PULP AND PAPERMAKING PROPERTIES OF BAMBOO SPECIES *MELOCANNA BACCIFERA*

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Pulp and paper making properties of bamboo species *Melocanna baccifera* were studied with a focus on the physical properties and chemical composition of bamboo chips, on pulping behavior, bleaching response, fiber morphology, refining behavior and strength properties of the bleached pulp. *Melocanna baccifera* species was found to have 52.8% cellulose, 21.1% hemicelluloses and 25.2% lignin, *i.e.* similar to hardwood. The produced pulp could be bleached to 89 ± 1% ISO brightness. The bleached pulp refined to 25 °SR had 54.6 Nm/g tensile index, 10.7 mN.m^2/g tear index, 4.95 kN.m^2/g burst index and 328 double folds. Also, the bleached pulp had an average fiber length of 1.68 mm, which is higher than that of hardwood pulp (0.88-1.1 mm), but lower than that of softwood pulp (2.2-3.5 mm). Meanwhile, the pulp had an average fiber width of 17.1 μm, which is similar to that of hardwood fiber (16-20 μm), but lower than that of softwood fiber (28-35 μm).

Keywords: bamboo, bleaching, extractives, papermaking properties, pulping

INTRODUCTION

Bamboo is one of the most versatile plants in the world. Bamboo is widely used as a fibrous raw material for papermaking due to its long fiber and chemical composition similar to that of hardwoods.[1] Bamboo has become a very useful reinforcing fiber in Asian countries, specifically in India and China, on the one hand, due to its large availability and on the other because of the scarcity of softwood in these regions. Two large pulp and paper mills in India are producing about 200,000 t/year paper pulp exclusively from bamboo. A new bamboo based pulp mill has been installed in China with a capacity of 200,000 tons per year bleached pulp production using the TCF bleaching sequence.[2] A pulp mill in Thailand is reported to produce 210,000 ton per year, making pulp largely from bamboo by the SuperBatch cooking system, oxygen delignification, followed by ECF bleaching sequence $D_0E_OD_1D_2$.[3]

There are over 1,000 species of bamboo throughout the world, growing in a wide range of climates and regions. Morphological properties and pulping behavior of different bamboo species have been studied and wide variation in fiber dimensions has been reported among the species, but no significant differences in the chemical composition of bamboo chips or pulps have been found, nor in the amount of alkali consumed during pulping.[4] The chemical properties of different species of bamboo, *viz. Bambusa vulgaris*,[5] *Bambusa stenostachya* Hackle,[6] *Neosinocalamus affinis*[7] and *Bambusa balcooa*,[8] have been analyzed and reported in the literature.

In recent years, studies conducted on pulping of different bamboo species showed that, by reducing the cooking temperature and prolonging the cooking time, a higher pulp yield, higher xylan content, and unchanged pulp viscosity could be obtained without affecting fiber length.[9] It was also found that the bamboo cooked with higher alkali and sulphidity, had a higher yield and higher alpha-cellulose content.[10] Unbleached pulp yield and pulp viscosity were reported to increase by 1.7-2.3% and 1.1-1.8 cp, respectively, when AQ was used in combination with a surfactant, compared to kraft pulping.[11] Bamboo species *Bambusa vulgaris* was studied with regard to its pulp and paper potential. The results showed that an increase in pulping temperature greatly

affected pulp yield.[12] Three species of bamboo were studied concerning their mechano-chemical properties. It was reported that bamboo species *Bambusa balcooa* Roxb. has higher cellulose, lignin and pentosan content, followed by *Bambusa tulda* and *Dendrocalamus giganteus*.[13] Another study on organosolv pulping of bamboo species *Phyllostachys acuta* showed that the formic acid pulping process produced relatively pure and high-quality lignin, which was suitable for further applications.[14] The suitability of bamboo species *Bambusa vulgaris* for making rayon grade pulp was investigated and it was found that the desired quality of dissolving grade pulp can be produced by modifying the bleaching process. Authors also compared the chemical constituents and reported the highest holocellulose content, of 75.5%, in bamboo species *Melocanna baccifera*, followed by 71.6% in *Bambusa vulgaris* and 71.1% in *Dendrocalamus strictus.*[15]

Several studies have been conducted to assess the bleachability of bamboo pulp using different bleaching sequences. Bamboo kraft pulp is difficult to bleach above 80% ISO brightness using the CEH sequence.[16] Partial substitution of chlorine with chlorine dioxide and its use in replacement of hypo in the final stage of bleaching or using the ECF bleaching sequence, bamboo pulp can be bleached to a brightness level greater than 85% ISO with reduced effluent load.[17] With the TCF bleaching sequence, bamboo pulp was bleached to a brightness level of 83.6% and improved pulp viscosity was also obtained.[18] Replacing the final D stage in ECF bleaching by QP or Q(PO) stages caused difficulties in obtaining brightness higher than 88%.[19] Bamboo pulp can be easily bleached to a brightness of 88% ISO by the $D_0E_{OP}D_1$ bleaching sequence, which also yields good brightness stability, viscosity and strength.[20] Fiber fractionation followed by selective processing of each fraction appears to be a better option for producing paper of improved quality in terms of strength and optical properties. Thus, the physical strength properties of long fiber pulp fractions were found to be better than those of the initial pulp.[21] Fractionating the bamboo pulp also improved bleachability, the pulp requiring a lesser amount of bleaching chemicals – thus, the long fiber fraction pulp was bleached to a brightness level of 89.5% ISO.[22]

Very little literature is available on pulp and papermaking properties of bamboo species *Melocanna baccifera*. S. R. D. Guha reported that the strength properties of pulp from bamboo species *Melocanna baccifera* were slightly lower, but the pulp yield higher compared to *Demdrocalamus strictus.*[23] In the present study, bamboo species *Melocanna baccifera* is investigated to assess its chemical constituents, pulping behavior, bleaching response, morphological properties, refining behavior and strength properties of bleached pulp.

EXPERIMENTAL

Materials and methods

Samples of bamboo species *Melocanna baccifera*, collected from the northeast part of India, were chipped in a drum chipper. Chip samples were mixed thoroughly and kept in a polythene bag to attain uniform moisture. The moisture content of the chip samples was determined as per standard procedures prior to pulping experiments. Bamboo chip samples were analyzed for proximate analysis after grinding in a Wiley mill and screening on a 40 mesh sieve. Prior to analyzing the chemical constituents, *viz*. cellulose, hemicelluloses, holocellulose and lignin, extractives were removed to prevent their interference in chemical analysis.

Pulping experiments were performed in an autoclave digester consisting of six bombs of 2.5 L capacity, rotating in an electrically heated polyethylene glycol bath. The pulping conditions, such as time, temperature, bath ratio and sulphidity, were optimized to obtain unbleached pulp of about 20 kappa number. During pulping, the temperature was raised to 130 °C in 90 minutes and kept constant for 60 minutes to facilitate impregnation of the cooking liquor into the chip matrix. Temperature was further raised to 160 °C in 90 minutes and kept constant for 60 minutes for pulping.

Unbleached pulp of kappa number ~20 was bleached by using the $C_DE_{OP}DD$ sequence. Bleached pulp was characterized with regard to brightness and CIE whiteness. During bleaching experiments, consistency, temperature and time were maintained at 3.0%, 35 °C and 45 min; 10.0%, 70 °C and 120 min; 10.0%, 75 °C and 180 min; 10.0%, 75 °C and 180 min; in C_D, E_{OP}, D_1, D_2 stages, respectively.

Fiber morphological properties of the bleached pulp were determined by using an L&W fiber tester. The bleached pulp was refined in a PFI mill to different CSF levels and handsheets were prepared for determining physical strength properties using standard test methods.

The analytical techniques used for determining different parameters are given in Table 1. All the analysis/experiments were carried out in duplicate (in a few cases, in triplicate) and the average values of different parameters are reported.

Table 1
Analytical methods

Parameters	Test methods followed
Basic density and moisture	Tappi T 258
Brightness of the pulp	ISO 2470
Cellulose	Updegroff[24]
Freeness of pulp	Tappi T 227
Handsheet making	Tappi T 205
Hemicellulose	Deschatelets and Errest[25]
Holocellulose	Wise *et al*.[26]
Hot water solubility	Tappi T 207
Kappa number of pulp	Tappi T 236
Klason lignin	Tappi T 222
Laboratory refining of pulp	Tappi T 248
Moisture content of pulp	Tappi T 412
NaOH solubility	Tappi T 212
Physical strength properties	Tappi T 220
Schopper-Reigler value (°SR)	Scan C 19:65
Sieve analysis of bamboo chips	Tappi UM 21
Total extractives	Tappi T 204 and T 264
Viscosity of pulp	Tappi T 230

Table 2
Physical properties of the bamboo chips

Parameter	Value
Density of chips	
Bulk density of chips (kg/m^3)	209 ±4
Basic density of chips (kg/m^3)	510 ±3
Classification of chips	
+45 mm hole (%)	2.1 ±0.3
-45 mm hole, +8 mm slot (%)	30.9 ±1.6
-8 mm slot, +7 mm hole (%)	62.0 ±2.3
-7 mm hole, +3 mm hole (%)	4.2 ±0.4
-3 mm hole (%)	0.8 ±0.1

RESULTS AND DISCUSSION

Physical properties

The bamboo chips were analyzed to assess their bulk and basic density, and to establish a classification as a function of their dimensions. It was found that the chips of bamboo species *Melocanna baccifera* had 209 kg/m^3 bulk density and 510 kg/m^3 basic density. Also, chips screening revealed that they were made up of 1.5% oversize chips (+45 mm hole), 31.9% over-thick chips (-45 mm hole, +8 mm slot), 61.0% accept chips (-8 mm slot, +7 mm hole), 4.6% pin chips (-7 mm hole, +3 mm hole) and 0.8% dust (-3 mm hole). Detailed results on the physical properties of bamboo chips are given in Table 2.

Proximate chemical analysis

Bamboo species *Melocanna baccifera* was analyzed for proximate chemical analysis. The results indicated that this species of bamboo has 19.5% NaOH solubility, and contains 3.48% alcohol benzene extractives, 52.8% cellulose, 21.1% hemicelluloses and 25.2% Klason lignin. The values found for cellulose, hemicelluloses and lignin in *Melocanna baccifera* are higher than those reported for bamboo species *Bambusa tulda*, *Dendrocalamus giganteus* and *Bambusa balcooa* Roxb.,[13] and comparable to those of the bamboo species *Bambusa stenostachya* Hackle.[6] Detailed results of the proximate chemical analysis of bamboo are given in Table 3, while the proportion of cellulose, hemicelluloses and lignin in the studied species is shown in Figure 1.

Pulping

Pulping conditions and cooking chemical dosages were optimized to produce unbleached pulp of ~20 kappa number from bamboo. Active alkali dosages (AA) of 14, 15.5 and 17% as Na_2O were applied, maintaining the other pulping conditions

constant for all the sets. The optimum AA dose in order to get a target kappa number pulp was found to be 15.5%. The unbleached pulp yield obtained for bamboo species *Melocanna baccifera* was 50.3-52.3%, which is higher than the reported values for bamboo species *Bambusa stenostachya* Hackle, *i.e.* 45.6-48.3%.[6] Detailed results for bamboo pulping listed in Table 4, while the effect of active alkali dose on the kappa number and free alkali of the pulp is illustrated in Figure 2.

Bleaching

After pulping, the bamboo pulp produced was subjected to bleaching using the $C_DE_{OP}D_1D_2$ sequence, targeting to achieve bleached pulp of 89±1% ISO brightness, and as a result, a pulp brightness of 88.3% was obtained In the chlorination stage, the total chlorine added corresponded to a kappa factor of 0.22, 10% of it was chlorine dioxide. The brightness levels achieved in the E_{OP} stage, D_1 and D_2 stages were of 58.1, 84.1, 88.3% ISO. Pulp shrinkage during bleaching was of 5.5%. Thus, the pulp produced from bamboo species *Melocanna baccifera* was easily bleachable to a brightness level of 88.3% ISO, which is comparable to the 85-88% ISO brightness reported for different other bamboo species pulps.[17,19,20,22] Detailed bleaching results are provided in Table 5. Also, the evolution of brightness throughout the different bleaching stages is exhibited in Figure 3.

Table 3
Proximate chemical analysis of bamboo

Parameter	Value
Hot water solubility (%)	4.13 ±0.2
1% NaOH solubility (%)	19.5 ±1.3
A-B extractives (%)	3.48 ±0.3
Ethanol extractives (%)	1.02 ±0.2
Water extractives (%)	3.24 ±0.3
Total extractives (%)	7.74 ±0.3
Cellulose (%)	52.78 ±0.8
Hemicelluloses (%)	21.1 ±0.9
Klason lignin (%)	25.2 ±1.1
Holocellulose (%)	73.5 ±1.4
Ash (%)	2.45 ±0.1

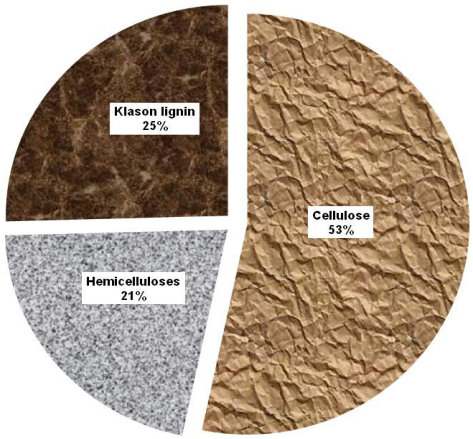

Figure 1: Proportion of cellulose, hemicelluloses and lignin in bamboo

Table 4
Optimization of kraft cooking chemical dose

Parameter	Value		
Active alkali as Na_2O (%)	14.0	15.5	17.0
Kappa number	24.4	19.6	17.1
Yield (%)	52.3	51.6	50.3
Rejects (%)	2.1	nil	nil
Free alkali (g/l) as Na_2O	4.1	7.8	9.1
Free alkali (g/l) as Na_2O at 20% solids	4.34	7.95	8.75
Black liquor solids (%)	18.9	19.6	20.8

Sulphidity: 23.0%, cooking temperature: 160 °C, cooking time: 60 min

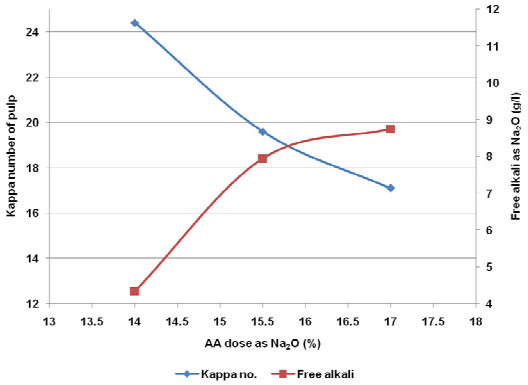

Figure 2: Effect of AA dose on kappa number and free alkali

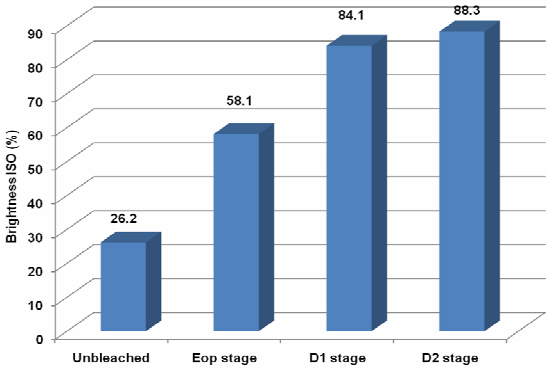

Figure 3: Brightness development throughout bleaching stages

Table 5
Bleaching of bamboo using $C_DE_{OP}D_1D_2$ sequence

Parameter	Value
Kappa number	19.6
Kappa factor	0.22
C_D stage	
Cl_2/ClO_2 added (%)	3.88/0.16
End pH	1.8
E_{OP} stage	
$NaOH/H_2O_2$ added (%)	2.37/0.5
Final pH	11.4
E_{OP} pulp kappa number	2.0
E_{OP} pulp brightness (% ISO)	58.1
D_1 stage	
ClO_2 added (%)	0.90
Final pH	3.50
Brightness (%ISO)	84.1
D_2 stage	
ClO_2 added (%)	0.3
Final pH	3.5
Brightness (%ISO)	88.3
Whiteness (%ISO)	78.2
Viscosity (cp)	20.0
Bld. pulp yield (%)	94.5

Physical strength properties of bleached pulps

Bleached bamboo pulp was refined in a PFI mill at 1800, 3100 and 4100 PFI revolutions to get a pulp freeness of 20±1, 25±1 and 30±1 °SR, respectively.

Handsheets of the bleached bamboo pulps refined at different freeness levels were prepared and tested with regard to a number of physical strength and surface properties. Detailed physical strength properties of bleached bamboo pulps at different CSF levels are given in Table 6, and the influence of refining on the handsheet properties, such as tear and tensile index, smoothness and folding endurance, burst index, stiffness and porosity, is shown in Figures 4, 5 and 6, respectively.

Table 6
Physical strength properties of bleached bamboo

Parameter	Value			
No. of revolutions	0	1800	3100	4100
Freeness (ml, CSF)	720	615	515	413
°SR	14.5	19.5	24.5	31.0
Bulk (cc/g)	1.88	1.50	1.41	1.35
Tensile index (N.m/g)	24.62	49.21	54.64	59.71
Burst index (kN.m^2/g)	1.18	4.02	4.95	5.47
Tear index (mN.m^2/g)	12.2	13.5	12.3	11.0
Double fold (no.)	6	149	328	522
Porosity (s/100 ml)	1.27	1.87	6.67	17.4
Smoothness (ml/min)	1113	411	217	173

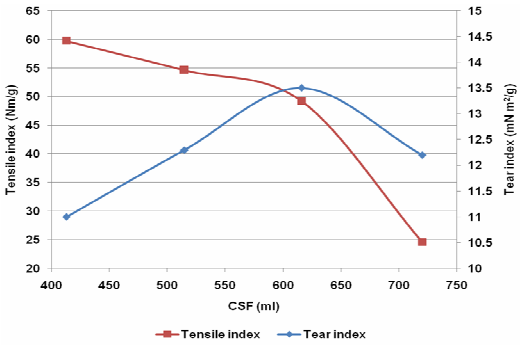

Figure 4: Effect of refining on the evolution of tear and tensile index

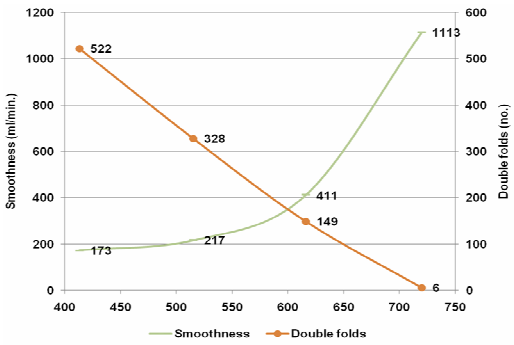

Figure 5: Effect of refining on smoothness and folding endurance

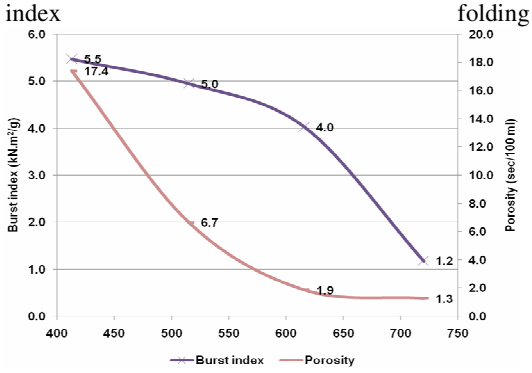

Figure 6: Effect of refining on burst index and porosity

Morphological properties of bamboo pulps

The morphological properties of the bleached bamboo pulp were also analyzed by using an L&W fiber tester. As a result, it was found that the pulp had an average fiber length of 1.68 mm, width of 17.1 µm, coarseness of 103.2 µg/m and content of fines on mass basis of 3.8%. The average fiber length, width and coarseness of

Dendrocalamus strictus were reported to achieve values of 1.56 mm, 19.7 μm and 89.4 μg/m, respectively.[21] It may be noted that *Melocanna baccifera* pulp has longer average fiber length, higher coarseness and lower fiber width compared to *Dendrocalamus strictus* pulp. Detailed results on the morphological properties of the bleached bamboo pulp are given in Table 7.

Table 7
Morphological properties of bleached bamboo pulp

Parameter	Value
Average fiber length (mm)	1.68
Width (μm)	17.1
Fiber shape, length weighted (%)	84.7
Vessels per lacks fiber	146
Coarseness (μg/m)	103.2
Fines, mass basis (%)	3.8
Number of kinks per fiber	0.756
Mean kink index	1.556

CONCLUSION

The study investigated different pulp and papermaking properties of bamboo species *Melocanna baccifera*. The tests led to the following findings.

- Bamboo species *Melocanna baccifera* has 52.78% cellulose, 21.1% hemicelluloses and 25.2% lignin, which is a similar composition to that of hardwood.
- The bleachability of bamboo species *Melocanna baccifera* is also comparable to that of hardwood. Using 38.8 kg/t chlorine and 12.6 kg/t chlorine dioxide, the pulp can be bleached to 89±1% ISO brightness. CED viscosity of the pulp is comparatively better than that of hardwood pulp, *i.e.* 20 cp.
- The physical strength properties of the handsheets made from *Melocanna baccifera* pulp refined at 25 °SR are sufficiently good: tensile index of 54.6 Nm/g, tear index of 12.3 $mN.m^2/g$, burst index of 4.95 $kN.m^2/g$ and folding endurance of 328 double folds.
- The pulp obtained from *Melocanna baccifera* has a fiber length of 1.68 mm, which means, it is longer than that of hardwood (0.88-1.1 mm), but shorter than that of softwood (2.2-3.5 mm). Also, fiber width is 17.1 μm, which similar to that of hardwood (16-20 μm), but lower than that of softwood (28-35 μm).

The results obtained will be useful as reference for researchers and specialists in the papermaking field, as well as for pulp and paper manufacturers in search of new raw material for the papermaking process.

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