulp sample visually under a microscope at low magnification. This test complemented measurement of drainage rate and screen fractionation by identifying the pulp elements that were retained on the fractionation screens. Operator choices may bias the pulp composition results.

Fiber dimensions were determined by measuring fiber length and diameter under a microscope. These measurements yielded very accurate information about physical changes occurring in the fiber and thus complemented and helped explain the results from drainage rate and screen fractionation tests. There was a correlation between measured fiber length and fiber length index.

SEM provided the clearest and most detailed picture of the fiber surfaces, so that damage and changes occurring to the fiber could be minutely studied. Photographs taken by the SEM were useful in confirming and explaining some of the changes measured in the previous tests.

**Literature cited**