

Papermaking properties and morphology of cellulose fiber recovered from municipal solid waste

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ABSTRACT: A new steam autoclave process can recover cellulose fiber directly from municipal solid waste (MSW). The drainage rates of this fiber source are unusually high and are superior to those exhibited by fiber from recycled old corrugated containers (OCC). The cause of this freeness increase appears to be that MSW fibers are less collapsed and fibrillated than are OCC fibers. Strength values of handsheets made from MSW fiber were approximately equal to those of handsheets made from OCC fiber. Sheets of 100% MSW fiber produced on a pilot paper machine were at least as strong as sheets made from 100% OCC. A blend of 50:50 MSW and OCC fiber gave the best overall balance of strength properties needed in the production of corrugating medium.

Application: The use of MSW fiber in paper production has potential economic benefits and could substantially reduce the amount of municipal waste sent to landfills.

As of 1996, an estimated 70% of all municipal solid waste (MSW) generated in the United States was sent to landfills, which amounts to approximately 209 million tons of waste per year [1]. Consequently, landfill space is continually being depleted. Highly populated cities regularly need to ship their waste to other parts of the U.S. and have gone so far as to ship MSW to other countries. As the population continues to increase, so will the amount of generated waste, and the amount of space available for landfilling will continue to decrease.

In areas where there is no separation of waste material, as much as 50% of the MSW sent to landfills is composed of paper products. If this fiber were reclaimed and processed such that it had market value in the form of a raw material for papermaking operations, this fiber would present an opportunity for reducing waste bound for landfills. One potential process for recovering papermaking-quality fiber from MSW is the steam autoclave process [2]. This process is capable of reducing the mass of solid waste sent to landfills by approximately two-thirds. The steam autoclave process also offers the potential to produce a gas mixture of methane and CO₂ via anaerobic digestion of the waste liquor [3].

Preliminary tests on cellulose fiber produced by this process [4] indicated some differences between this type of fiber and recycled fibers from old corrugated containers (OCC). For example, the water drainage rate of this fiber was high-

er than that of OCC. To verify these findings and expand on them, we explored the fiber characteristics of MSW fibers produced by the steam autoclave process. We also studied the properties of MSW handsheets and sheets made from MSW pulp on a pilot paper machine.

METHODS AND MATERIALS

Freeness was measured according to TAPPI T 227 om-94 for unrefined samples of both OCC and MSW. To determine the "fines" fraction of each sample, we used a Bauer-McNett fiber classifier (screens of 26, 48, 100, and 200 mesh) (T 233 cm-95). The freeness of fiber sample caught on the 26 mesh screen was measured for each of the two fiber types.

Characterization of fiber properties

Hydrated samples of both MSW and OCC were freeze-dried to fix the shape the fibers had when suspended in water. We wanted the fibers to retain their shape because we wanted to find out if the shape had any effect on drainage. Some of the fiber lumens, for example, may have been more expanded than others in the hydrated state.

After freeze-drying, portions of each sample (MSW and OCC) were embedded in an epoxy, and cross-sectional slices were cut with a microtome. With these slices affixed to slides, we examined the fiber cross-sections with a light microscope to ascertain the state of the lumens. We simply counted the number of expanded (or circular) lumens and the

number of collapsed lumens. We examined the individual fibers under a scanning electron microscope (SEM) to characterize the surfaces of the two types of fiber.

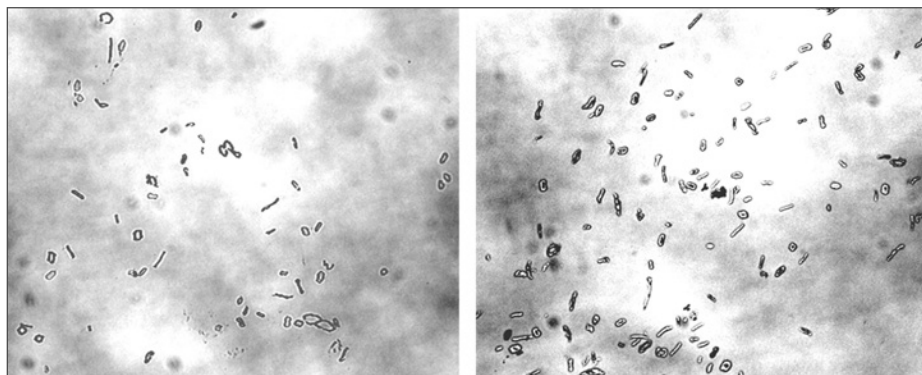
Papermaking properties

We carried out two different studies to determine the papermaking properties of MSW fiber. The first study was designed to determine whether or not fine screening of MSW fibers had any effect on its strength in a sheet. MSW fibers were screened in a Valley Flat Screen with warm water (~35°C). Three sizes of screens (0.010, 0.006, and 0.003 in. slots) were used. In addition, the accepted fiber from the 0.003 in. screen was refined to a freeness value of about 450 mL CSF in a Sprout-Waldron disc refiner to allow us to assess the fiber strength under conditions that resemble refining conditions in a mill. Handsheets were made for each sample, and tests for tensile strength, burst index, stiffness, short-span compression, and flat crush were performed.

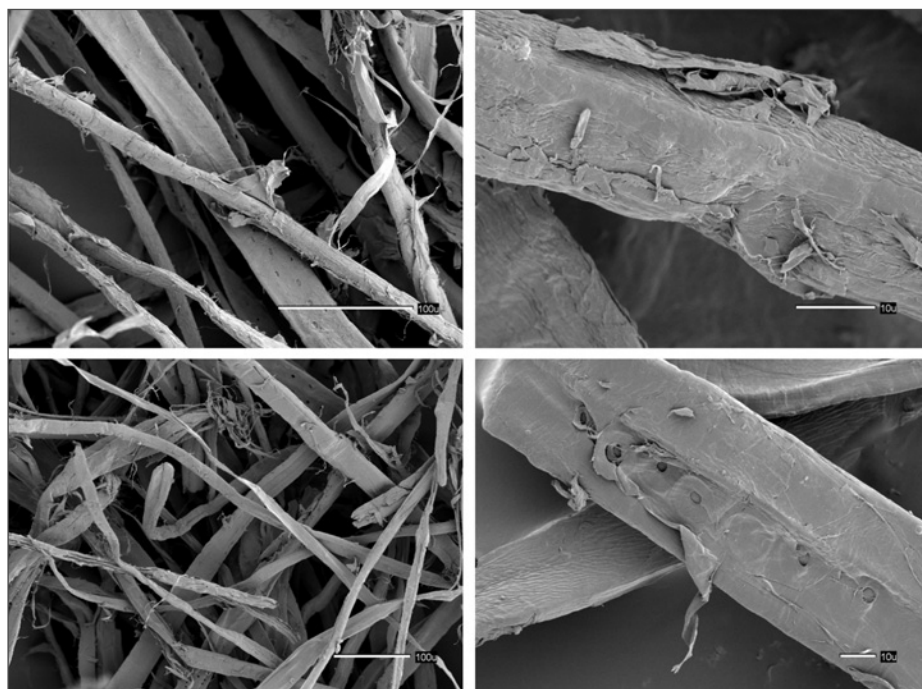
The second study was performed on paper produced on a laboratory paper machine. The goal was to produce a simulated corrugating medium consisting of MSW and OCC in the following amounts:

1. 100% OCC
2. 75% OCC, 25% MSW
3. 50% OCC, 50% MSW
4. 50% OCC, 25% MSW, 25% ONP
5. 100% MSW.

RECYCLING



1. Microtomed fiber cross-sections of OCC (left) and MSW (right).



2. Electron micrographs of OCC (top) and MSW (bottom) fibers.

These papers were produced under conditions similar to those found in a mill. The trial conditions and additives were chosen to mimic those of typical of corrugated medium production. Cationic starch was added to enhance strength. Tensile strength, burst index, short-span compression, and stiffness tests were performed after the paper samples were conditioned according to TAPPI methods.

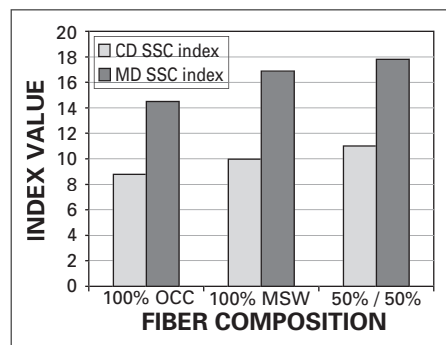
RESULTS AND DISCUSSION

Fiber characterization

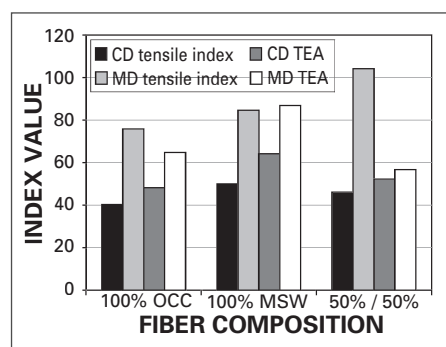
The average freeness values for *unscreened* MSW and OCC were 661 mL and 509 mL CSF, respectively. The MSW pulp sample exhibits a freeness value that is about 150 mL higher than that of OCC. This freeness gain is typical of recycled fiber recovered from MSW by this partic-

ular process. However, the high freeness is somewhat surprising in light of the fact that MSW is composed of virtually every type of pulp fiber imaginable, including corrugated boxboard, newsprint, foodboard, xerographic waste, and tissue, much of which has been refined to a considerable extent. This outcome suggested to us that there may be a fundamental difference in either the furnish composition (a disproportionate amount of long fiber, or a lack of fines) or in the fiber properties themselves.

One theory we considered was the idea that most of the fines fraction was being washed out in a rejects stream, since the MSW fiber was processed on a 0.020 in. sidehill screen at the pilot production facility. However, as **Table I**



3. Tensile index and TEA for 100% MSW, 100% OCC, and a 50:50 blend of MSW and OCC.



4. Short-span compression index for 100% MSW, 100% OCC, and a 50:50 blend of MSW and OCC.

SCREEN	MSW, %	OCC, %
26	57.57	56.45
48	19.00	17.26
100	3.78	4.78
200	3.14	8.70
Fines	16.51	14.81

I. Bauer-McNett classifications of fiber samples

shows, the fines fraction in the MSW fiber sample (before any fine screening was performed) was actually *greater* than that of the OCC sample (16.5% vs. 14.8%). Furthermore, the freeness value of the long fiber fraction (that retained on the 26 mesh screen) was only 40 percentage points greater than the freeness of the complete furnish (for both MSW and OCC). These observations indicate that the freeness elevation was simply not related to any lack of fiber fines.

Next, we focused on the physical shape and surface of the MSW fiber to explain for the higher drainage rate. It could be that the higher freeness was being caused by a physical change in the fiber that occurs during steam autoclaving. The alternating pressurization and

BASIS WEIGHT 125, g/m ²	SAMPLE ID	TENSILE INDEX, Nm/g	BURST INDEX, kPa·m ² /g	STIFFNESS GURLEY, mg	FLAT CRUSH, psi	SHORT SPAN COMPRESSION, kN/m	CFS, mL
	Corrugated medium	38.92	2.79	108.23	17.20	1.26	~500
	OCC	30.65	3.25	749.38	15.85	0.96	~500
	10-cut	15.04	2.05	690.38	13.00	2.43	~720
	6-cut	20.01	2.39	1727.16	13.00	2.78	~700
	3-cut + refined	35.27	2.84	2100.46	15.90	1.04	~450

II. Strength data for handsheet trials

OCC, %	MSW, %	ONP, %	Basis wt., g/m ²	Burst index	Tensile index		TEA index		SSC index	
					CD	MD	CD	MD	CD	MD
100	—	—	148.96	1.77	40.28	75.86	48.30	64.80	8.77	14.50
75	25	—	116.66	1.24	30.86	66.01	30.00	27.50	11.04	16.96
*75	25	—	117.51	1.56	40.00	82.55	40.90	36.60	8.58	13.96
50	50	—	119.08	1.78	46.19	104.13	52.20	56.60	11.00	17.80
50	25	25	158.45	1.15	33.45	73.84	32.50	34.60	7.39	13.30
—	100	—	130.01	1.80	50.00	84.61	64.20	86.80	9.97	16.88

*Starch added.

III. Strength data for paper machine trial

vacuum treatment the fiber is subjected to could actually be reforming the fiber in some way. More specifically, there were two possibilities we chose to explore:

1. The steam autoclave portion of the MSW reclamation process somehow "re-inflated" the lumens of the fibers, improving drainage.
2. The MSW fiber had less surface fibrillation than other recycled fiber sources.

We tested the first possibility by using a microtome to obtain cross-sections of freeze-dried fiber samples of both MSW and OCC. Examples of cross-sections are shown in **Fig. 1** for OCC and MSW. In terms of the percentage of expanded fibers, the cross-sectional analysis showed about 28% for OCC and about 36% for MSW, indicating more lumen expansion in the MSW fibers. Perhaps some portion of the freeness elevation in MSW pulp is caused by an increase in the quantity of open fiber lumens.

We tested the second possibility by generating SEMs of freeze-dried samples of MSW and OCC to compare the extent of surface fibrillation. While this test is qualitative only in that we attempted no numeric measurement of fibrillation, close examination of these images revealed that MSW tended to be less fibrillated. **Figure 2** presents sample micrographs at different magnifications, showing the relative extent of fibrillation. Although the difference is not dramatic, the extent of fiber fibrillation for MSW appears to be somewhat less pronounced, which may account for some of the higher freeness of the MSW fiber.

Sheet properties

Handsheet testing. **Table II** presents the results of the strength study of handsheets made from 100% OCC and 100% MSW fiber, as compared to each other and to a sample of commercially produced corrugating medium. Three different forms of MSW fiber were used in making handsheets:

1. Screened: 0.010 in. slots
2. Fine screened: 0.006 in. slots
3. Ultra-fine screened: 0.003 in. slots + refining.

Similar to the sample of commercial medium, the unrefined MSW sheets were somewhat weaker than those comprised of OCC. However, the refined samples approached or exceeded those of OCC. It is surprising that the MSW sheets were close in strength to a commercial medium sample, which would likely contain starch and possibly other strength additives. Overall, handsheets made from refined 100% MSW fiber compared reasonably well in strength to either medium or OCC. This result was encouraging for consideration of a pilot paper machine trial where MSW and OCC could be blended together. It seemed entirely possible that acceptable strength properties could be obtained from a blend of between 25 and 50% MSW fiber with OCC.

Compared to the OCC sample available to us, MSW sheets were stronger, even without refining. (Refining improved these values even further.) It is surprising that the MSW sheets were close in strength to that of a commercial medium sample, which would likely contain starch and possibly other strength

additives. Overall, handsheets made from refined 100% MSW fiber compared reasonably well in strength to both corrugating medium and OCC.

Pilot paper machine trial. The results of the handsheet tests encouraged us to proceed with a pilot machine trial in which MSW could be blended with OCC. It seemed entirely possible that acceptable strength properties could be obtained from a blend of 25-50% MSW fiber with OCC. One trial was also performed with a blend of MSW, OCC, and ONP.

Strength data for paper made on the laboratory paper machine are shown in **Table III**. Conditions were selected to mimic those of a 125 g/m² sheet, the most common basis weight of corrugating medium grades. Wet-end starch was added at 7 lb/ton as a dry strength aid. Both OCC and MSW were refined slightly for this trial, to values of 570 and 600 mL, respectively.

The strength values are not representative of the actual strength that would be attained on a full-sized, commercial paper machine. Our pilot machine does not have a true wet pressing section, which limits wet compaction and the development of sheet density. However, we can compare the data against a sheet made from OCC pulp under identical conditions. While the actual sheet basis weight varied somewhat from the target of 125 g/m², all of the strength tests except for the tensile energy absorption (TEA) index are indices normalized for basis weight. In one trial, we incorporated deinked old newsprint (ONP) at 25% along with MSW and OCC.

Overall, the sheet of 100% MSW was equal to the sheet of 100% OCC in burst strength, and was somewhat better in tensile strength, TEA, and short-span compression (SSC). The sheet composed of 50% MSW and 50% OCC had the most favorable strength properties overall. This 50:50 blend had greater test values in MD tensile strength (Fig. 3) and in both CD and MD SSC index (Fig. 4) than either source had in its pure state. The 50:50 blend produced strength properties superior to those of the other three blends listed in the table and would be a reasonable choice for a commercial corrugating medium mill to use as a fiber mixture.

The strength properties of MSW fiber blended in a corrugating medium sheet were achieved without extensive refining. The MSW stock was refined to a freeness of about 600 mL CSF, and the OCC was refined to a freeness of about 570 mL. OCC is commonly refined to a freeness of 400–500 mL CSF for use in either medium or linerboard. Consequently, if the strength values achieved in this study are acceptable, some energy savings in the form of reduced refining should be realized if MSW fiber is used. On the other hand, an increase in sheet strength could be produced without an excessively detrimental effect on sheet drainage if MSW fiber is further refined.

CONCLUSIONS

Cellulose fiber reclaimed from municipal solid waste by the steam autoclave

process appears to have unusually high freeness properties, even though the fiber types are highly heterogeneous. Apparently, this freeness increase is not simply the result of fines removal by fiber fractionation. The MSW fibers tend to be both less collapsed and less fibrillated than recycled OCC fibers of a comparable sample, as indicated by both light and scanning electron microscopy. The MSW fibers are coarser fibers that produce a network that drains more freely than the OCC sample.

The alternating pressure and vacuum treatment cycles of the steam autoclave could be reforming fiber into this state. Further laboratory simulations of the autoclave vessel are planned to firmly establish that the process has this apparently beneficial effect. Regardless of its origin, higher freeness values of recycled fiber for either corrugating medium or linerboard production are desirable from an economic and performance standpoint.

Handsheet and pilot paper machine experiments revealed that MSW fiber compares favorably with either commercial corrugating medium or OCC in terms of basic strength properties germane to medium. In pilot machine trials, a 50:50 blend of MSW and OCC produced paper with a favorable combination of strength properties and with properties superior to those of a sheet made from 100% OCC. The use of MSW fiber in paper and board products will

facilitate the adoption of processes that can help reduce the amount of waste being sent to landfills. **TJ**

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INSIGHTS FROM THE AUTHORS

Comprehensive Resources, Recovery, and Reuse asked our help in studying some unusual properties of fiber produced by its MSW reclamation process. We had done research on processing optimization and on the properties of secondary fiber. MSW fiber is another type of secondary fiber with the potential to be part of the furnish in paper and paperboard products. Its commercial use could help reduce landfill demand.

One difficulty we ran into was trying to find a way to examine the fiber structure after the steam autoclave process. We worked with Weyerhaeuser on a method of freeze-drying the fibers and embedding them in a plastic mount so we could view them under high magnification.

We found that even though cellulose fiber derived from MSW is highly heterogeneous, it has some properties that could make it advantageous for use in a commercial product like corrugating medium. The

enhanced drainage of the MSW fiber, for example, is one of its most interesting aspects.

For mills using large amounts of OCC in making corrugating medium or linerboard, MSW could be a less expensive raw material. In fact, the next step for us is to run a mill trial with MSW fiber included as part of the furnish for a corrugating medium sheet. A trial with 20% or 30% MSW fiber should show the feasibility of utilizing this fiber source.

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