VALUE-ADDED MECHANICAL PULPS FOR LIGHT WEIGHT, HIGH OPACITY PAPER

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ABSTRACT

Brightness, strength, economy, and paper machine runnability are common concerns of pacemakers who use virgin or recycled fiber furnishes. Fiber loadining, a process that precipitates calcium carbonate partially inside the fiber lumen, is a cost-effective technology that could substantially upgrade mechanical pulp furnishes. This study demonstrates the optical and physical handsheet property advantages of fiber loading typical newsprint and thermomechanical pulp (TMP) furnishes. Inclusion of hydrogen peroxide during fiber loading prevented the expected alkaline darkening. Moreover, brief heating of the pulp after complete carbonate conversion resulted in several additional brightness points. Alternative approaches for stabilizing the brightness of fiber-loaded blends of mechanical and deinked pulps are presented. Our comparison of strength and optical properties of handsheets made by these methods suggests that fiber loading can be used to produce paper with high opacity and low basis weight from mechanical pulp.

INTRODUCTION

An estimated 15.7 million metric tons of newsprint, almost half the worldwide production, was made in North America in 1997. Paired with a recovery rate of over 50%, newsprint is a major player in U.S. pulp and paper industries. The demand for value-added grades has inspired the use of mechanical pulps for producing a broad array of higher value printing papers that range from newsprint at the low end of the groundwood-grade spectrum to lightweight coated (LWC) papers at the high end [1]. New paper grades are providing more alternatives between these traditional paper grades. Higher brightness, greater smoothness for improved printing, greater strength, and lower basis weight are some of the requirements driving the development of new grades while simultaneously lowering cost. Calendering, filling and treating paper surfaces are some of the techniques used to meet these requirements and to expand the applications of mechanical pulps.

Neutral or alkaline papermaking is becoming an attractive processing method for mechanical fibers because it improves fiber strength, which permits higher levels of fillers. As alkaline papermaking in North America expands to match the established lead of European mills, papermakers who use mechanical fibers have a unique opportunity to expand their choice of paper fillers Calcium carbonate is an excellent option for a filler because it is inexpensive to use and increases paper brightness, printing qualities, and permanence [2,3].

While it is advantageous to substitute fiber with as much calcium carbonate as possible to reduce cost and improve the optical properties of paper, high levels of filler interfere with interfiber bonding and reduce paper strength. However, when calcium carbonate is manufactured *in situ* by the fiber loading technique, paper strength is improved [4].

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Strength enhancement is an important benefit especially for mechanical and recycled fibers. Fiber loading could be a significant factor in achieving low basis weight, high opacity paper.

BACKGROUND

Fiber loading, a patented process (US Patent 5223,090, 1993) developed at the Forest Products Laboratory of the USDA Forest Service, incorporates calcium hydroxide into pulp and subsequently converts hydroxide to carbonate by reacting the mixture with carbon dioxide under pressure at high consistency [4]. A pressurized batch refiner is used as the reacting chamber and tired mixer for the process.

In initial trials, never-dried bleached softwood or hardwood kraft pulp fiber (for printing and writing grade paper) was loaded with precipitated calcium carbonate (PCC). We later discovered that dried chemical fibers could also be loaded and that additional benefits could be realized from fiber loading recycled office papers [5]. Residual ink and stickie contaminants in recycled sorted office papers could be masked and brightness enhanced. Paper strength could be improved from both the high consistency mixing under alkaline conditions and the deposition of part of the filler inside the fibers. It was also possible to use fiber loading to incorporate PCC into the lumen of mechanical fibers. This observation expanded the usefulness of fiber loading technology and opened the possibility of upgrading both virgin mechanical fibers and deinked lignin-containing pulps.

However, an obvious limitation of fiber loading of mechanical fibers is the loss of brightness caused by alkaline darkening. Typically, five to seven brightness points are lost when a high level of calcium hydroxide is added to mechanical pulp in the first step of fiber loading [6]. Brightness is also lost when a fiber-loaded pulp is blended with TMP or groundwood. The presence of PCC restores final handsheet brightness, but to realize a net gain in brightness, alkaline darkening has to be prevented or at least minimized. Incorporation of PCC into typical mechanical and recycled pulp blends presents two challenges to the papermaker: maintaining paper strength and preventing brightness loss under alkaline conditions.

We explored the benefits and some limitations experienced in fiber loading a typical blend of TMP and deinked newsprint/magazine pulps (DIP). We present alternative methods for addressing these limitations. We also explored various methods for addressing brightness stability when fiber-loaded furnishes are blended with mechanical pulps.

EXPERIMENTAL

Materials

An industrial sample of TMP (70/30 mix of white spruce and balsam fir) and DIP (newsprint/magazine) was used in dewatered pulp form. These pulps are typically used in an 80/20 TMP/DIP blend. The pulps permitted us to compare relative properties of paper from a realistic commercial furish. Calcium hydroxide used for fiber-loading experiments was an indusrnal grade, Mississippi Codex hydrated lime (Mississippi Lime Company, Alton, Illinois); comparative direct loadmg of pulp was done with papermaker-grade (HO) calcium carbonate obtained from Specialty Minerals, Inc. (Bethlehem, Pennsylvania). Sodium percarbonate, calcium peroxide, and sodium perborate monohydrate added for stabilizing brightness were provided by Solvay Interox Inc. (Houston, Texas).

Equipment

A Hobart (Troy, Ohio) 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 Ohio) using refiner plates at wide gap. A Bauer-McNett classifier (Testing Machines, Inc., Islandia, New York) 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 chemicals were distributed throughout the moist pulp at high consistency (20%), day calcium hydroxide 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 calculated quite accurately. After the addition of calcium hydroxide and mixing, the pulp mixtures were reacted with carbon dioxide in the holding chamber of the refiner pressurized at 207 kPa. After 10-min retention, the pulp was passed through the refiner at a wide (0.6-mm) plate gap. Exit tempemture of pulp was less than 40°C.

Handsheets for comparative direct loading were made by adding papermeker-grade PCC into the doler tank during handsheet manufacture. Since a retention aid is not used, the amount of PCC retained in the handsheets is initially determined by estimation and then readjusted as necessary. A large excess PCC is always required to achieve target ash level. It is very difficult to match the handsheet ash level of fiber-loaded and direct-loaded pulps for exact comparison of the strength and optical properties of handsheets.

The deinked fiber was fractionated using a Bauer-McNett classifier with 48-, 100-, and 200-mesh screens. Pulp was processed in 30-g samples and washed for 20 min. The long fiber (LF) fraction, approximately 53% of each sample, was collected on the 48-mesh screen; an additional 17% was retained almost equally on the 100- and 200-mesh screens. Ash and frees, approximately 30% of the original sample, 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 by a modification of Tappi method T205. For all handsheets, cationic potato starch (0.5% on pulp weight) was added into the doler tank as a retention aid. Tappi method T220 was followed for optical and physical testing; pulp freeness was measured by T227; and paper ash was measured at 400°C by T211.

RESULTS AND DISCUSSION

Paper Strength

Unbleached softwood TMP and DIP pulps were blended in a 80/20 ratio of TMP to DIP. Initial properties of this blend are presented in Table I. PCC was added to the pulp blend by either conventional direct loading (DL) or fiber loading (FL). For this study, we targeted the carbonate level to be retained by handsheets at less than 8% traditionally the upper level of ash used for newsprint-grade paper.

Handsheets made from the 80/20 pulp blend contained approximately 1.8% residual ash (non-carbonate) contributed by the deinked pulp. As expected, direct loading of PCC to 6.9% ash reduced burst tensile, and tear indices of the initial blend. However, when PCC was incorporated by fiber loading strength properties increased even though the ash level of 6.5% was comparable to that of the DL handsheets and was significantly higher than that of the initial blend. This improved strength can be attributed to the combination of high consistency-high pH processing used in fiber loading and to the deposition of a portion of the carbonate inside the fiber, which improved bonding for a specific filler load.

The increased strength indices caused by fiber loading permitted us to reduce handsheet basis weight from 48.9 g/m^2 for the control to 43.9 g/m^2 for the fiber-loaded (FL) blend without loss in tensile strength. Even at a lower basis weight and 4.7 percentage points more ash, the FL handsheets were as strong as the control. Reduced basis weight, without strength loss, suggests significant potential cost savings.

Table I. Effect of PCC on Strength Properties of Handsheets

Sample[a]	Basis weight (g/m^2)	Ash (%)	Burst index (kPa·m^2/g)	Tensile index (N·m/g)	Tear index (mN·m^2/g)	Tensile strength (N/m)
Initial 80/20 blend	48.9	1.8	1.36	26.08	4.70	1,280
DL 80/20 blend	43.7	6.9	1.20	24.11	4.21	1,050
FL 80 TMP + 20 DIP	43.9	6.5	1.43	27.50	4.85	1,210
FL 80/20 blend	45.7	5.7	1.28	25.62	4.99	1,170

[a]DL is direct loaded; FL, fiber loaded; and DIP, deinked newsprint/magazine pulp.

Table II. Effect of Fiber Loading of Long Fiber Fraction of 80/20 Blend on Handsheet Strength

Sample[a]	Basis weight (g/m^2)	Ash (%)	Burst index (kPa·m/g)	Tensile index (N·m/g)	Tear index (mN·m/g)	Tensile strength (N/m)
FL 80/20 LF blend	45.5	5.6	1.60	31.14	5.35	1,420
FL 80/20 LF blend + SF	47.1	5.7	1.66	30.72	5.17	1,450

[a]LF is long fiber fraction; SF, short fiber fraction.

We observed another interesting phenomenon, however, when we premixed the two pulps and then fiber loaded the 80/20 blend. The resulting handsheet ash was only 5.7%, but the burst, tensile, and tear values were only slightly better than those of the DL handsheets with 6.9% ash (Table I).

Residual ash and frees in the deinked pulp apparently prevent optimum fiber loading inside the fiber lumen, which usually improves bonding and paper strength. Because DIP furnish consists of varied wood species and fillers subjected to diverse papermaking and deinking chemicals, pulp charge and chemistry are altered, which interferes with the usual PCC formation during fiber loading [7].

We tested this hypothesis by removing fines and ash from the deinked pulp by fiber fractionation [8] and by using only the isolated long fiber fraction in the 80/20 blend. Fiber loading of this mixture resulted in significantly superior strength properties. We found that fiber loading the long fiber fraction (comprised of intact fibers and considerably less residual ash) with TMP substantially increased handsheet burst, tensile, and tear properties when compared with the strength properties of handsheets made from DIP without fractionation (Table II).
While it is logical to fiber load the strongest fiber component to develop strength, other factors such as residual noncarbonated fillers or altered fiber charge from deinking chemicals could also influence carbonate deposition during fiber loading. Fiber fractionation is an accepted technique for upgrading a recycled pulp containing a heterogeneous fiber furnish by enhancing the most appropriate fibers for a specific end use [9]. Most often, the long fiber fraction is refined to restore bonding capability and 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 furnish. The improvement of pulp freeness resulting from removal of fines and filler can also be critical to paper machine performance.

During papermaking, short fiber (SF) fractions can be added with the FL long fraction to improve opacity and scattering coefficient without significantly changing strength properties or DIP yield (Table II). In this case, ash and fines were not collected, so the data reflect only the added short fibers retained on the 100- and 200-mesh screens. However, these results are consistent with those of other researchers who recombined all fractions and found increased handsheet density but minimal changes in bonding properties [10, 11].

Brightness

The second issue addressed in this study was maintaining brightness when applying alkaline papermaking to lignin-containing pulps. The obvious problem is the inevitable loss of brightness. Just adding PCC to a pulp slurry as we did in the direct loading experiments reduces pulp brightness by approximately 3 points at pH 8 to 8.5, the pH of slurried calcium carbonate. In contrast the fiber loading process introduces a high level of calcium hydroxide into the pulp, resulting in pH 11 or higher, before carbon dioxide converts the hydroxide to donate. At that high a pH, substantial darkening occurs. Table III illustrates typical brightness loss for a fiber-loaded industrial recycled newsprint sample. The data also show that brightness loss can be inhibited by the addition of 1% (based on pulp weight) hydrogen peroxide to the pulp prior to incorporating calcium hydroxide. Additional brightness can be achieved by briefly heating (15 min at 65°C) the peroxide-containing pulp after fiber loading [6].

Table III. Effect of Fiber Loading on Pulp Brightness of an Industrial Sample

Sample	Ash (%)	Brightness (%)
Industrial sample	2.8	63.5
FL – peroxide	6.7	65.6
FL + peroxide	6.7	69.9
FL + peroxide heated[a]	6.7	72.3

[a]65°C, 15 min

Different approaches can be taken to prevent brightness loss. The PCC can be made "acid tolerant" by altering it with additives such as sodium aluminate or sodium hexametaphosphate [12,13], or the pulp slurry can be buffered prior to adding the alkaline source, as we did in this study. With fiber loading, alkaline darkening is primarily a problem before PCC is formed; therefore, we found it critical to buffer lignin-containing pulps at a neutral pH prior to introducing calcium hydroxide. Buffering mechanical pulps to which a fiber-loaded deinked pulp is added is also important to minimize brightness loss. Simply lowering the pH by adding an acid is not a viable approach because the carbonate decomposes in an acidic medium, decreasing filler content and causing brightness loss.

In addition to using stabilized hydrogen peroxide, which we have used successfully in the past [14], we ran preliminary trails is to compare other peroxygen compounds, such as sodium perborate [15,16], sodium percarbonate, and calcium peroxide, to stabilize the fiber prior to adding the calcium hydroxide required for the fiber loading process. The use of either percarbonate or perborate resulted in higher paper brightness than was obtained with hydrogen or calcium peroxide (Table IV).

An unexpected result was the strength enhancement obtained with calcium peroxide compared with the other peroxygen compounds. This increase in strength is even more impressive when one considers the increased ash level of these handsheets. Calcium from calcium peroxide, as well as from calcium hydroxide, was converted to carbonate during fiber loading, thereby decreasing process by products. Incorporation of either sodium perborate or sodium percarbonate increased TMP brightness to 62%, almost seven brightness points higher than that obtained with hydrogen or calcium peroxide. However, strength properties obtained with perborate or percarbonate were not as high as those obtained with peroxides.

Using these peroxygen compounds only as brightness stabilizers rather than bleaching agents minimizes the advantage of incorporating them into the fiber loading process. Because the fiber is loaded at ambient temperature (<40°C), bleaching chemicals are not activated and the only benefit realized is their buffering capacity.

To exploit the bleaching potential of these compounds, we plan to add a short bleaching step at elevated temperature prior to or following the reaction with carbon dioxide in the pressurized refiner. Alternately, tetraacetyl, ethylenediamine (TAED), a known peroxide activator [17], could be added to initiate bleaching at a lower temperature. Other researchers have demonstrated the synergy of perborate with TAED on TMP [18].

Table IV. Effect of Incorporating Peroxygen Compounds in Pulp Before Fiber Loading

TMP or peroxygen compound	Basis weight (g/m^2)	Ash (%)	Brightness (%)	Opacity (%)	Scattering coefficient (m^2/kg)	Burst index	Tensile index	Tear index
Initial TMP	47.8	0.7	56.4	94.7	60.7	1.04	20.59	4.66
Hydrogen peroxide	45.7	5.9	55.4	94.0	67.7	1.28	26.63	4.79
Calcium peroxide	45.5	9.4	55.7	94.6	69.6	1.43	27.10	4.78
Perborate	46.2	7.7	62.0	91.6	68.2	1.08	23.47	4.82
Percarbonate	45.4	7.3	62.3	90.6	66.9	1.22	24.48	5.05

CONCLUSION

Our results indicate that fiber loading of pulp allows maintenance of strength and optical properties of handsheets with reduced basis weights. Increased levels of precipitated calcium carbonate (PCC) can be incorporated into de-inked newspaper/magazines (DIP) and TMP by the fiber loading process without compromising paper strength. Alkaline darkening can either be prevented or brightness enhanced by including a peroxygen compound, Replacement of fiber with PCC is economical and should improve paper machine runnability and printing.

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