EXTENDING FIBER RESOURCES: FIBER LOADING RECYCLED FIBER AND MECHANICAL PULPS FOR LIGHTWEIGHT, HIGH OPACITY PAPER

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ABSTRACT

Production of a lightweight, high opacity printing paper is a common goal of papermakers using virgin or recycled fibers. Fiber loading is an innovative, commercially viable process that can substantially upgrade and extend most types of wood fibers. Fiber loading, a process carried out at high consistency and high alkalinity, precipitates calcium carbonate (PCC) *in situ* within pulp fibers. Because paper made from fiber-loaded pulp is stronger than that made by the conventional addition of PCC, it is an ideal technology for producing a reduced basis-weight paper from virgin and recycled high-yield pulps. This paper summarizes the fiber-loading technology and illistrates how it can be applied on a typical recycled newsprint and thermomechanical pulp (IMP) furnish to produce light-weight paper without compromising strength or optical properties. Economic, environmental, and energy advantages of the fiber-loading technology for producing lightweight, high opacity paper are projected for a hypothetical huge capacity U.S. newsprint mill.

INTRODUCTORY COMMENTS

Global fiber demand for paper products is expected to increase substantially within the next decade (1). It has been estimated that by 2010 China, alone, will require an additional 15 to 25 million tons of fiber annually, widening the gap that already exists between their fiber demand and domestic production (2). How can the global community meet these. fiber needs? Several obvious solutions include increasing the recovery and utilization of recycled fiber and optimizing virgin fiber yield by relying more heavily on high-yield mechanical pulping. Fiber also can be extended by adding fillers or decreasing the paper basis-weight. Unfortunately, these approaches often compromise both the strength and optical properties of the resulting paper products.

China, with limited fiber resources, is in a unique position to address its increasing fiber requirement creatively and responsibly. Expansion of China’s pulp and paper Industry at this time offers an opportunity to develop this industry based on technology appropriate for the new millennium. “Breakthrough technology that significantly increases the capital effectiveness of...papermaking” (3) should be the highest criterion for selection Fiber loading could be such a technology.

BACKGROUND

Extending fiber resources is an economic necessity even in a fiber-rich society (4). It is even more critical where resources are limited. The demand for value-added grades has prompted increased use of high-yield mechanical pulps for the production of a broad array of higher value printing papers, ranging from newsprint at the lower end of the spectrum to lightweight coated (LWC) papers at the top end of the groundwood grades (5). New paper grades provide alternatives and a competitive edge compared with traditional paper grades. The current challenge is to develop higher value paper grades at reduced basis-weight with comparable strength and optical properties. Calendering, filling, and coating paper surfaces are some of the techniques used to meet these requirements and expand the applications of mechanical pulps.

At a time when alkaline papermaking in North America is increasing to match the established lead of European mills, papermakers using mechanical fibers have an opportunity to expand their choice of paper fillers as they move from traditional acid papermaking. Neutral or alkaline papermaking is an appropriate processing method for mechanical fibers because it contributes improved strength permitting incorporation of more filler. Calcium carbonate is a superior choice because it has excellent optical properties, is inexpensive to manufacture, and improves the permanence of lignin-containing papers (6.7).

Although it is advantageous to substitute as much fiber as possible with filler to reduce cost and improve optical properties, high levels of fillers interfere with inter-fiber bonding reducing paper strength. However, when calcium carbonate is manufactured *in situ* by the fiber-loading technique, improved paper strength results (8). Strength enhancement is especially advantageous for increasing the use of high-yield and recycled fibers. This process uses conventional mill equipment and has no byproducts. PCC formed *in situ* eliminates the need for a satellite PCC Plant.

Fiber loading is a two-step process carried out at high consistency and high alkalinity. Calcium hydroxide is mixed into moist pulp and reacted with carbon dioxide under pressure, converting the calcium hydroxide to PCC *in situ* (9). A pressurized batch refiner is used as the reacting chamber and final mixer for the process.

Initial fiber-loading trials precipitated calcium carbonate (PCC) in never-dried, bleached kraft pulp for printing end writing grade paper. Table I, containing previously unpublished data, illustrates the role that high-consistency processing in the pressurized refiner plays in fiber strength enhancement. This strength advantage is maintained when ash is incorporated by the fiber-loading (F/L) method. However, strength is lost when ash is added by the conventional direct-loading (D/L) method. Increased paper strength in the F/L sample results from both from the high consistency mixing under alkaline conditions and the deposition of a portion of the filler inside fibers that permits improved bonding (10).

We found that fiber loading could also be applied to dried fibers and mechanical fibers. Additional benefits were realized in industrial-scale trials using recycled paper; residual ink and stickie contaminants were masked end brightness enhanced (11, 12). These trials opened the possibility of upgrading both virgin and recycled lignin-containing fibers and suggested that the fiber-loading technology could be key to producing an inexpensive, strong, lightweight paper.

Incorporation of PCC into typical mechanical and recycled pulp blends presents several challenges to the papermaker: preventing brightness loss under alkaline conditions and maintaining paper strength. The benefits, and some of the limitations, experienced in fiber loading a typical blend of thermomechanical pulp (TMP) end deinked newsprint/magazine pulps (DIP) were explored previously and alternatives were offered (13).

Data reported in this paper focus on the application of fiber loading to a typical recycled newsprint and thermomechanical pulp (TMP) furnish. It illustrates how this technology can be used to produce lightweight paper without compromising the strength or optical properties of the resulting handsheets. Finally, an economic analysis is made for a hypothetical 600 metric ton per day newsprint mill.

Table I Effect of high consistency processing in fiber loading a softwood kraft pulp.

Sample Identification	Ash (%)	CSF (ml)	Burst index (kN/g)	Tear index (mN·m^2/g)	Tensile index (Nm/g)	Brightness G.E.(%)	Printing opacity (%)
Initial SW control	-	730	1.75	16.17	25.3	66.0	78.2
Refiner control	-	690	2.55	19.08	32.3	64.2	75.6
F/L SW	8.2	730	1.93	15.98	26.8	70.9	80.7
D/L SW	8.5	740	1.00	12.07	16.2	75.0	84.8

EXPERIMENTAL

Materials

For this study, we used TMP (70:30 mix of white spruce and balsam fir) and DIP (newsprint/magazine) in dewatered pulp form. Typically, these pulps are used in an 80:20 blend of TMPDIP in the preparation of newsprint. These pulps permitted us to compare relative paper properties on a realistic commercial furnish. The calcium hydroxide used for fiber-loading experiments was an industrial grade, Mississippi Codex hydrated lime (Mississippi Lime Co, Alton, IL); comparative direct loading of pulp was done with papermakers grade (HO) precipitated calcium carbonate obtained from Specialty Minerals, Inc. (Bethlehem, PA).

Equipment

A Hobart (Troy, OH) mixer was used to incorporate calcium hydroxide into moist pulps. Subsequent reaction with carbon dioxide. was carried out in a 305-mm-diameter pressurized disk refiner manufactured by Sprout Bauer (Springfield, OH) using refiner plates at wide gap (0.6 mm). A Bauer Mc-Nett classifier was used for fiber fractionation.

Methods

For fiber loading, 500-g batches of pulp were buffered by the addition of hydrogen peroxide and typical peroxide stabilizers (3% sodium silicate, 0.05% magnesium sulfate) into a Hobart mixer. After the buffering chemical were distributed throughout the moist pulp at high consistency (20%), dry calciumhydroxide was added and mixed for 15 min. (The amount of calcium hydroxide added is determined by how much ash is desired in the final pulp blend. Since the conversion to PCC is essentially 100%, the amount of lime required to meet a target ash content can be figured quite accurately.) Next, the pulp mixtures were reacted with carbon dioxide in the holding chamber of the refiner pressurized at 207 kPa (30 lb/in). After a 10-min retention, the pulp was passed through the refiner at a wide (0.6 mm) plate gap. Exit temperature of pulp is approximately 40°C.

Handsheets for comparative direct loading were made by adding papermaker's grade PCC into the doler tank during handsheet preparation. A cationic potato starch (0.5% on dry pulp weight) was added at the doler tank to improve PCC retention for both the fiber loaded and direct-loaded handsheets. Because a retention aid was not used, the amount of PCC retained in the handsheets was determined initially by estimation, then readjusted as necessary. A large excess of PCC is required to achieve target ash level It is very difficult to match exactly the ash levels retained in handsheets made from fiber-loaded and direct-loaded pulps for accurate comparison of strength and optical properties. However, the ash levels compared were close enough to demonstrate significant differences between the methods for the parameters measured.

Fractionation of the deinked fiber was done using a Bauer McNett classifier. The long fiber fraction, approximately 53% of each sample, was cdllected on the 48-mesh screen; an additional 17% was retained almost equally on the 100- and 200-mesh screens Ash and fines were removed in the wash water.

Pulp and Paper Tests

Low basis-weight 40 to 50 g/m^2 handsheets were prepared from the pulp blends modifying Tappi method T205. A cationic potato starch was added into the doler tank in place of a standard retention aid for all sheets made in this study. Tappi standard method T220 was followed for optical and physical testing. Pulp freeness was measured by T227, paper ash at 400°C according to T211.

DISCUSSION OF RESULTS

Paper Strength

Unbleached softwood TMP end DIP pulps were blended in an 80:20 ratio of TMP to DIP. Initial properties of this blend are presented in Table II. PCC was added to the pulp blends either by conventional direct loading (DL) or by

Table II Effect of adding PCC by fiber loading (FL) and direct loading (DL) on handsheet strength.

	Basis-weight (g/m^2)	Ash (%)	Burst index (kPa·m^2/g)	Tensile index (N·m/g)	Tear index (mNm^2/g)	Tensile strength (N/m)
80:20 blend	48.9	1.8	1.36	26.08	4.70	1280
DL 80:20 blend	43.7	6.9	1.2	24.11	4.21	1050
FL 80 TMP + 20 DIP	43.9	6.5	1.43	27.50	4.85	1210

Table III Effect of fiber loading on handsheet strength of an 80:20 blend in which only the long fiber fraction of DIP (newsprint/magazine) was loaded.

	Basis-weight (g/m^2)	Ash (%)	Burst index (kP·m^2/g)	Tensile index (mN·m^2/g)	Tear index (mN·m^2/g)	Tensile strength (N/m)
FL 80:20LF blend	45.5	5.6	1.60	31.14	5.35	1420
FL 80:20LF blend + short fibers	47.1	5.7	1.66	30.72	5.17	1450

incorporating the PCC by fiber loading the TMP portion prior to blending with the DIP. For this study, we targeted the carbonate level retained in handsheets at less than 8%, the upper level of ash traditionally used or newsprint grade paper in the United States. The results summarized in Tables II and III were reported previously (13).

Handsheets made from this 80:20 blend contained approximately 1.8% residual ash (non-carbonate) contributed by the deinked pulp. As expected, the direct loading (DL) addition of PCC to 6.9% ash reduced the burst, tensile, end tear indices of the initial blend. However, when calcium carbonate was incorporated into the TMP by fiber loading before blending with 20% DIP, strength properties increased, even though the ash level of 6.5% was comparable to that of the DL handsheets and was significantly greater than that of the initial blend. Improved strength can be attributed to the combination of the high consistency and high pH processing used during fiber loading and to the deposition of a portion of the carbonate inside the fiber permitting improved bonding at a specific filler load.

The increased strength indices as a result of fiber loading permitted us to reduce handsheet basis-weight from 48.9 g/m^2 (30.0 lb/3000 ft^2) of the control blend to 43.9 g/m^2 (27.0 lb/3000 ft^2) for the fiber-loaded TMP blend without loss in tensile strength. Even at a lower basis-weight and 4.7 percentage points more ash, the fiber-loaded sheets were as strong at the control. Reduced basis-weight, without strength loss, indicates significant cost savings.

We attempted to improve the strength of the pulp blend even more by fractionating the deinked pulp and using only the long fiber fractions for fiber loading. Additional strength resulted from fractionation of the deinked pulp (Table III).

Although it is logical to fiber load the strongest fiber component to develop strength, other factors such as residual non-carbonate fillers or altered fiber charge from deinking chemicals could also influence the carbonate deposition during fiber loading. Fiber fractionation is an accepted technique for upgrading recycled pulp by enhancing the most appropiate fibers for a specific end use (14). Frequently, the long fiber fraction is refined to restore bonding capability end minimize refining energy. Removal of fines and fillers also enables a more efficient use of bleach chemicals by targeting only a portion of the total pulp furnish. Shorter fiber fractions can be added back with the fiber-loaded long fraction during papermaking to improve opacity and scattering coefficient without significantly changing strength properties or DIP yield (Table III). In this case, the ash and fines (approximately 30% of the deinked pulp) were not collected, so data reflect only the addition of short fibers retained on the 100- end 200-mesh screens. These results, however, are consistent with those of other researchers who recombined all fractions and found increased sheet density but minimal changes in bonded properties (15, 16).

Table IV Estimated savings for fiber loading for a 600 ton per day newsprint mill.

Savings/Return	Amount
Savings from reduced drying	1.15 x 10^5\$/year
Savings from reduced basis-weight and increased ash, at $75/ton	2.75 x 10^6 \$/year
Savings from reduced basis-weight and increased ash, at $150/ton	2.15 x 10^6 \$/year
Return on investment at $75/ton PCC	39.0%
Return on investment at $150/ton PCC	26.7%

Process Economics

An estimation of the economics for producing lightweight, high opacity newsprint using fiber-loading technology in a hypothetical 600 metric tons per day newsprint mill is summarized in Table IV (17). Basic assumptions for this analysis are reported in the Appendix.

At a reduced grammage of 4 g/m^2 (from 49 g/m^2) and increased ash of 4%, we estimated savings of $115,000 per year from reduced drying requirements. For raw material savings from reduced grammage and substitution of PCC for fiber, we calculated two scenarios based on assumed costs of PCC at both $75 and $150 per metric ton the high and low end price range for carbon dioxide and calcium hydroxide at the mill site.

At $75 per ton for PCC, we calculated $2,750,000 per year savings in raw materials, and $2,150,000 per year for PCC at $150 per ton. The return on investment (ROI) at $75 per ton PCC is 39.0% and a 26.7% ROI for $150 per ton PCC (1 7).

CONCLUDING REMARKS

- Fiber loading is a commercially viable, mature technology applicable to both virgin and recycled fiber.

Addition of PCC to lignin-containing fibers increases permanence, smoothness, and opacity.

- Fiber loading substitutes low cost filler for high cost fiber.

Fiber loading, by precipitating PCC p&ally within fibers, results in increased strength at a given ash level.

- Processing at alkaline pH and high consistency contribute to strength development without significantly reducing pulp freeness.
- Fractionation of recycled fiber prior to fiber loading enhances strength.
- Fiber loading is an appropriate technology to achieve low basis-weight paper without compromising strength or optical properties.
- For a 600-metric tons per day newsprint production, a return on investment of 26.7% to 39.0% is estimated, depending on the price of raw materials for PCC.

Fiber Loading is an environmentally benign technology that could substantially extended fiber resources.

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APPENDIX

Economic analysis for fiber loading (Table IV) was based on the following Assumptions:

- 600 metric tons per day were being produced from an 80:20 blend of TMP and DIP
- Fiber fractionation resulted in 300 metric tons per day of the long fiber fraction used for fiber loading
- $5,860,000 for the installed fiber-loading equipment
- $50,000 per year for additional people to operate fiber-loading equipment
- $0.04 per kW for electricity
- 798 kWh for operating fiber-loading equipment
- $280,000 per year for electrical energy to operate the fiber-loading equipment
- 550 kWh for drying a ton of pulp (dry pulp basis)
- $0.08 per ft^3 of natural gas
- 3086 kWh per metric ton for processing TMP
- 550 kWh per metric ton for processing DIP
- Value of fiber at $242 per metric ton in the mill
- Bleaching chemicals as 1.0% hydrogen peroxide and typical peroxide stabilizers (3% sodium silicate and 0.05% magnesium sulfate)

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