12-1983

The Use of Old Corrugated Board in the Manufacture of High Quality White Papers

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THE USE OF OLD CORRUGATED BOARD
IN THE MANUFACTURE OF
HIGH QUALITY WHITE PAPERS

by

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A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University

Kalamazoo, Michigan

December, 1983

ABSTRACT

Clean corrugated board waste was fractionated into its softwood/hardwood fiber components, repulped using a kraft pulping process, and bleached using a CEHD bleaching sequence in an effort to produce high brightness fiber suitable for use in medium to high quality white paper.

The papers produced had almost equivalent mechanical strengths and opacity, but possessed unsatisfactory brightness and cleanliness when compared to commercially manufactured bleached kraft pulps of identical softwood/hardwood contents.

Based on this experimental data, the use of recycled fiber from corrugated board as a fiber substitute in the manufacture of high quality printing and writing papers is not recommended due to its inferior brightness and cleanliness. The pulps might find applications in the manufacture of medium quality printing and writing papers if used as a partial fiber substitute for kraft pulps.

KEY WORDS: Corrugating Board, Recycling, Pulping, Bleaching

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INTRODUCTION

Due to the increasing costs and shortages of prime pulp producing raw materials on a world-wide scale, the paper industry has had to look for and utilize alternative fiber sources to fulfill its requirements. One of these many sources is waste paper or, to which this paper is concerned, corrugated board.

When compared to the other waste paper grades, used corrugated board offers an abundant and economical source of fiber which can be easily collected with only minor traces of impurities. The corrugating business has been the largest single container business since 1978 and is growing 3-3½% per year [1] but only 24% of the corrugated containers (including converter waste) produced is recovered or reused, little better than the 20% recycling ratio for all fibers. It is therefore evident that an ample opportunity exists to expand the overall recycling ratio and to "upgrade the end uses for the fiber".

Old corrugated containers used for industrial or commercial purposes are less likely to be contaminated with undesirable materials commonly found in other post-consumer grades for waste paper. Also, commercial-industrial waste is more concentrated (than house-hold waste) and, consequently, is easier to collect and will present fewer sorting problems. Normal pulping of old corrugated produces considerably less pollution than does kraft pulping so there is no air pollution, no odor, and less water pollution.[2,3]

The main disadvantages to the increased usage of recycled corrugated boxes are the loss in strength properties of the recycled product and the economics of the process. Most of the strength loss is due to the deterioration of the fiber characteristics that occur in the recycling

operations and are, therefore, not recoverable.[4]

The objective of this study is to focus on determining a procedure that will upgrade the fiber characteristics from the corrugated waste board and then to assess the usefulness of the recycled paper for the manufacture of medium to high quality white paper, e.g. book paper.

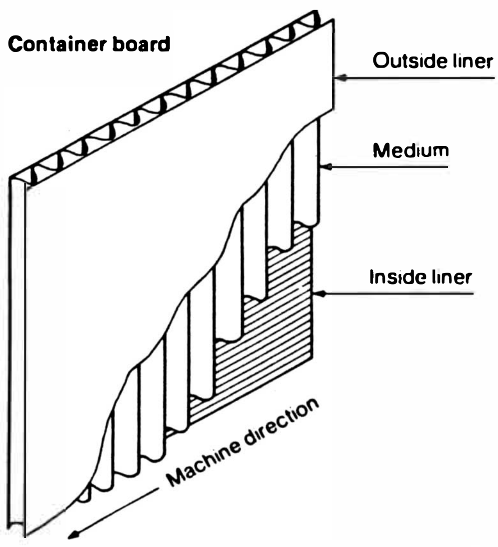
BACKGROUND DISCUSSION

Corrugated Board

As stated previously, corrugated board is the largest single grade of paper produced and still growing rapidly.[5] It is also the largest packaging container material, representing almost two-thirds of the $10 billion packaging industry.

Corrugated is a fairly recent form of paperboard packaging receiving its first patent (for its present form) during 1871 by an American innovator by the name of A.L. Jones. Previously, corrugated fiberboard began as a fluted portion of paper which served as a sweat band in gentlemen's top hats during the 19th century and later as a protective covering for vials and bottles. It was not until three years afterwards that Jones sandwiched the fluting between two flat sheets of paper which was the beginning of the corrugating industry.[6]

Corrugated board consists of two types of products made from the paper industry: the corrugated medium or the fluted portion and the linerboard which includes the top and bottom of the "sandwich":[7]



Corrugated Medium

Hardwood semi-chemical pulps are most commonly used in the production of corrugated medium with neutral sulfite semichemical being the most popular followed by modified kraft and soda cooking processes. Pulps of hardwood composition are used since it is less costly than softwood pulps and it contributes to the particular type of strength and stiffness needed in the corrugated medium though up to 20% softwood kraft long fiber may be added to improve paper machine runnability.

The pulp used for the corrugated medium contains a high lignin and hemicellulose content and is typically refered to as a "raw cook". By deliberately using weak cooking conditions and little washing, these compounds will remain with the fibers and assist in forming the rigid fluted shaped required.

Also used in the manufacture of some types of medium is recycled or secondary fibers normally originating from old corrugated containers and cuttings from corrugating plants. Commonly, up to 40% of the weight of paper can be secondary fibers but strength and stiffness usually suffer. Bogus medium (100% recycled) using mixed waste, waste news, and old corrugated containers is sometimes used where low cost is needed and strength and stiffness are not important.[8, 9]

Linerboard

The production of linerboard is primarily restricted to the use of virgin softwood fibers with up to 20% hardwood or secondary fiber. Strength is the predominant reason for the utilization of long fibered softwood pulps.

The kraft pulping process is most commonly used in the manufacture of this board with several high-yield processes being recommended. The

pulp requires some refining to increase strength and like the medium, the pulp is cleaned and washed only enough to reclaim the waste chemicals and, therefore, contains relatively high concentrations of lignin and hemicellulose.[10, 11]

Historical Review

In the past, the use of recycled corrugated has been limited to the manufacture of construction and combination board (75% of total corrugated recycled) or semi-chemical corrugating, bogus medium corrugating, and jute and kraft linerboard (25% of total corrugated recycled).[12] Union Camp of Savannah, Georgia was among the first to use old corrugated in their kraft liner. Richard Chase of the corporation states, "Our installations illustrates two incentives for supplementing old corrugated waste in kraft liner: to increase capacity or to reduce pulp cost. There is a third incentive which could become more urgent then either of the others. The national problem of solid waste disposal has placed strong emphasis on recycling". Their mill in Montgomery, Alabama was designed for 700 tons per day but their paper machine could operate at 1000 tons per day. They were able to increase their mill production to 850 tons per day but no further. So during 1970, a repulping system to handle old corrugated was constructed adding 150 tons per day extra to their overall production.[13, 14]

Other examples of this type of operations are the Interstate Paper Corp. at Riceboro, Georgia and the Great Southern Paper at Cedar Springs, Georgia which both added a 150 ton per day corrugated waste repulper during the early 1970's to complement their present systems.[15, 16]

Investigations into the use of old corrugated for other than the above mentioned applications are few, especially concerning the upgrading

of the fibers to that such as in the manufacture of high quality white papers.

In one investigation by Baczynska and Krol, two bleaching schemes were used in order to determine the possibility of increasing the brightness of waste board to 60-65% while maintaining its strength to that of nonbleached sulfite pulp. Using only the corrugated medium (semi-chemical birch and semi-chemical straw pulps), CEH (Chlorination, Alkali Extraction, Hypochlorite) and HP (Hypochlorite, Peroxide) bleaching schemes were performed on laboratory and pilot-plant scales, examing the influence of various bleaching chemical amounts (% as chlorine in chlorination and hypochlorite stages) on brightness, brightness stability, yield, and strength properties of the finished product. These values were used as criteria for evaluating the quality of the semi-bleached papers.

It was discovered that for waste corrugated containing semi-chemical birch pulp, the optimum amount of chlorine that should be added in the chlorination stage was about 10% with respect to the pulp mass while any quantities less then 9% produced unsatisfactory brightnesses (57-59%). Increasing the chlorine addition in the first stage to 12.5% increased the brightness to 75% but because of the high levels of unused chlorine, it was considered excessive and not economical.

In the case of the hypochlorite stage, chlorine concentrations of 3.5-4.0% was found to give the desired brightness when used with at least 10% chlorine in the first stage.

Therefore, waste corrugated medium containing semi-chemical birch can be bleached in a CEH system to a brightness of 60-65% by the total addition of 13.5-14.0% active chlorine.

Semi-chemical straw corrugated medium was found to be less desirable for upgrading by bleaching due to excessive strength losses.

Bleaching using the HP system was found to be uneconomical due to the high cost of hydrogen peroxide and the low brightness achieved (59%). One advantage of this bleaching sequence was that the pulp yield was 3% higher then that of the CEH sequence.

Conclusions drawn from this study were as follows:

1. The CEH bleaching of corrugated medium gives a yield of 88%, a brightness of 60-70%, and strength properties equal to nonbleached sulfite cellulose pulp.

2. Replacement of nonbleached sulfite cellulose pulp with semi-bleached waste paper pulp from corrugated board will reduce the cost of raw materials.

3. Semi-bleached waste paper pulp from corrugated board represents a valuable substitute raw material.[17]

In a second research study, by Szymanski and Szmit, corrugated board (as well as other waste papers) were bleached specifically for the use as replacement fibers in the manufacture of high quality white papers. Clean corrugated board waste was first fiberized in a hydrapulper and then bleached using a CEH sequence (variant I) and a CEHP sequence (variant II). Chlorination was carried out at 3.5% consistency, alkali extraction and hypochlorite at 5.5% consistency. The pulp was acidified using SO_2 to a pH 4, washed then screened.

White papers obtained from the corrugated were evaluated for their optical, structural, and mechanical properties and, most importantly, their printing capabilities, i.e. maximum ink distribution coefficient, show through, picking, etc. These were determined by actually printing on the papers using laboratory-size letterpress, gravure, and offset presses.

The results of the study concerning the use of corrugated waste board are summarized as follows:

1. The bleached pulp, additionally treated with hydrogen peroxide (variant II), exhibited good dewatering capacity and runnability on the paper machine, possessed high mechanical strength properties not typically found with secondary fibers, high brightness (73%), and purity.

2. The pulp can be used in the manufacture of groundwood-free printing and writing papers but papers containing these pulps has lower brightness and mechanical strength but higher opacity and dimensional stability when compared to traditional papers. Printing was comparable. 18

EXPERIMENTAL PROCEDURE

Part I: Fractionation

The fractionation of the corrugated board into its softwood/hardwood constituents was performed using the equipment available in the Fiber Processing Pilot Plant (see Appendix for Flowchart). Two hundred pounds of clean trim corrugated scrap with 2.5% (based on air-dried weight of corrugated) NaOH and 1.0% (based on A.D. corrugated) TSPP to aid in fiber separation were added to the Black Clawson Hydrapulper containing 472 gallons of water (5% consistency) and cooked for 15 minutes at 140°F. The stock was then diluted to 2.5% consistency using cold water and sent acrossed the Bird-Jonsson Vibrating Screen (1/8" holes) to clean the pulp of contaminants.

The accepted pulp was diluted to 1.0% consistency and pumped through the Black Clawson Selectifier, utilizing a screen cylinder with 0.062" holes, to separate the long softwood fibers (linerboard) from the short hardwood fibers (corrugated medium). Samples were collected from both fractions for fiber length classification (T 233 os-75; Fiber Length of Pulp by Classification-Clark Classifier). Each fraction was separately pumped to the Paper Pilot Plant, formed into paper, and stored in a constant humidity room until ready for repulping. Fiber microscopy was performed on the two fractions to determine the actual softwood/hardwood ratio since fiber separations are rarely 100% efficient.

Part II: Pulping

Both fiber fractions were separately pulped using the kraft cooking process controlling the following variables: chemicals, i.e., percent sulphidity, active alkali, and liquor to fiber ratio, time of cook, and length of cook. Criteria for selecting the optimum cook was based

primarily on Kappa Number (T 236 os-76; Kappa Number of Pulp). It was felt that a Kappa Number of 30 would be sufficient for the softwood and 20-25 for the hardwood.

A. Preliminary Pulping

For the preliminary trials, the Oil Bath digester was used to determine the best combination of the above stated variables since several cooking conditions and wood types could be performed simultaneously at the same temperature. The paper was torn into one inch squares and an equivalent oven-dried weight of 100 grams (percent moisture of the air-dried paper was estimated as 7%) placed into a steel bomb. Since the pulping liquor could contact and saturate the fibers directly (that is, did not require time for penetration or diffusion to occur), the size of the paper squares and the impregnation time were not a particular concern. The prepared liquor was poured into the bomb which was then sealed. A set of six bombs (duplications of three different cooking conditions using softwood and hardwood) was submerged into a oil bath preheated to at least 110°C and brought to cooking temperature as quickly as possible. During the digestion, the bombs were rotated continuously to achieve a uniform cook.

Two preliminary trials were necessary to determine the proper cooking conditions:

TABLE 1: PRELIMINARY PULPING

Trial	Bomb #	Wood Type	Cooking Temperature	Cooking Time	% Active Alkali*	White Liquor
1	1,2,3	Softwood	160°C	90 min.	15,10,5	17.7% sulphidity
	4,5,6	Hardwood	160	90	15,10,5	90.8 g/l active
2	1,2,3	Softwood	165	90	20,15,10	alkali as Na_2O
	4,5,6	Hardwood	165	90	20,15,10	

* based on oven-dried fiber.

During the first preliminary cook, which used a liquor to fiber ratio of 5:1, it was noticed that the paper had a tendency to absorb all the white liquor leaving no excess. Realizing that this might effect the uniformity of the cook since some fibers may never become saturated with cooking liquor, it was decided to increase the dilution factor to 10:1 during the second cook so that there would be a definite excess of liquor and to be sure that all the fibers were properly impregnated. The cooking temperature and percent active alkali for the second cook were increased since it was necessary to remove more lignin than that removed during the first trial.

After digestion, the bombs were cooled, opened and the black liquor collected. The pulp, which retained its original shape, was defiberized in a large Waring blender, washed with cold water, and drained over a Buchner funnel several times to assure complete removal of residual black liquor. The black liquor was analyzed for active alkali and the pulp tested for Kappa Number.

B. Final Pulping

Once the proper cooking conditions were determined using the Oil Bath (trial #2), the M&K digester was used to duplicate the conditions and to produce enough pulp (500-600 grams) for bleaching and handsheet making.

The M&K digester is a dual-digester system connected together by a cross-over valve. For this thesis, one digester was used for the pulping operations while the second digester was used to equalize the pressure of the first digester and to act as a blow tank (for the liquor only) after the cook was completed.

As with the preliminary pulping, the paper was torn into one inch squares but an equivalent oven-dried weight of 400 grams was used as a

charge. The paper was placed into a metal cylinder with a perforated bottom and set into one of the digesters. The required liquor was poured into the digester for a 10:1 dilution ratio and 20% active alkali on fiber and the pump activated to make certain the liquor was circulating properly. The digester was then sealed making sure the vent line was open and the heaters (continuous and control) activated after having set the rheostat on full and the control heater a few degrees higher than 165°C, the cooking temperature. The vent line was closed at the first sign of discharging liquor indicating that all the excess gases and water vapor were removed from the digester. Once at cooking temperature, the rheostat was reduced causing the continuous heater to shut down so the digester could be maintained at the proper temperature for the 90 minute cooking time.

During digestion, the second digester was prepared to receive the black liquor and pressure from the first digester by cleaning and sealing it. A heat exchanger set at the crossover valve was used to cool the liquor during the blowing operations.

After the cook was completed, the crossover valve was slowly opened and the first digester depressurized to atmospheric pressure. The black liquor was collected from the second digester and pulp removed from the first digester. The pulp was washed with cold tap water, defiberized, drained several times over a Buchner funnel with cold water, and pressed dry in a wine press. The black liquor was tested for active alkali and sulfide and the pulp tested for yield (note: this yield is based on paper) and Kappa Number. Two batches were required for the softwood fraction and three for the hardwood fraction since the yields were low enough that one batch would not supply the needed amount of pulp necessary for bleaching and handsheet making.

Though anticipated, the M&K digester, with its more effective method of liquor circulation, cooked the fiber to a lower Kappa Number then that in the Oil Bath at the same pulping conditions. This led to the proper amount of cooking required for the hardwood but it may have overcooked the softwood very slightly. It was decided that the overcooking was not severe enough to necessitate changing the cooking conditions.

Part III: Bleaching

The hardwood and softwood fractions were separately bleached using a four stage sequence of chlorination, caustic extraction, hypochlorite, and chlorine dioxide (CEHD). The controlling variables are percent chemicals (as chlorine) used in the first, third, and fourth stages, time, temperature, pH, and consistency. All the variables were kept contant except for the percent chlorine used in the first stage. Criteria for selecting the best bleaching scheme was primarily based on Kappa Number but viscosity (T 230 os-76; Viscosity of Pulp) and pulp brightness were also considered. It was felt that a Kappa Number of 3-5 after the second stage would be best for both fractions with as little cellulose degradation as possible (high viscosity).

A. Preliminary Bleaching

1. Chlorination Stage

Batches of 30 grams oven-dried pulp were disintigrated into 800 milliliters distilled water and the required amount of chlorine water and dilution water (distilled) carefully added (chlorine is very unstable in water). The pulp and liquor were blended for one minute in a Waring blender to assure adequate mixing, poured into a two liter beaker, covered to keep the chlorine from escaping, and left standing at room temperature for 45 minutes. At the end of this time, the pulp was drained in a Buchner funnel and the first

filtrate collected for chlorine consumption and pH determination. The pulp was then placed into the Waring blender with warm distilled water, defiberized, and again drained in the funnel. Lastly, to make sure all the chlorine residual was removed from the pulp, boiling distilled water was drained through the pulp.

2. Caustic Extraction Stage

After weighing the pulp to determine the amount of water present in the pad (for dilution purposes), the pad was disintigrated for one minute in a Waring blender with the required amount of NaOH for 3% on fiber and enough boiling distilled water to attain a consistency of 3%. This pulp was then poured into a two liter beaker and set a top a hot plate to maintain a temperature of 90-100°C for 60 minutes. At the end of this time, the pulp was drained in a Buchner funnel using hot distilled water as a wash. Approximately one-fourth of the pad was removed for viscosity and Kappa Number determinations. No residual liquor was collected.

3. Sodium Hypochlorite Stage

The remaining pulp (about 22 oven-dried grams) was weighed for water determination and disintigrated in a blender for one minute with the necessary amount of NaOCl ($1\frac{1}{2}$% as Cl_2 on fiber) and hot distilled water to achieve a final consistency of 3%. The pulp was poured into a two liter beaker and the pH tested to make sure it was within the proper range of pH 9-10 using dilute HCL or NaOH to decrease or increase the pH if and when necessary. The beaker was then placed into a water bath set at 40°C and left for 90 minutes with occasional stirring. The pH was tested at 10 minute intervals.

At the end of the dwell time, the pulp was drained and the first filtrate removed for pH and residual tests. The pulp was throughly

washed with hot distilled water and one-third of the pad removed for viscosity and brightness.

4. Chlorine Dioxide Stage

The remaining pulp (about 15 oven-dried grams) was weighed to determine the water present in the pad and disintigrated in a Waring blender for one minute with the proper amount of ClO_2 (½% as Cl_2 on fiber) and hot distilled water for a consistency of 3%. The pH was adjusted to between pH 4.5-5.5 and the pulp (in a beaker) placed into a water bath set at 65°C and left for 120 minutes stirring occasionally. PH was tested every 20 minutes. The pulp was then drained, collecting the first filtrate for pH and residual testing, and the pulp washed with hot distilled water. The remaining pulp was tested for viscosity and brightness.

B. Final Bleaching

Once the optimum bleaching scheme was determined (the proper amount of chlorine in the first stage determined), 500 oven-dried grams of pulp was used in the final bleaching using the same conditions but modifying the procedure slightly. An 18-gallon rubber bucket was used to contain the pulp and a mega-mixer and powerstat used to mix the pulp during the addition of the bleaching chemicals. A steam hose was used in Stages 2, 3, and 4 to maintain the proper pulp temperatures.

Part IV: Handsheet Making

It was decided to compare the bleached recycled pulp to commercially bleached kraft softwood and hardwood pulps found in the pilot plant for:

1. Brightness (T 452 os-77)
2. Opacity (T 425 om-81)
3. Tensile and stretch (T 494 om-81)
4. Tear Resistance (T 414 ts-65)
5. Folding Endurance (T 511 su-69)
6. Dirt Count (T 437 pm-78).

Since the fiber microscopy indicated that the recycled softwood fraction was composed of 60% softwood and 40% hardwood and the recycled hardwood of 60% hardwood and 40% softwood, commercial pulps of 100% and 60/40 blends of both softwood and hardwood were used in the comparison.

The Valley Beater (T 200 os-70; Laboratory Processing of Pulp-Beater Method) was used to separately refine the six pulps to slightly above and below 400 milliliters CSF (Canadian Standard Freeness) so the tests could be interpolated to 400 milliliters CSF.

The British Handsheet Mold (T 205; Forming Handsheets for Physical Testing of Pulp) was used to make 10-12 handsheets of each pulp which were left to condition at 72°F and 50% relative humidity for two days before testing. All physical and optical tests were preformed as specified for each test in TAPPI Standards.

RESULTS AND DISCUSSION

Fractionation

The fractionation of the corrugated board as described in this thesis turned out to be a poor method in separating the softwood from the hardwood fibers. As Table 2 indicates, only 60% of the fiber in the hardwood and softwood fractions was actually hardwood or softwood, respectively. Fiber classification using the Clark Classifier shows the softwood having a greater percentage of longer fibers (greater than 14 mesh) than the hardwood and approximately an equal percentage of shorter fibers including fines.

TABLE 2: FIBER CONTENT AND LENGTH

Fraction	%SW	%HW	Percentage of Total by Mesh Size				
			X>14	14>X>30	30>X>50	50>X>100	fines
Softwood	60	40	13.5	29.2	21.1	15.1	21.1
Hardwood	40	60	6.7	28.7	24.2	16.0	24.5

Therefore, fractionation by fiber length was not an effective method for separating the fibers since most of the softwood fibers were the same length as the hardwood. Unfortunately, this was not realized until after the two fractions had been repulped and bleached and the fiber microscopy performed.

An alternative to fractionation by fiber length might be by separating the fibers by fiber density using the appropriate cleaners.

Pulping

The final pulping conditions for the two fractions were identical though the softwood fraction may have been very slightly overcooked. The pulps consumed almost an equal amount of active alkali and obtained an equivalent Kappa Number, but there was a **definite difference** in the

yields based on the pilot plant paper after fractionation, an average of 74.3% for the softwood and 63.9% for the hardwood.

TABLE 3: FINAL PULPING

Wood Type*	% Yield**	Kappa Number	% Active Alkali Consumed
Softwood #1	88.2	22.1	10.0
Softwood #2	71.7	24.0	9.9
Hardwood #1	63.0	20.5	10.25
Hardwood #2	57.8	20.0	11.1
Hardwood #3	70.0	24.2	10.2

* by batch number
** based on paper

Since the hardwood was produced using a sulfite semi-chemical process with very little washing ("raw cook"), it possesses a larger quantity of lignin and hemicelluloses than the softwood which was produced using a modified kraft process. Therefore, a greater amount of material is dissolved during repulping leading to a lower yield. The difference in the yields is not as great as one would expect but this is due to the softwood/hardwood content in each fraction which also explains the identical pulping conditions.

The pulping conditions used in this thesis deviated slightly from the conditions used in a conventional kraft process because of time considerations and equipment contraints. A comparison of the important conditions are as follows:

TABLE 4: EXPERIMENTAL VS. MILL CONDITIONS

Pulping Conditions	Experimental	Kraft Mill*
Active Alkali (O.D. fiber)	18%	16-18%
Sulphidity	18%	20-25%
Liquor:Wood ratio	10:1	4:1
Cooking Temperature	165°C	160-170°C
Impregnation	Liquor applied directly to fibers	pre-steaming chips
Impregnation time	60 minutes	90 minutes
Cooking time	90 minutes	90 minutes

* Source:"The Pulping of Wood", McGraw-Hill, New York, 1969.

As discussed in the experimental procedure, a 10:1 liquor to wood ratio was necessary to assure all the fibers were completely saturated with cooking liquor. This resulted in a much lower alkali concentration in the digester than that found in a normal commercial cook on wood. Also, discussed was the reasoning behind the lack of impregnation and impregnation time required for this thesis since paper was used as a fiber charge instead of wood chips.

Bleaching

For the pulp used in the bleaching sequence, it was discovered that the hardwood fraction required a greater percentage of chlorine addition in the first stage than that required for the softwood (Table 5) despite the fact that both fractions possessed an equivalent Kappa Number (Table 3) before bleaching and also that the fractions contained almost the same softwood/hardwood content. This may be the result of a change in lignin chemistry caused by the repulping. The softwood lignins, which were originally pulped using a kraft process and then repulped using the same process, are probably different in type, quantity, and accessibility than the hardwood lignins which were originally pulped using a NSSC process and then repulped using a kraft process. This is a possible assumption since little work has been done in the study of lignin effects caused by repulping using different processes. The Kappa Numbers following the extraction stage were 2.86 for the softwood and 3.06 for the hardwood, almost identical.

Chemical consumption in stages 1, 3, and 4 were all quite low and displayed poor correlation when compared to the preliminary bleaching. The low consumptions may have been the result of too low a consistency in these stages as well as lower temperatures in stages 2, 3, and 4 since it was difficult to maintain these stages at the proper temperatures.

Table 5 demonstrates this:

TABLE 5: BLEACH CHEMICAL CONSUMPTIONS*

Stage	Wood	Consistency	Temperature		Percent on fiber**	% Consumed	
			Prelim.	Final		Prelim.	Final
Cl_2	SW	2.0%	25°C	25°C	4.5%	77.1%	86.6%
	HW	2.0	25	25	5.5	89.0	81.9
NaOCl	SW	3.0	40	37-42	1.5	75.8	41.6
	HW	3.0	40	37-42	1.5	74.2	58.2
ClO_2	SW	3.0	65	58-68	0.5	16.3	10.1
	HW	3.0	65	58-68	0.5	19.5	43.2

* All other conditions were the same. See Table 7.
** As Cl_2 on oven-dried fiber.

Viscosity, which is a measure of polymerization of the cellulose and which is used as a "general" indicator of pulp strength, was approximately the same for both fractions owing to the softwood/hardwood content of the fractions, and decreased steadily through each consecutive stage. This indicates that the cellulose chains are degrading and breaking.

TABLE 6: PULP VISCOSITIES

Stage	Viscosity (centipoise)	
	Softwood	Hardwood
Before Chlorination	8.73	9.08
Extraction	8.68	8.56
Hypochlorite	7.55	7.67
Chlorine Dioxide	7.01	7.17

The large decrease in viscosity at the hypochlorite and chlorine dioxide stages is caused by lack of selectivity of these oxidizing chemicals toward the carbohydrates. When compared to commercially bleached pulps, the recycled softwood fraction seem to be very degraded (viscosity of 7.01 as compared to 13.43 for the commercial softwood) while the recycled hardwood fraction showed little degradation (7.17 versus 6.58 for the commercial hardwood).

As with the pulping, bleaching conditions deviated from conditions used in a conventional bleach plant due to time and equipment constraints.

TABLE 7: EXPERIMENTAL VS. MILL CONDITIONS

Stage	Experimental	Bleach Plant*
Chlorination		
% Cl_2 based on dry wood	5.5 for hardwood 4.5 for softwood	4.5-5.0
Temperature (°C)	25	25
Dwell time (min.)	45	45-60
pH	1.2-1.7	2.0
Consistency (%)	2.0	3.0
Caustic Extraction		
% NaOH based on dry wood	3.0	1.5-2.0
Temperature (°C)	85-95	about 100
Dwell time (min.)	60	60
pH	12+	12+
Consistency (%)	3.0	12
Sodium Hypochlorite		
% as Cl_2 based on dry wood	1.5	1.0-1.5
Temperature (°C)	37-42	35
Dwell time (min.)	90	120-180
pH	9-10	10-11
Consistency (%)	3.0	10-12
Chlorine Dioxide		
% as Cl_2 based on dry wood	0.5	less than 1.0
Temperature (°C)	58-68	60
Dwell time (min.)	120	240-300
pH	4.5-5.5	4.5-5.5
Consistency (%)	3.0	8.0

* S.D. Warren; Muskegon, Michigan.

Bleaching temperatures were increased to increase reaction rates so as to decrease dwell times. The consistency was less since smaller quantities of pulp were used. As stated previously, these conditions greatly influenced the chemical consumption and as a result caused the consumption in all stages to be less than satisfactory.

Paper Properties

For the physical tests, folding endurance and internal tear resistance were used to simulate the principle stresses set up when a leaf of a book is turned. Tensile strength was used as a measure of fiber bonding and strength and percent elongation as an indication of the extensibility of the fibers. For the optical tests, opacity was used as an end-use property since show-through is an important consideration when printing on both sides of a sheet. Brightness was measured since it is important for printing and for asthetic reasons as is the amount of dirt in the pulp.

Physical Tests

The mechanical properties of the recycled pulps were generally very good when compared to commercially manufactured pulps having the same hardwood/softwood content.

TABLE 8: PHYSICAL TESTS*

Test	Softwood			Hardwood		
	Commercial		Recycled	Commercial		Recycled
	100%	60/40	60/40	100%	60/40	60/40
lb./ream 25 x38-500 sheets	37.9	40.0	38.6	39.7	40.0	40.7
Bulk (cc/gm)	1.43	1.42	1.67	1.50	1.47	1.65
Tensile Factor (m)	8130	5960	6140	5590	6270	5910
Tear Factor (gm)	85.9	100.7	100.9	65.6	96.4	96.1
Stretch (%)	2.19	2.25	2.16	1.75	2.27	2.21
Fold (cycles)	995	675	236	24	382	206

* All tests are at 400 ml CSF.

The tensile strength values of the recycled pulps were identical to their commercially manufactured counterparts, 6140 meters vs. 5960 meters for the softwood and 5910 meters vs. 6270 meters for the hardwood, suggesting equal fiber strength and fiber bonding. The tear resistance was also identical between the virgin and recycled pulps, 100.7 grams vs. 100.9 grams

for the softwood and 96.4 grams vs. 96.1 gramm for the hardwood, implying equal fiber bonding and extensibility. The folding endurance, a measure of fiber flexibility, was significantly different. The recycled pulps showed reduced flexibility caused by its stiff nature due to lack of hydration and its flat, ribbon-like shape.

In comparing the recycled softwood (60/40) to 100% virgin softwood, all the mechanical tests for the recycled pulp indicated less fiber-to-fiber bonding and decreased fiber length caused by the hardwood content. Tensile was greater for the virgin pulp since it contained a larger percentage of longer fibers and possessed superior bonding characteristics, 8130 meters vs. 6140 meters. Tear was higher for the recycled pulp due to less bonding and stiffer shorter fibers thus increasing work cuaed by friction, 100.9 grams vs. 85.9 grams. Fold was less for the recycled softwood since the short stiff fibers have reduced flexibility when compared to the longer fibers in the virgin softwood, 236 folds vs. 675 folds. For the hardwood, the mechanical tests for the recycled pulp indicated increased fiber length, strength, and flexibility due to the 40% softwood content with little or no improvement in bonding.

Optical Tests

Overall, the optical properties for the recycled pulps were not as good as those obtained from virgin pulp (see Table 9). Opacity in the softwood remained about the same, 68.9% for the virgin pulp containing 60/40 fiber blend vs. 68.2% for the recycled softwood. The opacity of the recycled hardwood was slightly higher due to the opacifying effects caused by recycled fibers, 71.8% vs. 69.9%. Brightness was extremely poor for the recycled fractions, 66.4% vs. 73.8% for the softwood pulps and 65.8% vs. 73.9% for the hardwood pulps. The brightness, though

TABLE 9: OPTICAL TESTS*

Tests	Softwood			Hardwood		
	Commercial		Recycled	Commercial		Recycled
	100%	60/40	60/40	100%	60/40	60/40
lb./ream 25 x 38-500 sheets	37.9	40.0	38.6	39.7	40.0	40.7
Opacity (%)	62.9	68.9	68.2	74.0	69.9	71.8
Brightness (%)	71.0	73.8	66.4	72.3	73.9	65.8
Dirt (ppm)	0.175	0.165	0.334	0.150	0.160	0.254

* All tests are at 400 ml CSF.

reduced by refining to some degree, was a result of the bleaching scheme used in this thesis. Increased retention times and higher consistencies (or higher bleach concentrations) might increase the brightness of the recycled pulps to that of the virgin pulps.

The amount of dirt found was greater in the recycled pulps than in the virgin pulps as one would expect since during the manufacture of corrugated board, very little washing (cleaning) is performed. Therefore, this dirt (or bark) remained in the pulp during the bleaching and because it is resistant to the bleaching chemicals it remained dark. Cleaning the pulp after fractionation might remove the excess dirt. The amount of dirt found in the recycled pulps may be deceiving (0.334 ppm vs. 0.165 ppm for the softwood and 0.254 ppm vs. 0.160 ppm for the hardwood) since it is believed that the steam coming from the steam hose used during the bleaching scheme may have been contaminated.

In comparison with 100% vrigin pulps, the opacity was greater for the recycled softwood pulp due to the hardwood fiver content and the opacifying effects caused by the recycled fibers, 68.2% vs. 62.9%. The opposite occured in the hardwood pulps. The virgin hardwood has a higher opacity since it was not contaminated with softwood fibers as was the recycled pulp, 71.8% vs. 74.0%. As for brightness, the same trend occured as mentioned in the above paragraph, reduced brightness in the recycled pulp due to the bleaching sequence used.

CONCLUSIONS

Repulped and bleached hardwood and softwood pulps obtained from fractionated clean corrugated board waste have almost equivalent tensile strength, tear resistance, and stretch when compared to bleached hardwood and softwood kraft pulps indicating equal fiber bonding, fiber strength, and fiber extensibility. The recycled pulps displayed reduced folding endurance implying less fiber flexibility than that found in virgin pulps and they were also bulkier.

Optical properties of the recycled pulps were rather poor in comparison to the virgin pulps. The opacity of the recycled pulps was the same or slightly better than that for the virgin pulps and the brightness was very low displaying a yellowish tint. Also, the dirt was very high in the recycled pulps.

From this study, it is felt that the pulps obtained from corrugated board are unsatisfactory as a total replacement fiber for kraft pulps used in high quality writing and printing papers because of its insufficient brightness and cleanliness. It seems, however, that the pulps could find applications in the manufacture of medium quality printing and writing papers if used as a partial fiber substitute for the kraft.

RECOMMENDATIONS

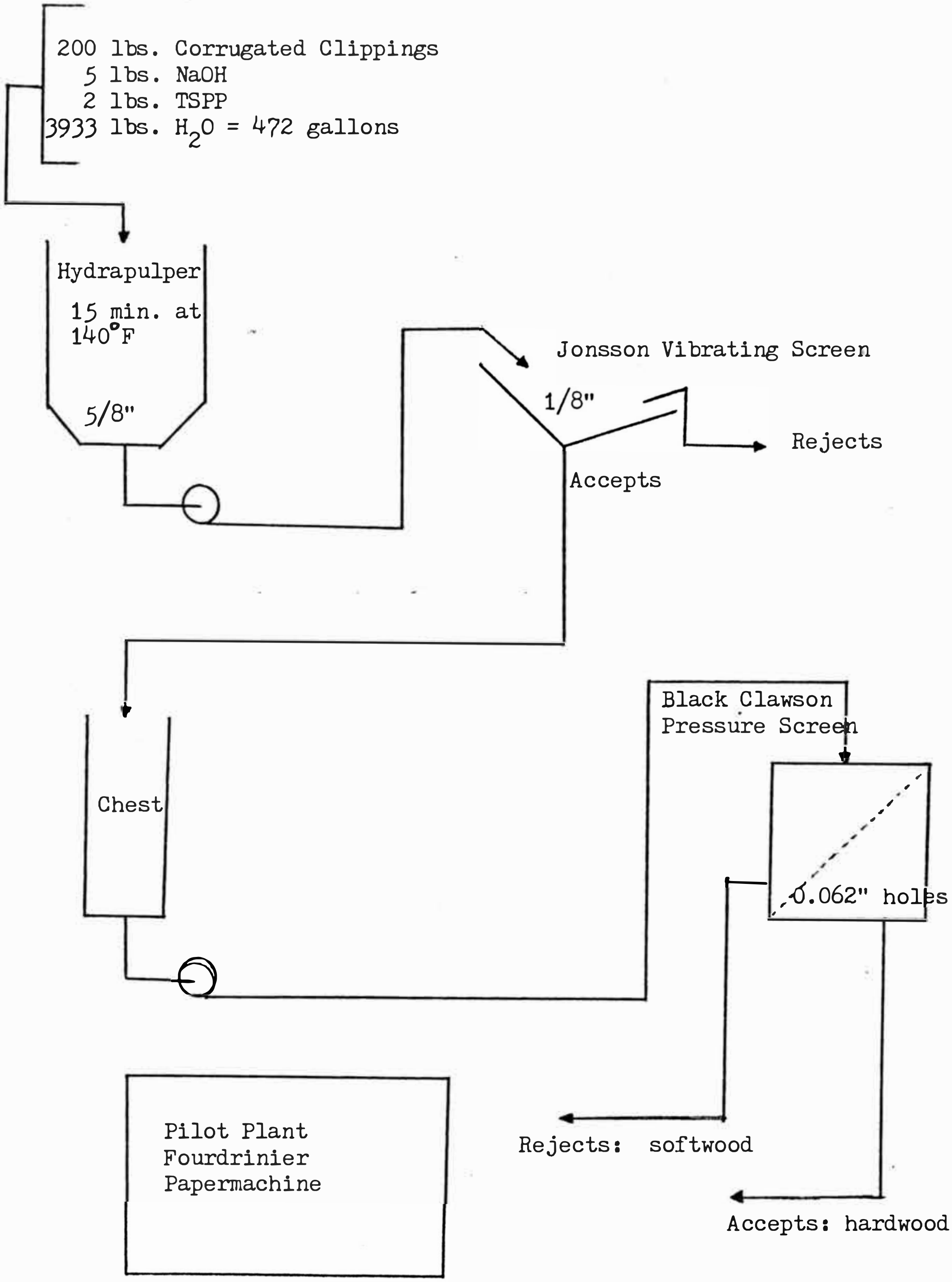
There are several possibilities for further studies involving the use of recycled corrugated as a upgraded fiber source.

The procedure used in this thesis could be re-preformed in an effort to improve the fiber separation during fractionation and to refine the pulping and bleaching conditions. This could involve using the same or different fractionation methods, pulping processes, bleaching sequences, etc. Also, a evaluation of the effects of the recycled pulps on the properties of printing papers manufactured from stock containing certain percentages of the recycled pulp is possible.

Another possibility could be concerned with the printability of the papers. This could involve actually printing on the papers using letter-press, gravure, and offset-type presses studying the properties of maximum ink distribution, show-through, picking, etc. The pilot Kamyr digester that is to be installed in the near future at the Paper Science and Engineering Department makes a pilot-plant study a real possibility.

APPENDIX

Fractionation Schematic



RAW DATA

Fractionation

Fiber Classification*

Softwood Fraction

Sample	% Consistency	Weight of Fiber in Fraction	Percent of Total
X 14 mesh	0.078%	0.78 grams	13.5%
14 X 30	0.169	1.69	29.2
30 X 50	0.122	1.22	21.1
50 X 100	0.087	0.87	15.1
fines	-----	1.22	21.1
		Total: 5.78 grams	Total: 100.0%

Hardwood Fraction

Sample	% Consistency	Weight of Fiber in Fraction	Percent of Total
X 14 mesh	0.040%	0.40 grams	6.7%
14 X 30	0.172	1.72	28.7
30 X 50	0.145	1.45	24.2
50 X 100	0.096	0.96	16.0
fines	-----	1.47	24.5
		Total: 6.00 grams	Total: 100.0%

* Pulp samples consisted of 1000 ml of approximately 0.6% stock added to the classifier.

Fiber Microscopy

Fraction	Number of Fibers Counted		Total	Percentage of Fibers	
	Softwood	Hardwood		Softwood	Hardwood
Softwood	300	201	501	60	40
Hardwood	117	175	292	40	60

Pulping

Preliminary Pulping

Active alkali, 90.8 g/l as Na_2O; effective alkali, 82.8 g/l as Na_2O; sulphidity, 17.7%; fiber charge, 100 oven-dried grams.

Trial #1 (maximum temperature, 160°C; time to maximum, 52 minutes; time at maximum, 90 minutes; liquor:wood ratio, 5:1)

Bombs	Wood Type	% Active Alkali on o.d. fiber	Kappa #	Active Alkali in Black Liquor
1	Softwood	15%	45.3	18.9 g/l
2	Softwood	10%	54.8	10.2
3	Softwood	5	----	----
4	Hardwood	15	36.4	14.2
5	Hardwood	10	54.0*	No black liquor
6	Hardwood	5	45.3	9.9

* Believed to have leaked.

Trial #2 (maximum temperature, 165°C; time to maximum, 65 minutes; time at maximum, 90 minutes; liquor:wood ratio, 10:1)

Bombs	Wood Type	% Active Alkali on o.d. fiber	Kappa #	Active Alkali in Black Liquor
1	Softwood	20%	38.6	12.9 g/l
2	Softwood	15	43.4	7.2
3	Softwood	10	51.1	4.2
4	Hardwood	20	36.6	11.1
5	Hardwood	15	42.0	6.9
6	Hardwood	10	----	3.7

Final Pulping

Active alkali, 90.8 g/l as Na_2O; effective alkali, 82.8 g/l as Na_2O; sulphidity, 17.7%; maximum temperature, 165°C; time to maximum, 51-64 min.; time at maximum, 90 min.; percent active alkali on o.d. fiber, 20%; liquor: wood ratio, 10:1; fiber charge, 400 oven-dried grams.

Wood Type	% Yield*	Kappa #	Black Liquor Concentrations: Active Alkali	Black Liquor Concentrations: Sodium Sulfide**
Softwood #1	88.2%	22.1	10.0 g/l	0 g/l
Softwood #2	71.7	24.0	10.1	0
Hardwood #1	63.0	20.5	9.75	0
Hardwood #2	57.8	20.0	8.9	0
Hardwood #3	70.0	24.2	9.8	0

* This yield is based on paper not wood.
** Sulfide levels questionable due to difficulties with equipment.

Wood Type	Percent Active Alkali		
	Charged	At End of Cook	Consumed
Softwood #1	20.0	10.0	10.0
Softwood #2	20.0	10.1	9.9
Hardwood #1	20.0	9.75	10.25
Hardwood #2	20.0	8.9	11.1
Hardwood #3	20.0	9.8	10.2

Bleaching

Preliminary Bleaching (fiber charge of 30 o.d. grams)

	Bleach #1		Bleach #2	
CHLORINATION (45 minutes, 25°C, 2% consistency)				
	Softwood (5%)	Hardwood (5%)	Softwood (4½%)	Hardwood (5½%)
Initial Liquor				
g/l	5.216	5.216	5.856	5.856
pH	1.7	1.7	1.5	1.5
Residual Liquor				
g/l	0.0426	0.0036	0.2059	0.1207
pH	2.2	2.2	2.5	2.4
% Consumed	95.7	99.6	77.1	89.0
CAUSTIC EXTRACTION (60 minutes, 90-100°C, 3% consistency)				
	Softwood (3%)	Hardwood (3%)	Softwood (3%)	Hardwood (3%)
Initial Liquor				
g/l	10.0	10.0	10.0	10.0
Kappa Number	2.33	4.41	2.40	2.40
Viscosity (cps)	5.45	8.20	4.93	6.18
SODIUM HYPOCHLORITE (90 minutes, 40°C, 3% consistency)				
	Softwood (1½%)	Hardwood (1½%)	Softwood (1½%)	Hardwood (1½%)
Initial Liquor				
g/l	8.627	8.627	8.660	8.660
pH	10.1	10.1	10.5	10.5
Residual Liquor				
g/l	0.1704	0.1562	0.1065	0.1136
pH	11.3	11.3	10.9	10.9
% Consumed	61.3	64.5	75.8	74.2
Viscosity (cps)	5.18	6.68	4.93	5.15
Brightness (%)	76.3	71.4	76.5	72.1

CHLORINE DIOXIDE (120 minutes, 65°C, 3% consistency)

	Softwood (½%)	Hardwood (½%)	Softwood (½%)	Hardwood (½%)
Initial Liquor				
g/l	12.014	12.014	11.120	11.120
pH	5.3	5.3	5.2	5.2
Residual Liquor				
g/l	0.1101	0.0994	0.1256	0.1207
pH	5.9	6.1	5.0	5.6
% Consumed	26.6	33.7	16.3	19.5
Viscosity (cps)	4.77	6.62	5.06	6.02
Brightness (%)	82.3	76.2	81.8	79.8

Final Bleaching (fiber charge of 500 o.d. grams)

CHLORINATION (45 minutes, 25°C, 2% consistency)

	Softwood (4½%)	Hardwood (5½%)
Initial Liquor		
g/l	6.056	5.700
pH	1.3	1.2
Residual Liquor		
g/l	0.1207	0.1988
pH	1.7	1.5
% Consumed	86.6	81.9

CAUSTIC EXTRACTION (60 minutes, 85-95°C, 3% consistency)

	Softwood (3%)	Hardwood (3%)
Initial Liquor		
g/l	10.0	10.0
Kappa Number	2.86	3.06
Viscosity (cps)	8.68 (8.73 before bleaching)	8.56 (9.08 before bleaching)

SODIUM HYPOCHLORITE (90 minutes, 37-42°C, 3% consistency)

	Softwood (1½%)	Hardwood (1½%)
Initial Liquor		
g/l	8.9482	9.1621
pH	10.5	10.1
Residual Liquor		
g/l	0.2627	0.1882
pH	9.4	9.4
% Consumed	41.6	58.2
Viscosity (cps)	7.55	7.67
Brightness (%)	74.3	73.8

CHLORINE DIOXIDE (120 minutes, 58-68°C, 3% consistency)

	Softwood (½%)	Hardwood (½%)
Initial Liquor		
g/l	11.0515	11.390
pH	4.7	4.7
Residual Liquor		
g/l	0.1349	0.0852
pH	4.7	4.8
% Consumed	10.1	43.2
Viscosity (cps)	7.01	7.17
Brightness (%)	78.6	76.9

Paper Properties

SOFTWOOD

Test	Commercial				Recycled	
Fiber blends	100%		60/40		60/40	
Canadian Standard Freeness:	427	354	476	341	427	368
Basis Weight (a.d.) g/m^2:	61.5	58.8	64.5	63.1	62.2	60.8
Basis Weight (o.d.) g/m^2:	56.9	54.7	60.0	58.7	57.8	56.5
Ream Weight (o.d.) 25 x 38:	38.4	36.9	40.5	39.6	39.0	38.1
Caliper (1/1000"):	3.2	3.1	3.6	3.1	3.8	3.7
Density (gm/cc):	0.698	0.706	0.653	0.755	0.597	0.605
Opacity (%):	63.6	61.6	70.8	67.5	68.7	67.5
Brightness (%):	72.3	68.8	76.8	71.5	67.5	65.1
Dirt (ppm)	-- 0.175 -----		--- 0.165 ---		--- 0.334 ----	
Tensile (kg/15mm):	7.55	5.66	5.16	5.40	5.35	5.17
Tensile Factor (m):	8850	6890	5730	6130	6170	6100
Tear (gm):	49.6	45.8	60.3	59.2	60.2	54.8
Tear Factor (gm):	87.2	83.7	100.5	100.9	104.2	97.0
Stretch (%):	2.39	1.86	2.45	2.10	2.20	2.11
Fold (cycles):	775	1261	387	898	184	299

Softwood data interpolated to 400 ml CSF:

Test	Commercial		Recycled
	100%	60/40	60/40
Ream Weight (o.d.) 25 x 38:	37.9	40.0	38.6
Opacity (%):	62.9	68.9	68.2
Brightness (%):	71.0	73.8	66.4
Dirt (ppm):	0.175	0.165	0.334
Tensile Factor (m):	8130	5960	6140
Tear Factor (gm):	85.9	100.7	100.9
Stretch (%):	2.19	2.25	2.16
Fold (cycles):	955	675	236
Bulk (cc/gm)*:	1.43	1.42	1.67

* Inverse of the interpolated density.

HARDWOOD

Test	Commercial				Recycled	
Fiber blends	100%		60/40		60/40	
Candadian Standard Freeness:	435	378	466	338	410	378
Basis Weight (a.d.) g/m^2:	66.2	61.4	61.1	66.3	65.3	64.0
Basis Weight (o.d.) g/m^2:	61.6	57.1	56.8	61.7	60.7	59.5
Ream Weight (o.d.) 25 x 38:	41.6	38.5	38.3	41.6	41.0	40.2
Caliper (1/1000"):	3.6	3.3	3.4	3.5	4.0	3.8
Density (gm/cc):	0.663	0.675	0.652	0.704	0.605	0.610
Opacity (%):	75.7	72.9	69.5	70.2	72.1	71.0
Brightness (%):	73.4	71.6	77.1	70.8	66.4	64.5
Dirt (ppm):	--- 0.150 ----		--- 0.160 ----		--- 0.254 ----	
Tensile (kg/15mm):	4.70	5.06	5.67	5.45	5.45	5.12
Tensile Factor (m)	5080	5910	6650	5900	5990	5740
Tear (gm):	42.2	36.4	56.6	57.6	58.8	56.2
Tear Factor (gm):	68.5	63.8	99.6	93.4	96.9	94.5
Stretch (%):	1.54	1.89	2.55	2.00	2.30	2.02
Fold (cycles):	18	27	322	439	196	229

Hardwood data interpolated to 400 ml CSF:

Test	Commercial		Recycled
	100%	60/40	60/40
Ream Weight (o.d.) 25 x 38:	39.7	40.0	40.7
Opacity (%):	74.0	69.9	71.8
Brightness (%):	72.3	73.9	65.8
Dirt (ppm):	0.150	0.160	0.254
Tensile Factor (m):	5590	6270	5910
Tear Factor (gm):	65.6	96.4	96.1
Stretch (%):	1.75	2.27	2.21
Fold (cycles):	24	382	206
Bulk (cc/gm)*:	1.50	1.47	1.65

* Inverse of the interpolated density.

Commercial Hardwood
100%

Commercial Hardwood
60/40

Recycled Hardwood
60/40

Commercial Softwood
100%

Commercial Softwood
60/40

Recycled Softwood
60/40

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