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Improvement of bleached wheat straw pulp properties by using aspen high-yield pulp

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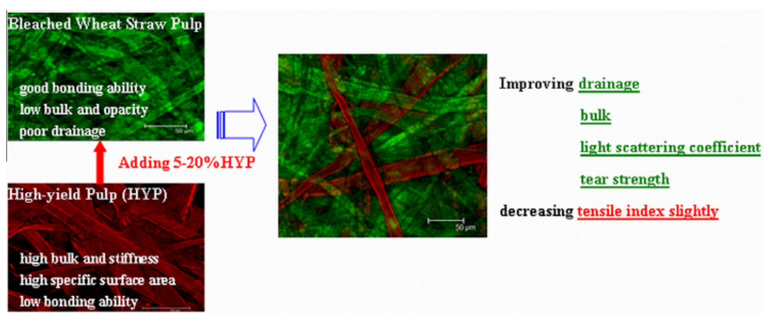
HIGHLIGHTS

- ▶ Addition of 5–20% aspen HYP into BWSP can improve its drainage and bulk obviously.
- ▶ Addition of HYP fibers resulted in more pores in the BWSP fiber network.
- ▶ Mixing BWSP with HYP had a synergistic effect on the light scattering coefficient.
- ▶ The BET surface area and micro-pore volume increased with increasing the HYP ratio.
- ▶ The addition of aspen HYP can significantly increase the tear index of BWSP.

GRAPHICAL ABSTRACT



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ABSTRACT

The bleached wheat straw pulp (BWSP) accounts for about 25% of the virgin fiber supply in the Chinese Pulp and Paper Industry. As a non-wood chemical pulp, BWSP is known to have low bulk, low light scattering coefficient and poor drainage due to its high content of parenchyma cells. In this study, a high-quality aspen high-yield pulp (HYP) was used to improve the BWSP properties at the laboratory scale. The results indicate that adding 5–20% aspen HYP into unrefined or refined BWSP can minimize many of the drawbacks associated with the BWSP: improving its drainage, bulk, light scattering coefficient and opacity. The addition of a small amount (up to 20%) of aspen HYP can also significantly increase the tear index of BWSP with only a slight decrease of the tensile index.

1. Introduction

Due to the shortage of forest resources in Asian countries, non-wood is one of the most important raw materials for pulp and paper production because of its abundance and cost-effectiveness. Many studies have been carried out on non-wood pulping, the resultant pulp properties, and their improvements (Ates et al., 2008; Fatehi et al., 2009; Hosseinpour et al., 2010; Jahan et al., 2007). By far, China is the biggest non-wood producer in the world, and wheat straw is the largest source of non-woods.

The Chinese Pulp and Paper Industry has been growing very fast in the recent 20 years; and the non-wood pulp fibers, including straws, bamboo, reeds, play an important role. Bleached wheat straw pulp (BWSP) is the main non-wood chemical pulp, and makes up more than 70% of total non-wood fibers in China (Hu et al., 2006b; Qin and Fu, 2007). BWSP is made of thin fibers with

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a high length/width ratio, offering a good paper surface smoothness; however, it has low bulk, low opacity and poor drainage, due to its high content of parenchyma cells, which are detrimental to the runnability of paper machine and/or to the paper qualities of many end-uses. Although different attempts have been reported to improve those pulp properties (Cheng and Bi, 2002; Liu and Li, 1994), limited success has been obtained.

In recent years, hardwood high yield pulps (HYPs) have found increasing applications in many paper grades (Hu et al., 2004, 2006a, 2007; Reis, 2001; Zhou, 2004). Compared to the chemical pulps, HYPs have some unique properties, including high bulk, opacity, stiffness, light scattering coefficient and specific surface area, good swelling and water retention values (Hui et al., 2009; Li et al., 2002). In particular, the relatively higher specific surface area of HYP fibers and fines (Li et al., 2002; Liu et al., 2009) may enhance the absorption of the broken parenchyma cells of BWSP, resulting in improved drainage of BWSP. In addition, a mixture of different pulp furnish may bring about some unexpected synergistic effect regarding the pulp properties (Resalati, 2006; Xu et al., 2008a,b). For example, it has been observed (Retulainen et al., 1993; Xu and Zhou, 2007; Zhang et al., 2011a,b,c) that when hardwood kraft pulp was partially substituted by HYP for the production of wood-free paper grades, the strength of the resulting paper was improved.

Using high-quality HYP to improve the papermaking properties associated with BWSP is a new concept. It is of practical importance to the Chinese Pulp and Paper Industry because (1) in China, BWSP is the main non-wood chemical pulp; (2) the new installment of paper making capacity would demand practical solutions to the property deficiencies associated with BWSP, such as poor drainage and low opacity.

2. Methods

2.1. Raw materials

A typical bleached wheat straw chemical pulp (BWSP) with medium brightness level was received from a mill in Shandong province, China, while an Aspen HYP (325/83) was obtained from a mill in Eastern Canada. A part of the BWSP was used as is (labeled as BWSP-0), and another part was refined for 2000 revolutions in a PFI mill (Manufactured by HAM-JERN, Norway), and thus the obtained sample was labeled as BWSP-2000; while the aspen HYP was used without further refining. The properties of these pulp samples were shown in Table 1.

2.2. Methods

2.2.1. Lab paper sheets (handsheets) preparation

The unrefined or refined BWSP was mixed with HYP at specified ratios in a standard disintegrator for 15,000 revolutions at a 1.2% pulp consistency. Subsequently, handsheets were made, which was conducted according to the Tappi standard method (T205 sp-95), the measurement of paper physical properties was performed in accordance with the Tappi standard method (T220 sp-96) as well.

Table 1
Properties of the aspen HYP (325/83) and unrefined and refined BWSP samples.

Types of pulp	Aspen HYP	BWSP-0	BWSP-2000
Freeness (ml)	510	343	139
Bulk (cm^3/g)	2.35	1.67	1.56
Tensile index (N m/g)	25.11	48.66	69.57
Tearing index (mN m^2/g)	3.36	2.75	2.36
Brightness (%ISO)	80.3	71.0	66.9
Light scattering coefficient (m^2/kg)	46.3	35.7	24.1

2.2.2. Confocal microscope examination

BWSP-0 was dyed with 1% BASF liquid Basol Green, and HYP was dyed with 1% BASF liquid Pergasol Yellow. Images were collected on a Leica TCS-SP2 confocal microscope (Leica Microsystems, Exton, PA, USA) using a 20× dry objective lens, NA 0.7, zoom 3×. Dyes were excited using an argon laser at 488 nm for fibers dyed with Pergasol Yellow and a helium–neon laser at 633 nm for fibers dyed with Basol Green. Detectors were configured to minimize any crosstalk between the channels. The emission for Pergasol Yellow was collected between 500 and 567 nm and the emission for Basol Green was collected between 720 and 813 nm.

2.2.3. Scanning electron microscopic observation

The cross section of the lab paper sheets was characterized using a JEOL JSM-6400 scanning electron microscope (SEM). Samples were cut with a single-use sharp blade and coated with gold using an Edwards S150A sputter coater, and the SEM images were taken at an accelerating voltage of 10 kV.

2.2.4. BET specific surface area and micro-pore volume

The specific surface area of the lab paper sheets was determined by nitrogen adsorption. The adsorption and desorption isotherms of nitrogen at 77 K were obtained using an Omnisorp-100 automatic analyzer after degassing the samples at 573 K for at least 4 h under vacuum 0.013–0.0013 Pa. The linear part of the Brunauer–Emmett–Teller (BET) equation (P/P_0 = 0.06–0.10) was used to calculate the specific surface area. The *t*-plot method was applied to quantitatively determine the micro-pore volume.

3. Results and discussion

3.1. Effect of HYP addition on the freeness and drainage of BWSP

BWSP is well known for its poor drainage and being much easier to be refined to low freeness in comparison with chemical wood pulps, mainly due to its high content of non-fiber cells, such as parenchyma cells (Chute, 2006; Guo et al., 2009). The freeness of the unrefined BWSP (BWSP-0 in Fig. 1a) was 343 ml Canadian standard freeness (CSF), and it dropped sharply to 139 ml CSF with 2000 PFI refining revolutions (BWSP-2000 in Fig. 1b). A low freeness means low dewatering efficiency in the papermaking process. To improve the freeness and drainage of BWSP, the high-freeness HYP may be added. As shown in Fig. 1a, the CSF increased significantly with increasing addition of the aspen HYP. The effect of HYP addition on freeness improvement was more pronounced with the refined BWSP (BWSP-2000 in Fig. 1b).

The drainage of a pulp may be better evaluated by determining the drainage time of the fiber suspension during the handsheet making process on a standard British handsheet machine that is equipped with a 150-mesh screen so that most of the fines is retained. As shown in Fig. 2a, the drainage time decreased significantly with increasing HYP addition, indicating that there was faster dewatering of the BWSP-0 in presence of HYP fibers. Fig. 2a also showed that there was a synergistic effect on the drainage in the two-component pulp system, since the tested drainage time was lower than that calculated as the sum of the calculated weight contribution from the two components. In the case of BWSP-2000 (refined BWSP), the impact of HYP addition and the apparent synergistic effect of BWSP and HYP on the drainage time were even more significant, as shown in Fig. 2b. This may be attributed to the relatively coarse and stiff HYP fibers that resulted in more pores in the fiber network of the paper sheets for greater water flow. To confirm this hypothesis, we measured the air permeability of lab paper sheets made with a mixture of BWSP and HYP at various ratios. It can be seen in Fig. 2c that the Gurley