REPLACEMENT OF SOFTWOOD KRAFT PULP WITH ECF-BLEACHED BAMBOO KRAFT PULP IN FINE PAPER

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Non-wood fibers such as bamboo and wheat straw have been playing important roles in the pulp and paper industry in China. In this study an ECF-bleached bamboo kraft pulp was compared with a bleached softwood kraft pulp (NBSK) as the reinforcement pulp in fine paper production. Areas that were examined include the refining of pure fibers, influence of bamboo on dewatering, retention, and sizing. The influence of bamboo kraft pulp as a part of a furnish replacing NBSK was compared as well. Results show that fiber shortening was more prominent with bamboo when refined. This resulted in a higher amount of fines, and addition wet-end chemicals may be required to compensate. Handsheets with bamboo as a reinforcement fiber showed similar mechanical and optical properties to handsheets containing NBSK.

Keywords: ECF-bleaching; DQP-bleaching; Bamboo; Fine paper; Retention; Drainage; Refining

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INTRODUCTION

The supply of wood raw materials for the pulp and paper industry in China is limited, and non-wood fibers are contributing a large proportion to the growth of pulp and paper production in China. The total production of non-wood pulps in China is projected to reach 13 million tons in 2020.

Bamboo is an important non-wood fiber resource in China. There are more than 500 species, and about 5.5 million hectares are cultivated (Wang et al. 2004). About 25% of the world's bamboos are produced in China, of which 40% are from the Southwest and Southeast regions of China (Zhang 2002). Among the 500 bamboo species, more than 30 are suitable for papermaking (Gan 2003), such as *Bambusa distegia*, *Phyllostachys pubescens*, and *Phyllostachys heteroclada*. Bamboos grow well and can be harvested in 3 to 5 years. The growth rate of bamboo is about 4.5-7.5 t/ha•y, which is about twice that of some fast-growing wood trees. The utilization of bamboos may be a solution to the fiber shortage of the pulp and paper industry in China.

Bamboo fiber has a medium-to-long length (1.5 to 2.0 mm) and a larger length-to-diameter ratio (110-220) than wheat straw, bagasse, reed, and other non-wood raw materials. The cell wall of bamboo fibers is thicker and the cell lumen is smaller (Singh et al. 1976), so bamboo fibers are in general less flexible, and they do not collapse as easily as softwood fibers in the papermaking process. In China, bamboo pulp is substituted for softwood pulp in the production of many paper grades. The pulping and bleaching processes for bamboos have been investigated in a number of studies (Greschik et al. 2004; Qin et al. 2004; Thi et al. 2004; Gao et al. 2005). At present, the annual production of bamboo pulp in China is about 1 million tons, and there are more than 10 bamboo pulp mills with an annual output exceeding 50,000 thousand tons. Qian et al. (2006) have shown that bamboo pulp has lower tensile than a (bleached softwood kraft pulp) NBSK at similar beating degrees (Qian et al 2006). They found that bamboo fibers were shortened to a greater extent during the PFI mill refining. To further show this, we also included in the present paper the results of pilot-scale refining of an elemental-chlorine-bleached bamboo pulp, in comparison to a NBSK pulp.

The elemental-chlorine-bleaching process will be replaced by the ECF bleaching process due to environmental concerns and government regulations. In this paper, bamboo pulps from the two bleaching processes were compared with the NBSK process as reinforcing fibers in fine paper. Criteria for a reinforcement fiber include providing good runnability for both paper manufacturing and converting operations, which require good wet web strength and dry strength. On the other hand, a reinforcement fiber should not impair the drainage and retention of a paper machine. In this paper, the suitability of bamboo to replace NBSK is examined. Besides strength properties, the drainage/retention, and sizing response were also examined. These properties, though normally not critical, can be relevant due to the higher fines content of bamboo which may be detrimental to the drainage/retention and sizing thus warranting some attention.

EXPERIMENTAL

Pulp samples

The following pulp samples were used in the studies: NBSK: bleached softwood (northern pines) kraft; BHKP: bleached hardwood (acacia) kraft from Indonesia; Laboratory-bleached bamboo kraft pulp: an unbleached bamboo kraft was obtained from the Yongfeng mill, Sichuan province of China; it was laboratory-bleached by either a CEH and or a DQP sequence at the State Key Laboratory of Pulp and Paper Engineering, South China University of Technology (SKLPPE, SCUT); mill-bleached bamboo kraft pulp: bleached by the CEH process at mill in China.

Chemicals

The following chemicals were used to make handsheets of fibers and filler.

- Flocculant cationic polyacrylamide: Eka PL 1510 ($M_w = 5.5\text{-}5.7\times10^6$, charge density = 10 %, 90 % solids content).
- Anionic polyacrylamide: Eka PL 8660 (60 % charge, 40-43 % solids content).
- Colloidal silica: Eka NP 882 (16.26 % solids content).
- AKD size: Eka DR D12 (15.5 % solids content).
- Starch: Tapioca (D.S. =0.018 %).
- PAC: Eka ATC 8210 (10.2 % active content (Al_2O_3)).
- Filler: PCC (particle size: 50 % were 3.0 to 3.5 μm).

Methods

Refining

Laboratory PFI refining was done according to ISO 5264-2:2002 at 10 % consistency. The beating force was at 3.33 N/mm. All three pulps were refined at 0, 1600, 3200, 4800, 6400, and 8000 revolutions. Laboratory refining with a Voith LR1 refiner was performed at 5 % consistency, pH 7, 0.6 J/m specific edge load. Refiner plates 2/3-0.73-20 and 3-0.84-30 were used. The former refiner plate is normally used for softwood pulp and the latter for hardwood pulp, with specific edge lengths of 2.92 and 1.12 km/s, respectively.

Wet-end

For investigations in drainage and dewatering and handsheets with bamboo and NBSK as reinforcement fibers, furnishes were prepared by mixing 80% of the hardwood kraft and 20% long fibers (bamboo kraft or NBSK). The filler content was approximately 30% of the total furnish. Filler was added after pH and conductivity adjustments. The furnish pH was 7.8, and the conductivity was 1000 µS/cm. For the drainage tests, a Mütek DFR was used at 1200 rpm. stirrer speed. For the ash retention, 500ml of the furnish was put into a Dynamic Drainage Jar (DDJ, Paper Research Materials Inc.) and stirred at 1500 rpm. Chemicals were added sequentially as follows.

- PAC 0 seconds
- Starch 15 seconds
- AKD size 22 seconds
- C-PAM 30 seconds
- Silica / A-PAM 40 seconds

The drainage was started at the 50th second.

Paper testing

Handsheets were made on a Canadian sheet former with a sheet diameter of 16 cm, without filtrate recirculation, according to ISO 5269-1:1998. The physical and optical properties of handsheets were tested according to ISO standards.

Thickness	ISO 534:1998
Grammage	ISO 536:1995
Schopper-Riegler	ISO 5267-1:1999
Tensile Index	ISO 1924-2:1994
Tear Index	ISO 1974:1990
Opacity	ISO 2471:1998
PPS	ISO 8791-4:1992

Fiber length measurement

L&W FiberMaster, L&W Fiber Tester, and Kajaani FS200 were used for fiber length measurement.

RESULTS AND DISCUSSION

Pilot Scale Refiner Trial of Pure Fiber

A pre-study was performed with a Voith LR-1 pilot-scale refiner to determine the refining response of bamboo kraft pulp. The Voith refiner has characteristics between those of a commercial refiner and the PFI refiner. Qian et al. (2006) have shown that considerable fiber shortening occurred with PFI refining, despite the fact that PFI refining gives a very gentle fiber treatment (Welch and Kerekes 1994). In this part of study, an elemental-chlorine-bleached bamboo kraft obtained from a pulp mill was compared to a NBSK.

Figure 1 shows that the bamboo kraft pulp required much less refining than the NBSK pulp to reach a target water retention value (WRV). Refining with a specific edge length of 1.12 km/s gave a more gentle refining and slower WRV development. However, similar specific refining energy was required for the bamboo kraft to achieve a tensile index similar to that of the NBSK, using the same refiner plate. It can be seen in Fig. 2 that the bamboo pulp had higher tensile stiffness index at lower sheet densities, or when the fiber were refined at lower energies. However, at higher refining energies or at higher sheet densities, the tensile stiffness index of bamboo started to level off while the NBSK continued to increase. The two refiner plates gave similar tensile stiffness development with the 1.12 km/s refiner plate giving marginally better tensile stiffness index. Therefore, the refiner plate pattern can influence the refining energy consumption, strength development, and WRV of the bamboo pulp. This is supported by Subrahmanyam's finding that pulp strength could be improved by low specific-edge-load refining without decreasing the drainage (Subrahmanyam et al. 2000).

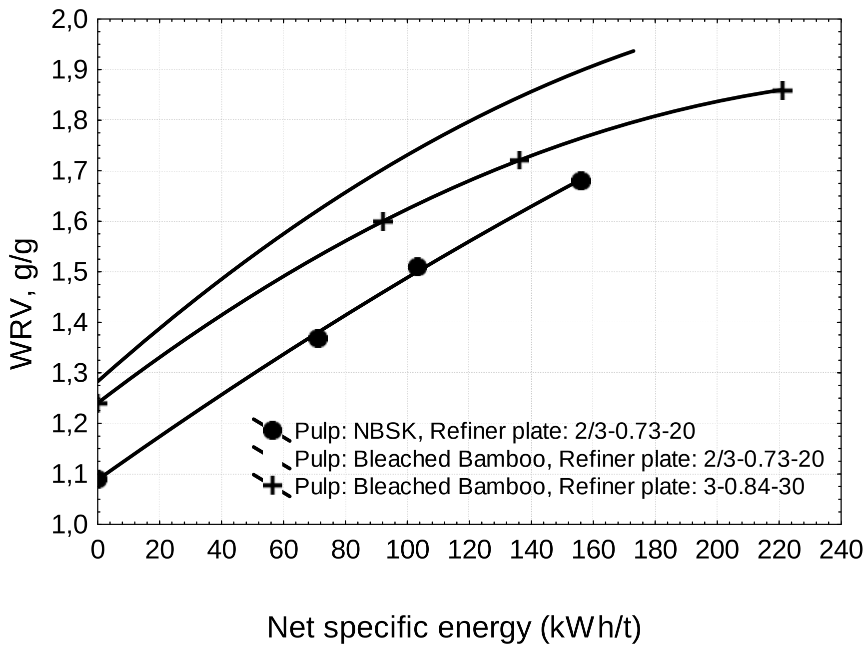

Fig. 1. Effect of refining energy on the water retention value (WRV) of three different pure fibers. Two different refiner plates were used on the bamboo.

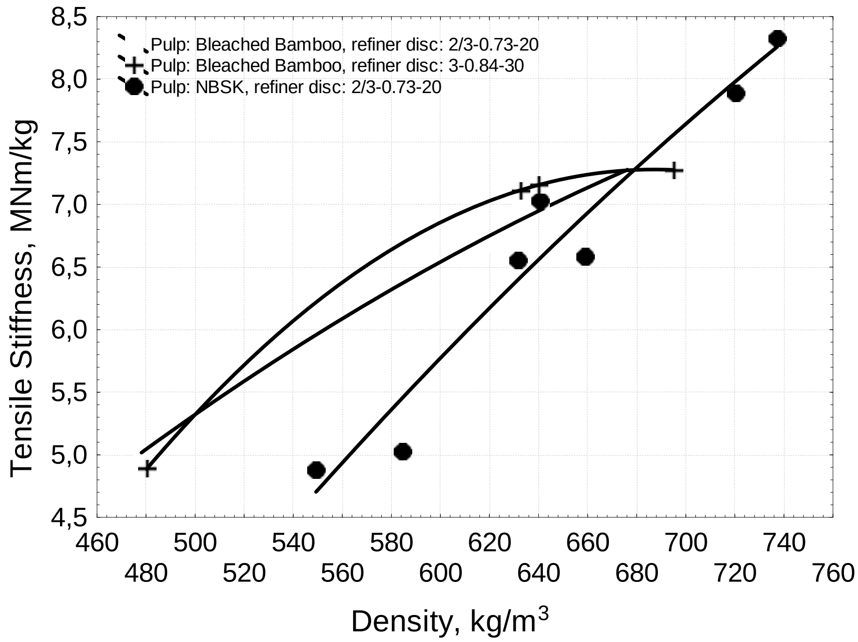

Fig. 2. Effect of sheet density on the tensile stiffness index for three different pure fibers. Two different refiner plates were used on the bamboo.

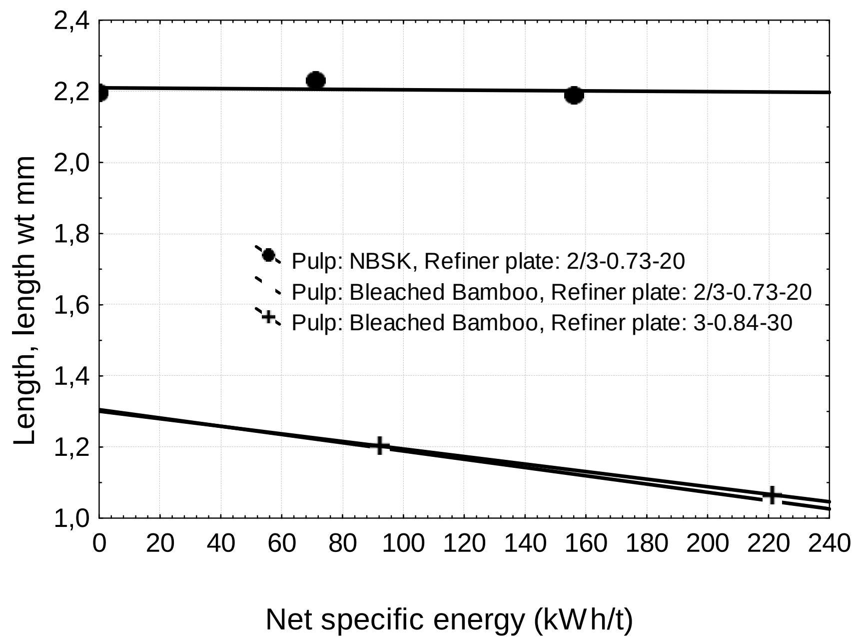

Fig. 3. Effect of specific refining energy on fiber length of three different pure fibers.

Figure 3 shows that refining resulted in considerable fiber shortening of the bamboo pulp; fiber length was decreased by about 15% at 170 kWh/t of specific refining energy input. The fiber shortening provide an explanation into the leveling off of tensile stiffness index at higher refining intensities or sheet density. No significant difference was observed in fiber length between the two refiner plates. As expected, no fiber shortening was observed in the case of the NBSK.

PFI Refining Results of Pure Fiber

Based on the results of the pilot-scale refining on a Voith LR-1 refiner, it was necessary to optimize the refining of the CEH- and DQP-bleached bamboo pulps with respect to drainage, retention, sizing, and paper properties. A PFI mill was used for this purpose.

Figure 4 shows the development of the tensile index in PFI refining. For a given SR value, the NBSK had the highest tensile index, followed by the DQP-bleached bamboo kraft. The CEH-bleached bamboo kraft had the lowest tensile index. This is in agreement with the results of Qian et al. (2006). Based on the results in Fig. 4, the three pulps were beaten to similar tensile indexes by different PFI revolutions.

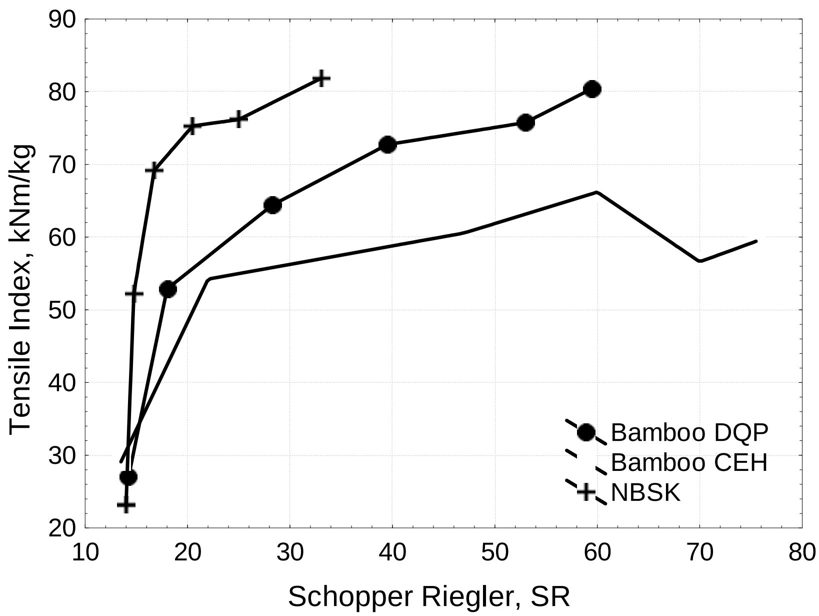

Fig. 4. Effect of beating degree (°SR) on the tensile index of three different pure fibers by PFI refining

Figure 5 shows that fiber shortening was obvious in the PFI refining of the CEH-bleached bamboo kraft, while the DQP-bleached bamboo kraft showed no reduction in fiber length during refining. Fiber length was measured with a Kajaani FS200 and expressed as the length weighted average fiber length. Figure 6 shows the fines contents of the three pulps refined to a similar tensile index. The fines contents of both bamboo kraft pulps were significantly higher than that of the NBSK pulp, which is in agreement with the findings of Wai et al. (1984), who reported that unrefined bamboo pulp contained a large amount of fines.

Drainage and Retention of Furnishes with Bamboo and NBSK

For the drainage and retention studies, the PAC, starch, and A-PAM dosages were kept constant, while the C-PAM (Eka PL 1510) and colloidal silica (Eka NP 882) dosages were varied. A Mütek DFR was used to measure the drainage rate, expressed as ml of filtrate drained per second. All chemical dosages were based on what were received. Fiber composition for the drainage/retention experiments was: 20% long fibers (NBSK or bamboo kraft) and 80% hardwood kraft (BHK).

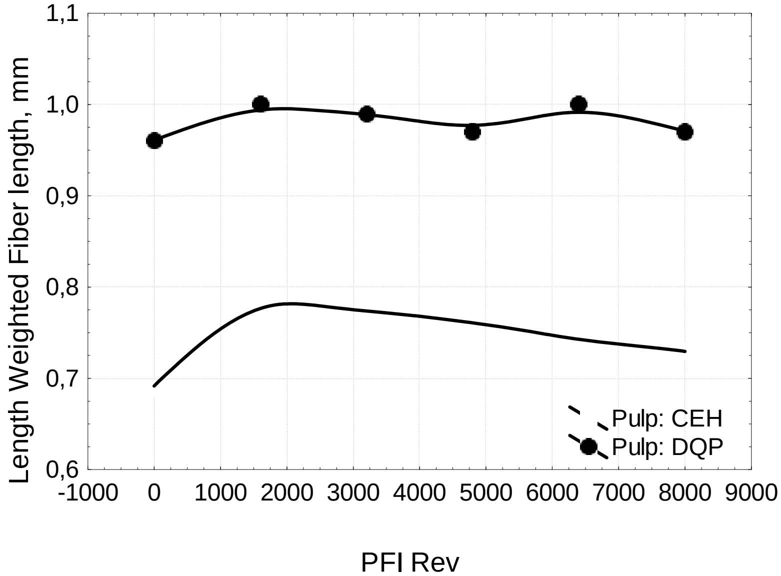

Fig. 5. Effect of beating degree (SR) on the length weighted fiber length of the two pure bamboo fibers from PFI refining (Kajaani FS200)

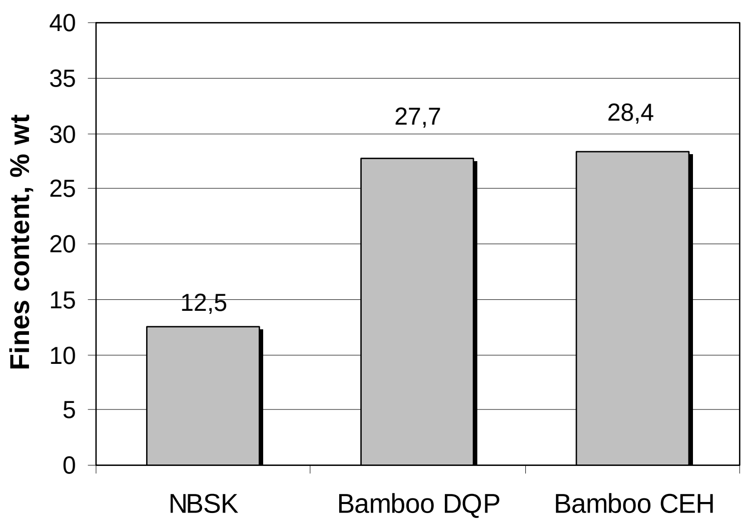

Fig. 6. Fines contenst of pulps beaten to similar tensile indexes by PFI refining (6500 revolutions for the NBSK and the DQP-bleached bamboo kraft pulp, and 8000 revolutions for the CEH-bleached bamboo kraft). Fines contents were measured on BDDJ with a 75 µm wire.

The results in Figure 7 show that the NBSK furnish (20% NBSK) required the lowest dosages of C-PAM and colloidal silica to achieve a given drainage rate. The DQP furnish (20% DQP) required a higher colloidal silica dosage to achieve the same dewatering rate as the NBSK furnish, while the CEH furnish required an additional amount of both C-PAM and colloidal silica to achieve a similar dewatering rate. The higher chemical dosages required by the bamboo pulps could be due to their higher fines contents. Another possibility could be that bamboo fibers have higher surface charge density than the NBSK fibers. These might also explain the results of total retention in Fig. 8, wherein the two bamboo furnishes had a maximum retention at 2 kg/t of colloidal silica, while the total retention of the NBSK furnish continued to increase, even at 4 kg/t colloidal silica.

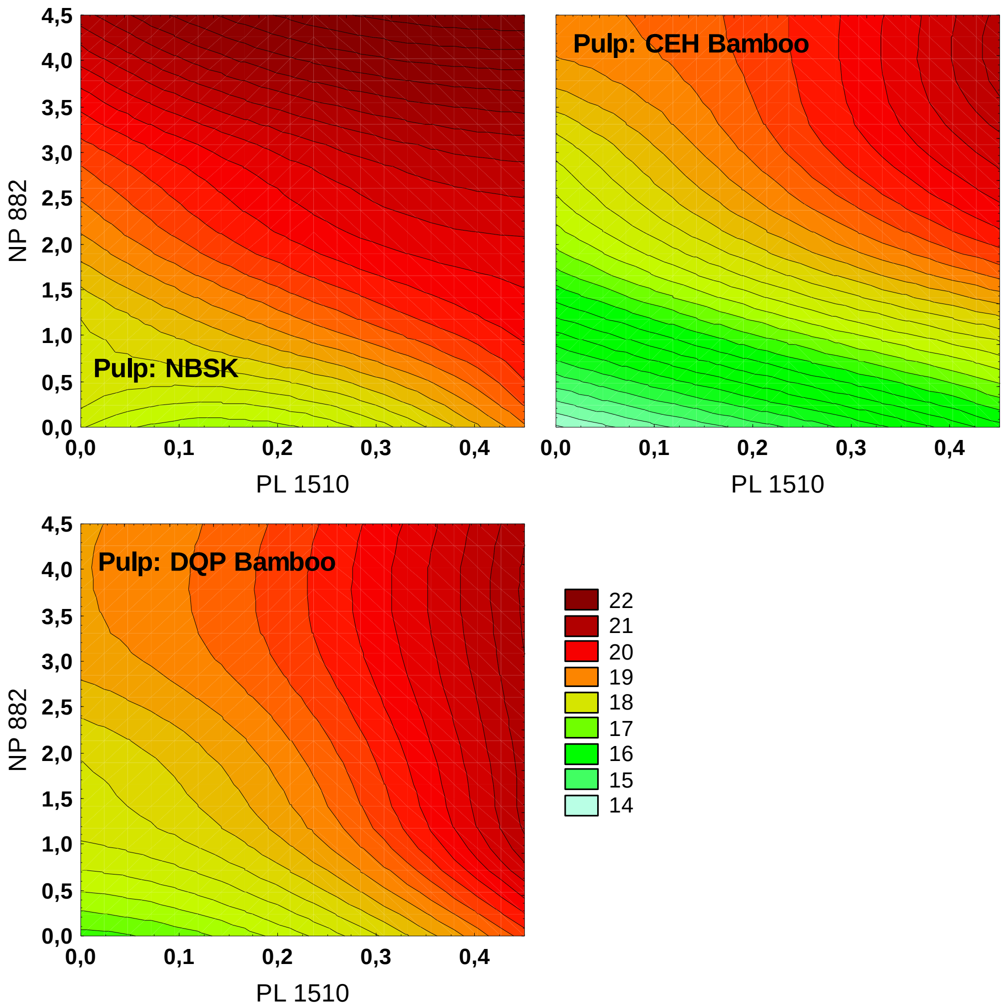

Fig. 7. Effect of C-PAM (Eka PL 1510) and colloidal silica (Eka NP 882) dosages on the drainage rate expressed as ml/s (z axis)

Figure 9 shows the AKD sizing response of the three stocks. The CEH-stock was the most difficult to size, while the NBSK stock was the easiest to size. The sizing response of the DQP-stock was between those of the NBSK and CEH stocks. Higher size dosages were required for the bamboo furnishes were probably due to their higher fines contents. The differences in Cobb values between the three stocks were observed even at higher filler contents.

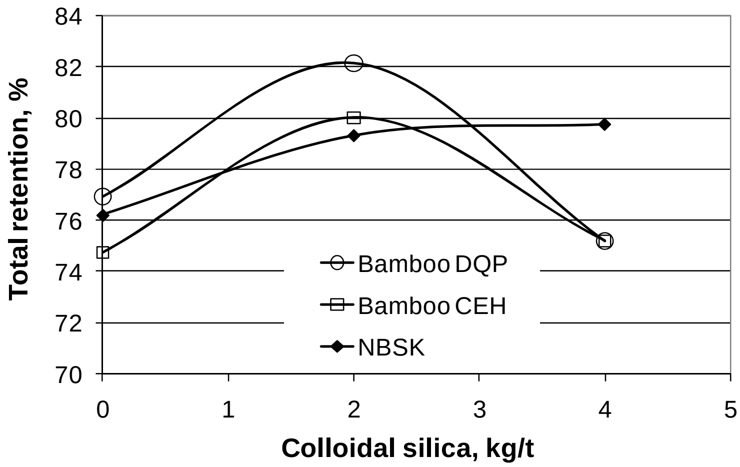

Fig. 8. Effect of colloidal silica dosage on the total retention. C-PAM dosed at 100 g/t.

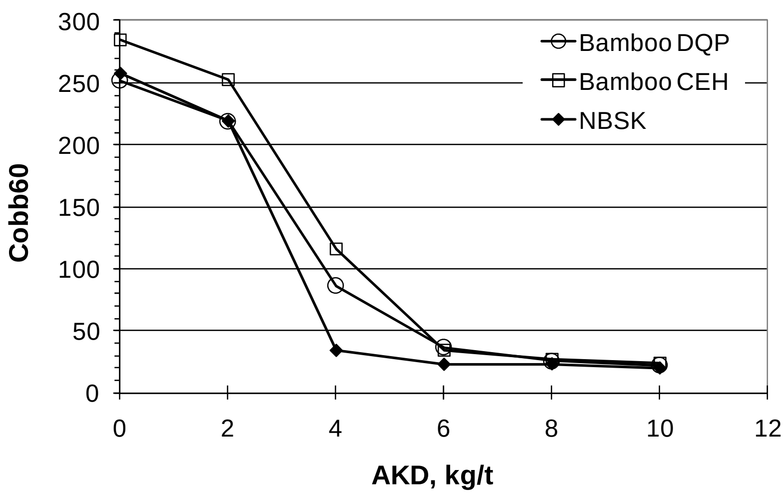

Fig. 9. Effect of AKD dosage on the $Cobb_{60}$ value

Handsheet Properties of Bamboo and NBSK as part of a Furnish

Figure 10 shows the relationship between tensile and tear index for the three furnishes at varied starch dosages. The DQP furnish had a tensile/tear index relationship similar to that of the NBSK furnish, while the CEH furnish had lower tear strength at a given tensile strength than the other two furnishes.

Figure 11 shows the opacity as a function of the ash content. The handsheets from the two bamboo furnishes had higher opacity than the NBSK furnish at the same ash content. This was probably due to their higher fines contents. Figure 12 shows that the handsheets from the bamboo furnishes had lower surface roughness due to smaller and shorter bamboo fibers. From Figure 12 one can also see that the effect of ash content on the roughness was small under the conditions. The implications may be that less filler and less calendering are required for the bamboo furnishes for target opacity and surface roughness of paper sheets.

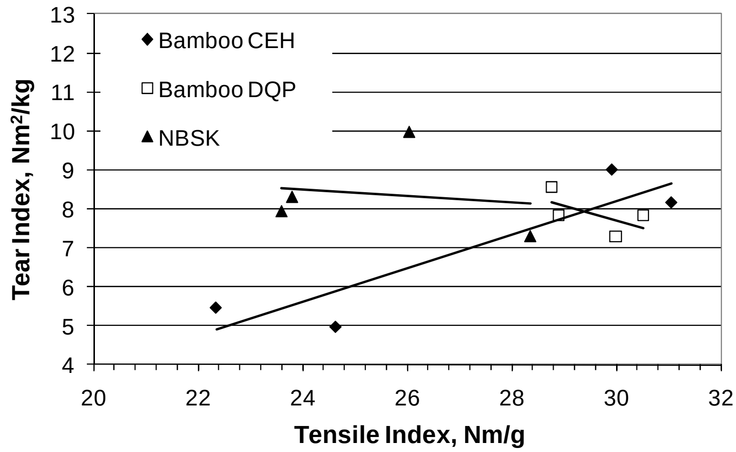

Fig. 10. The tensile and tear index relationship for the three furnishes at varied starch dosages

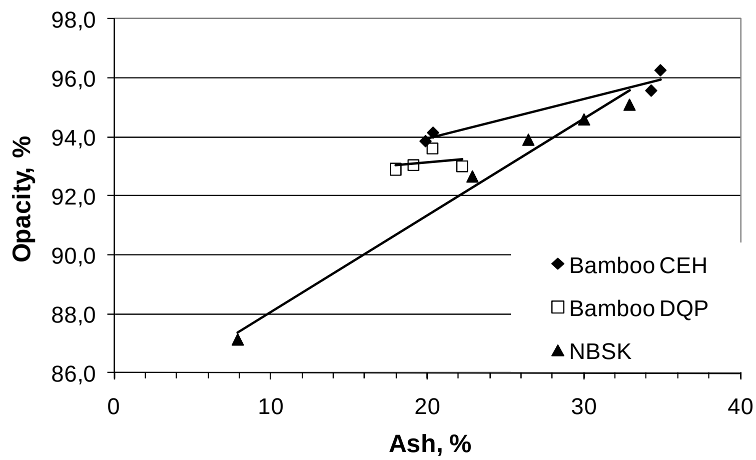

Fig. 11. Sheet opacity plotted as the function of the ash content

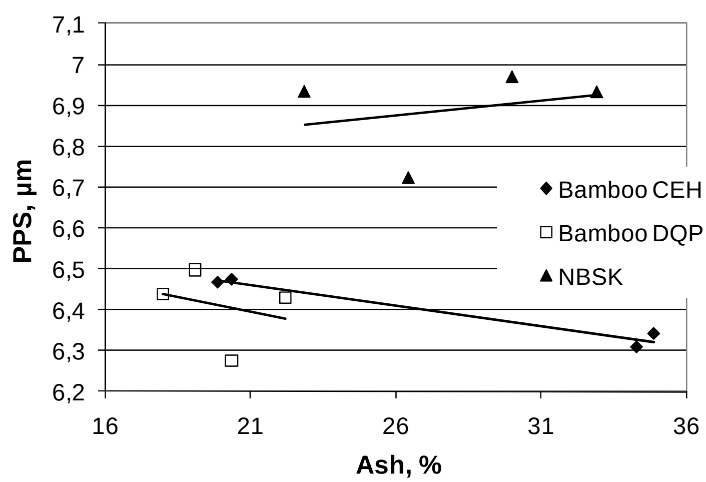

Fig. 12. Surface roughness plotted as the function of the ash content

CONCLUSIONS

In this paper an ECF-bleached bamboo kraft pulp was compared with a CEH-bleached bamboo kraft pulp and a bleached softwood kraft (NBSK) as a reinforcing pulp in fine paper production. It was shown that as pure pulp, the bamboo pulps required less refining energy than the NBSK for a target freeness, but the refining energy was similar for a given tensile index. Both DQP-bleaching and low-intensity refining could lead to increased tensile strength of the bamboo kraft pulp for a given SR-value. CEH-bleached bamboo kraft had a greater reduction of fiber length in PFI refining than the DQP-bleached bamboo kraft. Both pulps had more fines than the NBSK pulp. Therefore, when used as a reinforcement pulp in a furnish, NBSK required the least amount of retention chemicals and AKD size, while the CEH-bleached bamboo kraft required the most. The bamboo kraft pulps gave higher opacity and lower surface roughness than the NBSK pulp when used as a reinforcement pulp in a furnish.

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