Recycled fiber quality from a laboratory-scale blade separator/blender

Bei-Hong Liang
Stephen M. Shaler
Laurence Mott
Leslie Groom

Abstract

A simple and inexpensive fiber separator/blender was developed to generate useful secondary fibers from hydropulped waste paper. Processing wet hydropulped fiber resulted in a furnish with no change in average fiber length in three out of four types of recycled fibers tested. In all cases, the Canadian Standard freeness increased after processing compared to hydropulped-only fibers. Micrographs of the fibers obtained using an environmental scanning electron microscope indicate increased fiber flexibility and curl. Following fiber separation, the unit also doubles as a blender, permitting easy blending of fibers, liquid resins, and particulate matter such as thermoplastics, later used to manufacture composite panels.

Paper and paperboard products form a large portion of municipal solid wastes and now occupy 37.5 percent of landfill (2). Solid waste is becoming more difficult to dispose of as landfill sites become increasingly scarce. For these reasons, the recycling and re-use of waste materials has become a high priority both in research and industrial environments. To alleviate the increasing burden being placed on natural resources, new ways are being sought to utilize waste materials. In this regard, structural fiber/polymer composites seem promising in that certain waste fractions may be well suited to their manufacture in specific applications. However, dry processing separation methods by which secondary fibers are produced do not often lend themselves well to the production of fibers suitable for composite materials. The secondary fiber production process is primarily to blame and needs to be more effectively implemented to enhance retention of long fiber lengths, and to reduce damage to fiber wall structural integrity.

The bulk properties of fiber-reinforced polymer composites are highly dependent on the mechanical properties of the component materials themselves (i.e., fiber phase and polymer phase) (6). The geometry and the quality of the fibers are seen to play an important role in affecting the interfacial properties between reinforcing fibers and polymeric matrices. Unfortunately, recycled fibers, such as those hydropulped from newsprint, tend to display shorter average lengths and exhibit a greater degree of structural damage in comparison to virgin pulps (8).

It was found that hardboard produced from lab hammermilled/hydropulped recycled fiber displayed poor mechanical and dimensional stability properties (7). Medium density hardboards also displayed poor strength properties when shredded and pressurized disk-refined waste paper was used as the fiber source (3). Substandard properties of composites made from recycled wood fibers are a reflection of poor fiber quality. Improved fiber quality can be accomplished by the development of alternative separation techniques of individual secondary fibers from wastepaper.

The authors are, respectively, Graduate Research Assistant, Associate Professor, and Graduate Research Assistant, Dept. of Forest Management, Univ. of Maine, Orono, ME 04469-5755; and Research Technologist, USDA Forest Serv., Southern Forest Expt. Sta., 2500 Shreveport Hwy., Pineville, LA 71360-5500.

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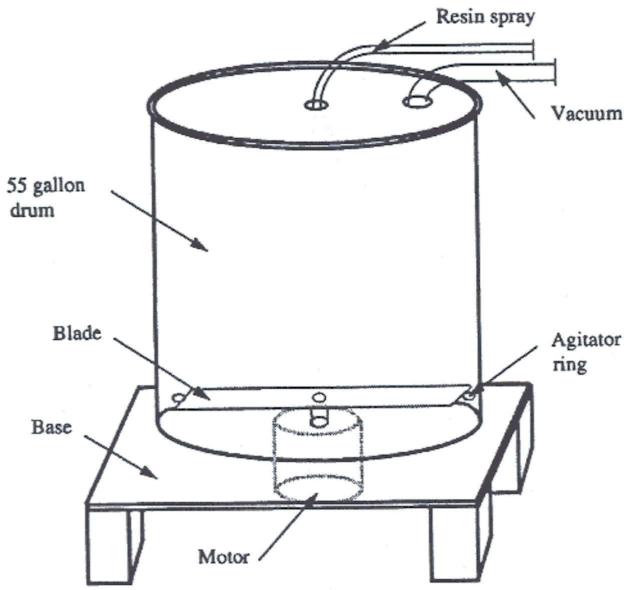

Figure 1. Schematic recycled fiber separator/blender.

A prototype lab-scale recycled fiber separator/blender was designed and built to overcome the deleterious effects inherent in processes such as shredding, hammermilling, and disk refining. This paper describes the construction and reports on the quantified effects of four different pulp types.

Materials and methods

Design of the recycled fiber separator/blender

The design of a new lab recycled fiber separator/blender was based on a research objective to reduce fiber bundles into individual fibers while simultaneously maintaining the pre-processed fiber length. As shown in Figure 1, the separator/blender is primarily comprised of a 55-gallon drum and an electric motor, which is attached to the base. The sealed motor turns a blade that rotates inside the drum at a designed speed of approximately 3,500 rpm. The speed of rotation and size of the blade are critical; the combined effect creates a fluid bed of suspended wet fiber lumps.

A 1-hp electric motor, designed to rotate at 3,450 rpm, and a 10.5-inch-long, 3-inch-wide blade made of a 1/5-inch-thick plywood were selected. A metal agitator ring was fixed to each end of the blade to prevent the fiber bundles from amassing beneath the blade while it was rotating. Blade length and diameter of agitator ring need to be adjusted to take into account the mass of the wet fibers in the drum and their average moisture content (MC). More material in the separator necessitates a shorter blade length if rotation speed is to be maintained. Also, a larger agitator ring is needed if fibers with a higher MC are to be separated. The blade was designed with blunt edges to prevent fibers from being damaged. The system described can produce up to 1 pound of separated fibers per batch.

The separator also functions as an efficient fiber resin blending system (Fig. 1.); the fluid bed effect allows a uniform distribution of resin over the entire fiber mass. This blending system appears to result in better resin distribution compared to traditional rotating drum blenders typically used for particle or flake blending. Evidence of this is based upon a lack of resin spots visible at board faces and improved mechanical properties.

Processing recycled fiber

Waste papers were obtained from the University of Maine recycling service. They were sorted into four different types: 1) old newspaper (ONP); 2) old corrugated containers (OCC); 3) book paper (BP); and 4) computer paper (CP).

Each type of waste paper was hydropulped in a lab hydropulper. After 10 to 20 minutes, a slurry with uniformly separated fibers was vacuum dried to remove the excess water and a wet fiber blanket was formed. It was noted that the newspaper fiber remained dark in color despite the fact that much of the ink was removed during hydropulping. However, Rowell (5) indicated that the inks do not affect fiber strength. The clay found in book paper was also partially removed during the hydropulping and water-suction process.

By using a separate lab solid-liquid blender (Model LB-7998), originally designed to mix paint, fiber blankets were reduced into large fiber bundles. The bundles were then kiln-dried at 180°F until an MC of 50 to 70 percent was achieved. This MC proved to be critical in order to further facilitate separation of fibers on an individual basis. The 50 to 70 percent MC fiber bundles were then weighed out and placed into the 55 gallon separator/blender and processed until individual fibers and very small fiber bundles were generated. This is necessary in order to obtain desired composites properties. A considerable increase in total volume of material was noted. The separation time varied from 10 to 30 minutes depending on the type of recycled fibers being processed.

Separation of the fibers was achieved through a semidry process. A fluid bed of fibers/bundles results from the high blade speed. The design of the separator allows the heavier bundles to drop through the fluid bed into the path of the rotating blade. The impact further reduces the bundles, creating lighter weight material. This process continues until very little contact is made between the blade and the furnish, it being largely suspended in the fluid bed. At this point, the material is deemed of good enough quality to use as composite furnish.

Freeness test of pulp

Canadian Standard freeness (10) values of respective pulp types were determined to examine the morphological and structural changes that occurred after fiber separation. Three handsheets of each pulp type were prepared to obtain freeness values following both initial hydropulping and after the described mechanical separation process.

Fiber length analysis

A Kajaani fiber length analyzer (model FS-100) was used to determine recycled fiber length and distribution. A very dilute solution of dispersed fiber, roughly 0.5 percent consistency, was prepared for each type of secondary pulp. A minimum run of 6,000 fibers was tested for each pulp type. Three types of average length values were obtained: length-weighted, mass-weighted, and arithmetic average length.

Fiber morphology

Microstructural details of the respective recycled fiber types were observed in an effort to assess the structural changes caused by the separation technique. A new generation of SEM, an environmental scanning electron microscope (ESEM) (ElectroScan Corp.) was employed to obtain the presented micrographs of the recycled fibers. The ESEM allows the observation of biological materials in their natural state without the need for conductive coatings and damaging material preparation.

Results and discussion

The furnish generated by the separator/blender consisted of individual secondary fibers and very small fiber bundles. As expected, fiber length and structural integrity remained largely unaffected. This is due to the absence of severe mechanical beating associated with hammermilling or the disk separation with dry paper or fiber. To quantify this effect, both freeness and fiber-length measurements were conducted.

TABLE 1. — *Freeness and fiber length measurement of recycled fibers.*

Fiber type	Freeness	No. of fibers	Average fiber length[a]
			(mm)
Before separation			
Old newspaper		**6,808**	**0.29**
Old corrugate		**6,355**	**0.42**
Computer paper		**6,785**	**0.43**
Book paper		**6,249**	**0.30**
After separation			
Old newspaper	695 22.54 131.67[d]	6,365	0.28 3.45[e]
Old corrugate	750 12.50 5.60	6,236	0.42 0.00
Computer paper	730 32.15 46.00	6,385	0.31 27.91
Book paper	700 5.20 35.92	6,961	0.28 6.67

[a] Arithmetic average length.
[b] Average freeness value.
[c] Standard deviation.
[d] Percentage increase in freeness.
[e] Percentage reduction in average fiber length.

Freeness values were high for the various recycled fiber types as shown in Table 1. These values are consistent with those reported by Ellis and Sedlachek (1) for recycled southern pine fibers, where freeness values of up to 780 ml were noted at different recycle levels. Freeness values for the recycled fiber types increased upon separation; this increase was likely attributable more to fiber curling than fibrillation (4). Given that the original freeness reading for OCC fiber was initially very high, no significant increase in freeness was expected or noted after separation. The remaining three fiber types underwent a dramatic increase in freeness, especially newspaper (130% gain). In trying to account for these results it was speculated that either length changes or morphological modifications would be present as a result of the mechanical separation.

To evaluate the suspected morphological changes in the recycled fibers after separation, handsheets

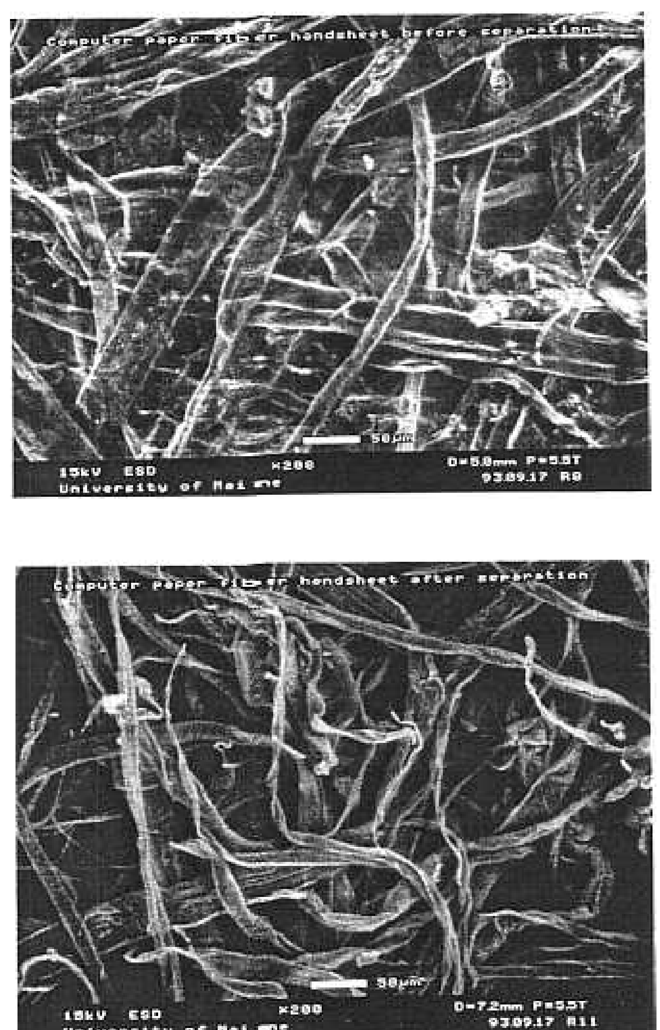

Figure 2. — Microstructure of recycled fiber from handsheets of computer paper fiber by environmental scanning electron microscope (ESEM). Above: Before fiber separation. Below: After fiber separation.

produced from hydropulped and mechanically separated fibers were examined with the ESEM. Examples of the obtained micrographs of CP type can be seen in Figure 2. The results suggest that the morphologies of recycled fibers before and after separation are quite different. In contrast to the flat and smooth lay-up of recycled fibers before separation, those examined after separation have a more curled and twisted shape. This results in less fiber-to-fiber contact and, hence, more void space in the internal structure of handsheets. The increase in coarseness accounts in part for the displayed increase in freeness. However, the series of micrographs gave no indication that further microstructural damage had occurred in the cell wall of the mechanically separated recycled fibers.

The curled and twisted shape exhibited by the mechanically separated fibers may have profoundly undesirable effects should they be used in the manufacture of paper. Used in the production of fiber composites this would not be a severe problem, as these shape effects could be largely ignored in the presence of high temperatures, pressures, and thermosetting adhesives. However, changes in individual fiber strength properties or fiber length could have a marked effect on composite performance. Given that fibers produced by this separation method are to be predominantly used in the manufacture of structural composite materials, the authors did not consider it appropriate to conduct zero-span tests to predict individual fiber strengths. Instead, individual fiber testing is underway to yield more accurate and relevant measurements of recycled fiber strength properties.

Kajaani tests report three fiber-length values based on a statistical evaluation. The average arithmetic fiber length represents the actual mean length of the recycled fiber obtained from over 6,000 individual fibers in each group. Among the four types of recycled fibers, three of them had the average arithmetic lengths only slightly changed or even unchanged. This implies that the recycled fibers generated by the fiber separator retained the longer fiber length, which is desirable in designing structural fiber composites. Computer paper was the exception to this; analysis revealed that the arithmetic average length dropped by 28 percent (Table 1). Pulping method, recycling level, as well as the total amount of retained material in the fiber cell wall could also impact the fiber length and strength properties.

It was observed that CP fibers are fine and more flexible in comparison to ONP and OCC fiber types. Tam Doo and Kerekes (9) reported that chemical pulps are 20 to 30 times more flexible than mechanical pulps from the same wood. It is proposed that the initial pulping process leads to the increased flexibility of computer papers. It is speculated, therefore, that the reduction in CP fiber length is more an indication of fiber shape change caused through curling and twisting instead of fiber breakage.

The semidry state (50% to 70% MC) at which the fibers were separated was thought to contribute to the ease with which fiber lumps would disintegrate. This excessive moisture is not conducive to good hydrogen bonding between fibers and makes them more flexible. It can be seen, therefore, that obtaining the correct MC is crucial to the performance of the separator/blender, both in terms of separating efficiency and in avoiding microstructural cell wall damage. Reducing the MC would render it more difficult to separate fiber bundles and reducing fiber flexibility would result in fiber length reduction, as well as increased energy costs. An initial MC significantly above the range suggested leads to re-clumping of the fibers once they start to dry after the fluid bed effect is removed.

Concluding remarks

Freeness values increased dramatically due to the effect of increased curling and twisting in fiber shape after mechanical separation. Based on observations with the ESEM, there was no indication that further microstructural damage occurred in the cell wall of mechanically recycled fibers as compared to the hydropulped-only samples. Fiber length underwent no significant reduction, with the exception of computer paper fiber (28%). It can be concluded that this mechanical separation process, in combination with a controlled fiber MC, can minimize fiber length reduction and microstructural damage in secondary fiber processing. Further investigation quantifying individual recycled fiber strength changes would improve understanding of this separation method.

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