Improved Bleached Chemical Reed Pulp Properties Using Atmospheric High Consistency Refining

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The influence of atmospheric high consistency refining (AHCR) on the properties of bleached chemical reed pulp was investigated. Fiber quality, water retention value (WRV), dynamic drainage, and physical properties of handsheets were determined. The results showed that compared with low consistency refining (LCR), AHCR maintained reed pulp fiber length, had lower fines generation, produced more fiber curl and kink, and improved WRV and dynamic drainage. Compared with LCR pulp, the tear index, folding strength, and tensile energy absorption (TEA) of AHCR pulp were increased, while tensile index was maintained at the same value. A mill trial was performed to demonstrate the benefits of using AHCR, which was to improve machine runnability and to enhance the performance of the paper made from reed pulp.

Keywords: Reed pulp; Atmospheric high consistency refining; Fiber quality; Dynamic drainage; Physical properties

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INTRODUCTION

Although reed pulp provides good formation and a smooth surface for paper, it has poor drainage and weak strength properties (especially tear strength and folding endurance). These disadvantages are due to its short fiber length and high quantity of parenchyma cells, which are detrimental to its runnability through the paper machine as well as the quality of end-products (Shatalov and Pereira 2002, 2007, 2013; Finell and Nilsson 2005).

Low consistency refining (LCR) can result in satisfactory tensile strength in reed pulp. However, the drainage and tear strength deteriorate after excessive fiber cutting and fines generation (Xie *et al*. 1991; Bhardwaj *et al*. 2007; Gharehkhania *et al.* 2015). Although chemicals such as polyacrylamide (PAM), cationic starch, and chitosan have a positive effect on the drainage and tensile strength of the reed pulp, their application is limited by high costs and negative effects on the water circulation system of papermaking (Fatehi *et al.* 2009; Shen and Fatehi 2013; Brenner *et al.* 2016). For example, cationic PAM can improve fines retention and pulp drainage, but excessive use could lead to more fiber flocculation and poor sheet uniformity. Cationic starch can also improve fines retention and paper physical strength, however it is easily accumulated in white water due to its low retention, which could result in the increase of anionic trash.

High consistency refining (HCR) is a well-established technology that is widely used for producing mechanical pulps and specialty papers such as sack paper. Refining chemical pulp with a pulp consistency range of 20 to 35% can increase the internal fibrillation, retention of fiber length, and fiber curl and kink while generating fewer fines (Senger and Ouellet 2002; Gurnagul *et al.* 2009; Ferritsius *et al.* 2012; Fernando *et al.* 2013; Kerekes 2015). Higher fiber length and more internal fibrillation improves the tear strength, while the generation of fewer fines improves the pulp drainage.

However, previous applications of HCR focused primarily on processing mechanical pulps and on the use of softwood kraft pulp for making sack paper. There have been very few studies using HCR with non-wood fibers. In this study, the potential advantages of using HCR with bleached chemical reed pulp were examined. The fiber quality and pulp properties were determined, and the differences between HCR and LCR on pulp and handsheet properties were investigated. A mill scale trial was performed to confirm the laboratory results.

EXPERIMENTAL

Materials

Bleached reed kraft pulp was obtained from Tiger Forest & Paper Co., Ltd. (Yueyang, China). The properties of the unrefined reed pulp are shown in Table 1.

Table 1. Main Properties of the Unrefined Reed Pulp

Sample	Freeness (mL)	Fiber Length[a] (mm)	Fiber Width[a] (µm)	Fines[a] < 0.2 mm (%)	Fiber Content(%)	Non-fiber Cell Content (%)	Brightness (%ISO)
Reed pulp	640±1.71	0.837±0.003	17.05±0.02	12.87±0.02	63.84±0.04	36.19±0.03	75.8±0.07

[a] Weight: avg length / FQA

Methods

Atmospheric high consistency refining (AHCR)

The reed pulp was conditioned to a consistency of 25.0 ± 0.5%. Subsequently, the AHCR treatment was carried out with a single-disc HC refiner (12 inches in diameter, with a rotational speed of 2700 rpm; model ZSP 300, Changsha CC Paper Mach Co., Ltd, Changsha, China) with a feed rate of 60 kg/h at room temperature and atmospheric pressure. A series of AHCR pulp with different freeness levels was obtained through controlling the specific refining energy.

Laboratory low consistency refining (LCR)

Low consistency refining was performed with a conventional laboratory Hollander beater at the pulp consistency of 1.57%, lever arm load of 29.4 N, and room temperature according to GB/T 24325-2009 (2009). A series of LCR pulps with similar target freeness to that of AHCR pulps were obtained through controlling the beating time. Another series of experiments verified that the reed pulp properties from the Hollander beater showed good agreement with the results from the double disc refiner at 4.5 to 5% consistency.

Pulp testing and analysis

Canadian standard freeness (CSF) was measured according to TAPPI T227 om-09 (2009). Fiber qualities such as weight average fiber length, fines content (below 0.2 mm), and fiber curl and kink were analyzed according to TAPPI T271 om-07 (2007) by a Fiber Quality Analyzer (FQA; OpTest Inc., Hawkesbury, Canada). The result of each sample was based on data from approximately 5,000 fibers. The water retention value (WRV) of the reed pulp was analyzed in accordance with TAPPI UM 256 um-11 (2011).

The dynamic drainage of the pulp was evaluated by testing the average drainage speed of the fiber suspension. A total of 1000 mL of pulp with a consistency of 1.0% was suspended in the cylinder of a dynamic drainage system (DDJ-2#, PRM. Inc., Seattle, USA) equipped with a 60-mesh screen and stirred for 25 s at 750 rpm. The drainage time was recorded after 100 mL was released into filtered liquor. The average speed of the dynamic drainage (ASDD) was calculated according to Eq. 1,

$$ASDD = V/t \qquad (1)$$

where $ASDD$ is the average speed of the dynamic drainage (mL/s), V is the volume of the filtered liquor (mL), and t is the drainage time of the first 100 mL into the filtered liquor(s).

Handsheet making and testing

The unrefined LCR- and AHCR-treated pulp had a consistency of 1.2% and was fully dispersed in a standard disintegrator for 15,000 revolutions. Subsequently, a handsheet with a basis weight of 60 g/m^2 was prepared according to TAPPI T205 sp-06 (2006). Handsheets were conditioned to 23 ± 1 °C with a relative humidity of 50 ± 2%. The tensile index, tensile energy absorption (TEA), tear index, and folding endurance were tested in accordance with TAPPI T220 sp-06 (2006).

RESULTS AND DISCUSSION

Fiber Quality

Table 2 shows the effects of LCR and AHCR treatments on the fiber length, fine content, and fiber curl and kink. As expected, the refining treatment, whether it was LCR or AHCR, noticeably decreased the freeness of the reed pulp due to the increased fines content from fiber cutting. However, for any given freeness, the AHCR treatment resulted in better retained fiber length and less fines generation than the LCR treatment.

As shown in Table 2, both the LCR and AHCR treatments decreased the fiber freeness but had the opposite effect on the curl and kink properties. The AHCR treatment increased the fiber curl and kink indexes, kink angle, and number of kinks per millimeter of reed fiber, while the LCR treatment decreased all of these fiber curl and kink properties. These findings can be explained by assuming that the AHCR treatment acted through more fiber-to-fiber interaction and less fiber cutting at high shear while introducing micro-compression and more fiber curl and kink. In contrast, LCR acted through single fiber cuttings from grinding teeth, resulting in more fiber cutting and less fiber curl and kink. It has been reported that LCR reduces the fiber curl and kink of unbleached softwood kraft pulp fiber, while HCR increases these two indexes (Page *et al.* 1985; Hartler 1995; Olejnik 2013). These increased curl and kink properties of reed pulp could decrease pulp freeness and drainage.

Table 2. Effect of LCR and AHCR on Fiber Quality

Treatment	Freeness (mL)	Fiber length (mm)	Fiber width (µm)	Fines <0.2 mm (%)	Curl index	Kink index	Kink angle (/°)	Kinks per mm
Unrefined	640 ±1.71	0.837 ±0.003	17.05 ±0.02	12.87 ±0.02	0.177 ±0.004	2.100 ±0.007	39.53 ±0.13	1.010 ±0.003
LCR	580 ±2.00	0.800 ±0.006	17.20 ±0.03	14.21 ±0.04	0.130 ±0.002	1.820 ±0.007	33.44 ±0.09	0.960 ±0.005
	522 ±1.63	0.722 ±0.004	17.35 ±0.02	15.50 ±0.09	0.123 ±0.005	1.750 ±0.004	31.86 ±0.04	0.926 ±0.005
	475 ±0.95	0.743 ±0.003	17.17 ±0.04	16.31 ±0.10	0.116 ±0.003	1.783 ±0.005	29.64 ±0.10	0.898 ±0.004
	410 ±2.34	0.697 ±0.007	17.65 ±0.01	17.72 ±0.07	0.113 ±0.004	1.750 ±0.003	28.71 ±0.08	0.885 ±003
	372 ±1.43	0.670 ±0.002	17.60 ±0.05	18.21 ±0.11	0.113 ±0.006	1.670 ±0.004	27.96 ±0.07	0.855 ±0.006
	280 ±2.11	0.605 ±0.003	17.65 ±0.03	19.94 ±0.08	0.113 ±0.002	1.578 ±0.005	26.17 ±0.09	0.836 ±0.007
AHCR	585 ±1.28	0.824 ±0.004	17.67 ±0.03	13.21 ±0.06	0.240 ±0.005	2.847 ±0.003	56.09 ±0.05	1.220 ±0.004
	520 ±0.69	0.815 ±0.005	17.50 ±0.02	13.55 ±0.13	0.255 ±0.007	2.983 ±0.004	58.24 ±0.07	1.287 ±.003
	475 ±1.78	0.805 ±0.003	17.60 ±0.04	13.98 ±0.05	0.272 ±0.002	3.070 ±0.002	61.71 ±0.11	1.293 ±0.005
	420 ±1.22	0.791 ±0.006	17.77 ±0.05	14.43 ±0.08	0.286 ±0.004	3.083 ±0.005	64.14 ±0.08	1.315 ±0.006
	366 ±2.45	0.765 ±0.002	17.65 ±0.04	14.80 ±0.03	0.294 ±0.003	3.140 ±0.003	67.86 ±0.05	1.327 ±0.004
	280 ±0.58	0.722 ±0.003	17.68 ±0.02	15.90 ±0.05	0.303 ±0.003	3.246 ±0.006	71.35 ±0.09	1.370 ±0.002

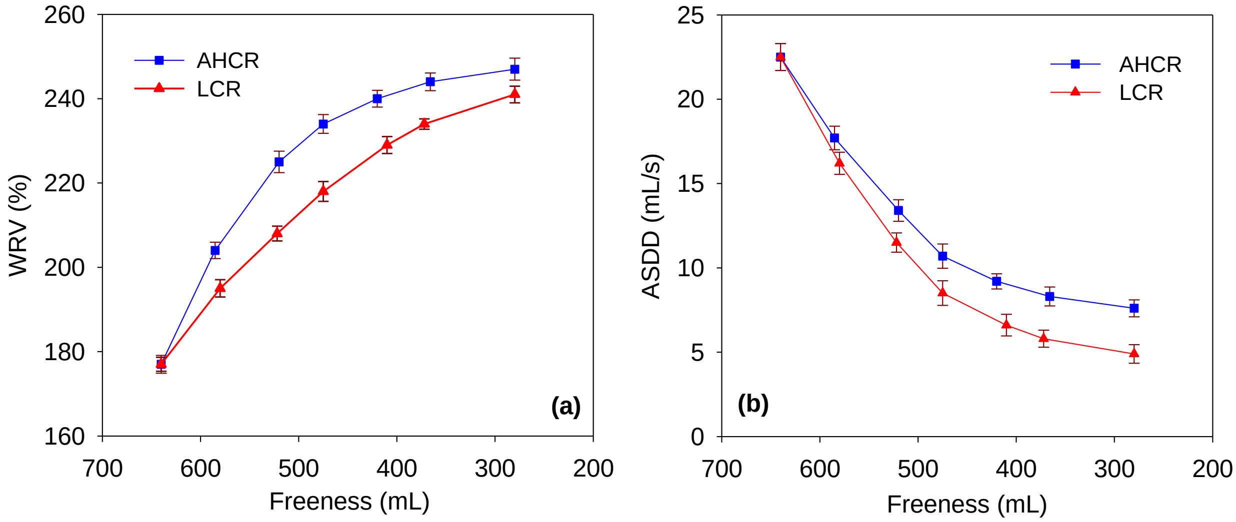

Fig. 1. Effect of freeness on (a) water retention value (WRV) and (b) average speed of dynamic drainage (ASDD)

Water Retention Value (WRV) and Dynamic Drainage

The effect of the LCR and AHCR on the WRV and dynamic drainage is shown in Fig. 1. For any given freeness, the AHCR treatment increased the WRV compared with the LCR treatment (Fig. 1a). Thus, more internal fibrillation occurred for AHCR by more intrafiber action, which can increase fiber flexibility and contact area. For the LCR or AHCR treatments, the reed pulp showed higher WRV levels, compared to softwood and hardwood pulps (Banavath *et al.* 2011). It has been also reported that WRVs for non-wood pulps, such as wheat straw pulp and bagasse pulp, are much higher than in softwood and hardwood pulps (Banavath *et al.* 2011). Better dynamic drainage was obtained for AHCR pulp, especially for low freeness (Fig. 1b). Less fines formation during AHCR resulted in more pores in the paper network, which improved the dewatering efficiency in the former and press sections during papermaking.

Physical Properties of Handsheets

Figure 2 shows the effect of LCR and AHCR treatments on the physical properties of handsheets, such as tensile index, tensile energy absorption (TEA), tear index, and folding strength.

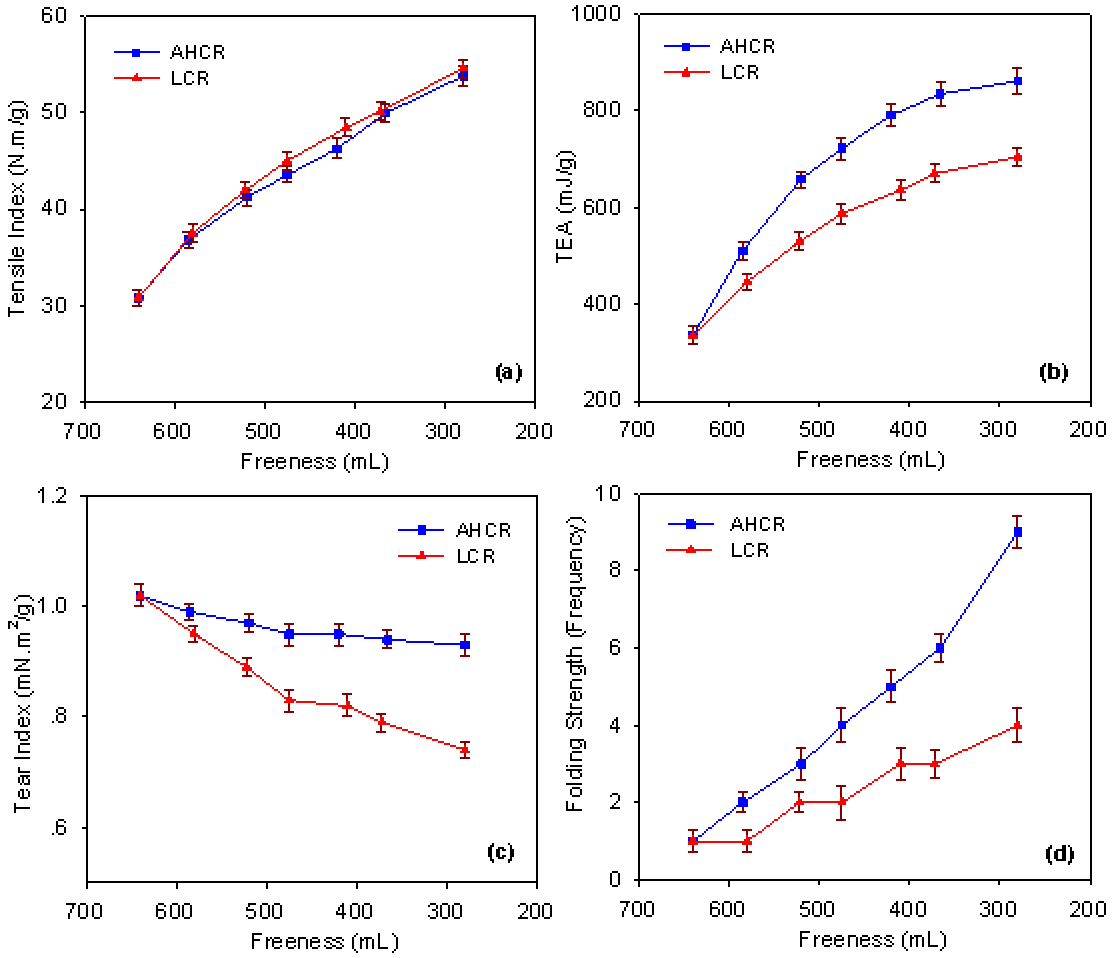

Fig. 2. Effect of freeness on (a) tensile index, (b) tensile energy absorption (TEA), (c) tear index, and (d) folding strength

For any given freeness, AHCR resulted in similar tensile indexes, while the TEA that was clearly higher than for LCR (Fig. 2a, b). It has been reported that fiber curl and kink during HCR decreased the tensile index of softwood pulp due to the resulted poor sheet uniformity (Sjöberg *et al.* 2008; Gurnagul *et al.* 2009). The improved TEA indicated that AHCR of the reed pulp generates more fiber curl and kink and micro-compressions, which together improve the stretch-potential and flexibility of fibers. This phenomenon was also observed during the HCR of unbleached softwood pulp that was successfully used for sack paper (Gurnagul *et al.* 2006, 2009).

In Fig. 2 (c) and (d), with the decrease of freeness, both the LCR and AHCR treatments resulted in a decrease in the tear index and an increase in the folding strength. For any given freeness, the AHCR treatment obviously improved the tear index and folding strength compared to the LCR treatment. It appeared that that better retained fiber length and improved flexibility from AHCR led to the improved tear and folding strength.

A Mill Case Study

A mill trial was conducted in collaboration with a paper mill in China to confirm the effect of AHCR. In the mill trial, 70 g/m^2 of offset paper was made on a Fourdrinier machine at a machine speed of 550 m/min and width of 3520 mm. The pulp furnish mixture consisted of 85% bleached chemical reed pulp, 15% softwood kraft pulp, and 25% precipitated calcium carbonate (PCC) filler. The chemical reed pulp was previously refined to a CSF of 560 mL with a consistency of 4.5% using two LC refiners, while the softwood pulp was refined to a CSF of 350 mL at a consistency of 4.0%. Previously the paper mill had not been able to improve the machine runnability, tear strength, and folding strength of the test paper when relying on low-consistency refining. Hence, one HC refiner was used to replace the two LC refiners used previously to refine the chemical reed pulp to the same target freeness, while the other conditions were the same. The benefits of pulp retention, runnability, and paper strength using AHCR treatment are shown in Table 3.

Table 3. Comparison of Mill Scale LCR and AHCR Treatments

Treatment	Freeness (mL)	First Pass Retention (%)	Machine Speed (m/min)	Tensile Index (N.m/g)	Tear Index (mN.m2/g)	Folding Strength (Frequency)	CD* Stretch at Break (%)
LCR	560±1.29	65.42±0.48	550±5.45	35.66±0.27	3.84±0.08	6±0.82	2.83±0.04
AHCR	562±1.73	69.78±0.74	595±4.97	35.31±0.31	4.57±0.07	11±0.58	3.64±0.10

*Cross direction

Compared with the LCR treatment, AHCR noticeably improved the machine runnability and physical properties of paper. For the AHCR treatment, the first pass retention efficiency improved by 6.6%, while the machine speed improved by 8.2%. These results were due to better drainage and less fines generation in the pulp furnish. Also, the tear index and folding strength of the AHCR pulp were improved, while the tensile strength was maintained. The mill trial confirmed the laboratory results and showed the potential application of AHCR treatment for the improvement of non-wood fibers.

CONCLUSIONS

1. Compared with LCR treatment, AHCR treatment of reed pulp can obtain better retained fiber length, less fines generation, higher water retention value (WRV), as well as better dynamic drainage; however the curl and kink properties were obviously increased.
2. Compared with LCR treatment, AHCR treatment of reed pulp can clearly improve tear index, folding strength, and tensile energy absorption (TEA), while maintaining the tensile index.
3. A mill trial successfully demonstrated the benefits of using AHCR to increase the first pass retention, machine speed, as well as to improve paper physical properties, such as tear and folding strength, and stretch at break.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Pierre LePoutre (FPInnovations advisor) for his insightful technical advice and help in polishing this manuscript and for the financial support from the Natural Science Foundation of Hunan Province (Grant No. 2015JJ2008) and the Open Fund of Key Laboratory of Pulp and Paper Science & Technology of Ministry of Education of China of Qilu University of Technology (Grant No. 08031340).

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Article submitted: November 12, 2016; Peer review completed: January 7, 2017; Revised version received and accepted: March 13, 2017; Published: March 20, 2017.
DOI: 10.15376/biores.12.2.3331-3339