Fiber fractionation as a method of improving handsheet properties after repeated recycling

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ABSTRACT: The objective of this secondary fiber research was to investigate the use of fiber fractionation to increase the utilization of office recovered paper by upgrading the quality of the fiber and thus minimizing the negative effects of recycling. Mixed office waste was collected, pulped, and cleaned. Handsheets were formed, repulped, and reformed to obtain pulps representing four recycles. A portion of the pulp from each recycle was fractionated to obtain long and short fiber fractions. Fractionation was successful in upgrading the long fiber component. Kajaani fiber analysis showed that the long fraction contained a significant portion of higher-grade papermaking fiber. Strength indexes were substantially enhanced by fractionation.

KEYWORDS: Fiber classification, fiber dimensions, fiber fractions, fiber length, hand sheets, length, mechanical properties, mixed waste papers, paper properties, paper sheets, reclaimed fibers, recycling, waste papers.

Repeated recycling causes fibers to become less suitable for papermaking. The fibers become less flexible and shorter than virgin fiber and do not conform as well. The results of this loss in flexibility and conformability are lower strength and less bonding between the fibers, which result in a weaker, lower grade of paper. To investigate the effects of repeated recycling on the paper properties, we collected a representative office recovered-paper sample. Handsheets were formed, repulped, and reformed until four stages of recycling had been represented. A portion of the pulp from each of the five cycles was then classified into long and short fiber fractions.

Literature references to the use of fractionation are few; even fewer examine the potential of fractionation to enhance the quality of secondary fiber furnish. The vast majority of the work on fractionation of secondary fiber considers the use of such fiber in corrugated medium and paperboard applications *(1, 2)*. To date, there has been virtually no documentation on using fractionation as a means of enhancing secondary fiber from office recovered paper.

Documentation on fiber fractionation lists many methods that may be used, at least theoretically, to separate fiber into long and short components *(3–5)*. Bauer-McNett and Clark fiber classifiers are used for fractionating fiber on a laboratory scale. Each method allows only a few grams of fiber to be classified at a time and is therefore very time consuming. Centrifugal cleaners, pressure screens, and nonpressurized screens are used on a commercial scale. The goals of the fractionation determine the method

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I. Effects of fractionation on average fiber length and coarseness of office recovered paper

Number of recycles	Length, mm		Coarseness, mg/m	
	Short fiber	Long fiber	Short fiber	Long fiber
0	1.46	2.80	0.122	0.153
1	1.01	2.49	0.097	0.158
2	0.97	2.22	0.085	0.143
3	0.94	2.10	0.093	0.132
4	0.93	1.91	0.093	0.134

II. Effects of fractionation on burst index after repeated recycling

Number of recycles	Burst index, kPa·m²/g	
	Short fraction	Long fraction
0	2.73	2.95
1	1.17	2.15
2	0.80	1.52
3	0.76	1.38
4	0.73	1.33

used. Following fractionation, the longer and stronger fibers can be refined to a higher strength, which reduces the need for more expensive virgin fiber furnish. Fractionation also results in the removal of fines from the furnish by separating out much of this material with the short fiber furnish. By separating out short, low-freeness fiber, only the longer portion of the furnish needs to be refined, resulting in a possible overall decrease in refining energy.

Fractionation is an integral part of producing multilayer paperboard and corrugated containers from secondary fiber. New cleaning and pulping technologies make the production of multilayer paperboard from secondary fiber inviting *(1)*. In multilayer paperboard manufacture, fractionation is used to produce a sheet that can be altered to fit the required properties *(2)*. The short fraction can be used as the filler in the center of the sheet, while the long fraction can be used as liner stock. Adjustments may be made to the proportion of long and short fractions to obtain desired properties. Similarly, in corrugated containers, the short fraction is used as the corrugated medium, while the stronger long fraction is used for the liner *(1)*. The fiber separation creates two fiber streams that are more valuable than the feed stream alone.

The greatest problems with utilizing secondary fiber are a continually changing source, the poor quality of furnish as compared to virgin fiber, and a lower-quality product *(6)*. Fractionation can help solve many of these problems. The long fiber component separated through fractionation theoretically contains mostly softwood fiber and contributes to strength properties. The short fiber component contributes to the smoothness and opacity of the sheet.

The main problems facing the widespread utilization of secondary fiber from office recovered paper include an ever-changing fiber supply and a lack of knowledge about process variables. The following problem areas need to be examined:

- Standard method for fractionating secondary fiber from office recovered papers
- Optimal separation (split) of fibers into long and short fractions
- Optimal amount of added virgin fiber to maintain strength and other valuable paper properties
- Classification system for properties of secondary fiber from office recovered paper.

Our study examined the effects of fractionation on the burst strength, tensile strength, and tear index of handsheets after repeated recycling.

Experimental work

To obtain a representative sample, office recovered paper was collected from ten sources including city offices, academic buildings, and a bank. The sample was visually inspected to remove all nontypical office recovered paper materials, including newsprint, cardboard, and carbon paper, as well as nonpaper items. Approximately 136 kg of office recovered paper remained in the sample for the secondary fiber research.

The recovered paper was prepared at the USDA Forest Service, Forest Products Laboratory in Madison, WI, to remove ink and other foreign materials that were not removed during the visual inspection. The entire recovered paper sample was pulped at approximately 4% consistency. Because of the size and capability of the equipment used in the cleaning process, the stock was then divided in two batches. The pulp was passed through a 0.30-mm vibrating screen at approximately 1% consistency to remove the larger foreign particles. A substantial amount of plastics and fastening devices was found in the sample. Many of the larger nonfibrous materials were successfully removed in the screening process.

The next stage in the stock preparation was centrifugal cleaning. The system consisted of one 152-mm and three 76-mm centrifugal cleaners as well as a single 102-mm reverse centrifugal cleaner. Centrifugal cleaning was successful in removing the majority of the smaller nonfibrous materials. To remove the adhering ink particles, flotation deinking was used in the next stage of cleaning. Caustic was added to the slurry in the storage tank to set the pH of the sample at 10.3 for flotation purposes. Approximately 50 mL (0.01% of fiber) of flotation aid was added. The

III. Effects of fractionation on tensile index after repeated recycling

	Tensile index, N·m/g	
Number of recycles	Short fraction	Long fraction
0	35.93	36.28
1	27.21	34.59
2	24.80	31.44
3	24.78	29.14
4	21.22	28.11

IV. Effects of fractionation on tear index after repeated recycling

	Tear index, mN·m²/g	
Number of recycles	Short fraction	Long fraction
0	15.32	28.89
1	8.40	21.20
2	7.00	23.21
3	6.62	22.38
4	6.45	18.40

slurry was passed through a six-cell deinking unit to skim the ink particles from the fiber suspension. The specimen was then passed through the centrifugal cleaner system a second time to remove remaining ink particles.

Following the second centrifugal cleaning, the pulp was collected and pressed to a consistency of 43% for dispersion. A pressurized refiner was used to disperse the smaller ink particles from the larger fibers. This multistage cleaning process resulted in the clean pulp specimen necessary for fractionation.

Handsheets were prepared and repulped to obtain pulps that represented recycling from zero to four times. Screen sizes of 14, 28, 48, and 100 (approximately 1.4 mm, 650 μm, 320 μm, and 149 μm, respectively) were used for the Bauer-McNett declassification. The fibers collected in the two largest mesh screens, sizes 14 and 28, were used as the long fiber fraction, while the fiber collected in the size 48 and 100 mesh screens were deemed short fiber. The screening process resulted in 51 different pulps varying in the number of recycles, long and short fiber composition, and amount of virgin fiber added.

Fiber analysis was conducted with a Kajaani FS-200 fiber analyzer[2]. Trials were made in triplicate and run according to instructions supplied by the manufacturer. Approximately 0.14 g of oven-dry (o.d.) fiber were disintegrated in 150 mL of water at 70°C. Disintegration was carried out for 100 strokes using the hand disintegrator provided with the Kajaani fiber analyzer. The test specimen was diluted to 1000 mL and mixed evenly to a consistency of 0.14%. A 50-mL sample was used for analysis, representing approximately 7.00 mg of dry fiber for fiber length and coarseness analysis. The values reported for the average fiber length and coarseness are an average of the trials run for each specimen.

[2]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Results and discussion

Fiber analysis

The success of the Bauer-McNett fractionation is most evident from the results of the Kajaani fiber analysis. Separation of the fibers into long and short fractions at each stage of recycling resulted in a long fiber component that was 105–147% longer than the short fiber. The weight fractions from different screens were nearly the same. For the unrecycled fiber, the difference in fiber length was 92%. For the recycled fibers, the coarseness of the long fiber component was 42–68% higher than that of the short fiber component, depending on the number of recycles. For the unrecycled fiber, the difference was only 25%. Hence, the recycling process had a more detrimental effect on the short fiber than on the long fiber with respect to fiber length and coarseness (**Table I**).

Burst strength

The long fiber fractionation had the highest burst index, as expected; the burst index was 82–90% higher than that of the short fractionation (**Table II**). As in the case of fiber length, the difference between burst indexes for the fractions of the unrecycled fiber was much smaller (8%). Interfiber bonding increased with longer fibers and resulted in a higher burst strength. Recycling from one to four times decreased burst strength as fibers break, stiffen, and are less able to conform together *(7)*. In our study, the greatest benefit of fractionation was the upgrading of the long fiber fraction as the specimens were repeatedly recycled.

Tensile strength

The success of the Bauer-McNett fractionation is again evident in the results of the tensile index measurements. The long fiber fractions had the highest tensile index values (**Table III**). The tensile index of the long fraction was 18–33% higher than that of the short fraction. For the unrecycled fiber, there was essentially no difference in the tensile strength of the long and short fibers. The long fibers were better able to overlap and conform and thus resulted in increased tensile strength for the pulp handsheets. Therefore, fractionation can be used to upgrade pulp strength.

Tear index

The most significant effects of fractionation into long and short fiber components is seen in the results of the tear index measurements. The longer fiber had more bonding potential, resulting in higher strength properties. The tear index of the long fraction was 152–238% higher than that of the short fraction (**Table IV**). For unrecycled fiber, the corresponding difference was only 89%. The decreased ability of the fibers to conform after repeated recycling resulted in a decrease in tear index. The short fibers, however, degraded more quickly than the long fibers with respect to this measurement.

Conclusions and recommendations

Fractionation on a laboratory scale with the Bauer-McNett fiber classifier proved successful at separating office recovered paper into two streams of different fiber length. The long fiber component resulting from fractionation was significantly upgraded compared to the short fiber fraction. Repeated recycling had a more detrimental effect on the short fiber fraction compared to the long fiber fraction.

The continuation of this research should focus on the feasibility of using commercial fractionation devices and methods to upgrade fibers from recycled office recovered paper. Pressure screens, centrifugal cleaners, nonpressurized screens, and selective pulping are among the available technologies. Investigation into the use of these technologies for upgrading office recovered paper is necessary to determine the commercial implications of the results of this study. The optimal split between long and short fibers can be determined by implementing commercial fractionation devices. This information is needed to realize the full benefits of using secondary fiber. The realization of the full benefits of secondary fiber fractionation also requires knowledge of the optimal level of virgin fiber, that is, the minimal amount of virgin fiber required to maintain acceptable paper properties for a specific grade of paper. This knowledge would allow refining to be limited to the long fiber fraction, which would result in increased strength properties. TJ

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