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Effect of beating on recycled properties of unbleached eucalyptus cellulose fiber

Yangmei Chen[a,c,*], Jinquan Wan[a,b,c,**], Xueliang Zhang[a], Yongwen Ma[a,b,c], Yan Wang[a,c]

[a] College of Environmental Science and Engineering, South China University of Technology, Guangzhou 510006, PR China
[b] State Key Lab Pulp and Paper Engineering, South China University of Technology, Guangzhou 510640, PR China
[c] The Key Lab of Pollution Control and Ecosystem Restoration in Industry Clusters, Ministry of Education, China, Guangzhou 510006, PR China

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ABSTRACT

The effects of beating on recycled properties of eucalyptus cellulose fiber were studied by analyzing the changes of morphological parameters (fiber length and the fines content), physical properties (tensile strength, breaking length and the stretch), WRV, crystal structure of cellulose and pore structure of cellulose fiber. The results showed that beating caused the fine content increase. Tensile strength, breaking length and the stretch increased with the increasing beating time. WRV of the first cycle beaten eucalyptus pulp was increased by 32.1%, compared to the first cycle unbeaten pulp. WRV increased with the increase in beating degree. However, crystallinity of cellulose increased, and then decreased with an increase in beating degree. FTIR spectra showed that there were no drastic changes in the functional groups of the eucalyptus pulp cellulose during beating. Fiber pore size was gradually diverted into macropore with the increase in beating degree, resulting in the mean pore volume increased.

1. Introduction

Specialists have predicted that the difference in yield between virgin plant cellulose fiber and plant cellulose fiber from recycled paper and paperboard will become larger. Recycled cellulose fiber will account for about 70% of the papermaking materials at the end of the 21st century (Wan & Ma, 2004). Plant cellulose fiber is the most abundant renewable and biodegradable carbohydrate polymer in the nature which have the complex composite structures that are mainly composed of cellulose, lignin and hemicelluloses (Liu et al., 2008; Rowell, Pettersen, Han, Rowell, & Tshabalala, 2005). Cellulose is a polymer chain formed of cellobiose base units (Clark, 1985). The cellobiose units form a long, flat polymer chain that exposes a number of hydroxyl groups, bonding sites that allow the polymer chain to form a large amount of hydrogen bonds (Smook, 1982). It is well known that cellulose fibers will undergo a decrease in quality during recycling. For example, the strength of paper decreases, and the decay will increase with each subsequent recycling, which decreases the papermaking potential of recycled cellulose fiber (Bouchard & Douek, 1994; Chatterjee, Kortschot & Whiting, 1993; Chen, Wan & Ma, 2009; Chen, Wan, Ma & Lv, 2010; Chen, Wang, Wan & Ma, 2010; Ellis & Sedlchek, 1993; Gratton, 1992; Howard & Bichard, 1992; Jahan, 2003; Klofa & Miller, 1994). So, it is very important to study the recycled properties of recycled cellulose fiber and find methods to improve recycled cellulose fiber properties.

At present, the modification of recycled cellulose fiber is mainly focused on using enzymes and chemicals to treat fibers, which will increase the pulp papermaking cost (Blomstedt & Vuorimen, 2007; Cao & Tan, 2004; Pala, Lemos, Mota & Gama, 2001; Rácz & Borsa, 1997). The use of chemicals will also aggravate environmental pollution. Beating is the term used to describe the process in which pulp cellulose is mechanically treated in the presence of water. Generally, it is carried out at low or medium consistency by passing the pulp cellulose suspension between revolving and stationary rotors which have bars approximately aligned across the direction of stock flow (Liu, Li, Lei, Cao & Li, 2003). Researches have shown that the strength properties of beaten pulps have generally been improved (Espenmiller, 1969; Liu, 2004; Smook, 1982). But most of this research was focused on virgin cellulose fiber; only limited research has involved recycled cellulose fiber.

Eucalyptus cellulose fiber has a mount of short fibers which are easily beaten. In this paper, the influences of beating on eucalyptus cellulose fiber morphology and the physical properties of paper made from eucalyptus cellulose pulp were studied, which will provide a theoretical foundation for modifying the reclamation properties of recycled cellulose fiber.

* Corresponding author at: College of Environmental Science and Engineering, South China University of Technology, Guangzhou 510006, PR China.
Tel.: +86 20 87114970; fax: +86 20 39380560.
** Corresponding author at: College of Environmental Science and Engineering, South China University of Technology, Guangzhou 510006, PR China.
Tel.: +86 20 87114970; fax: +86 20 39380560.
E-mail addresses: chenyangmei_2001@sina.com (Y. Chen), ppjqwan@scut.edu.cn (J. Wan).

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2. Materials and methods

2.1. Materials

Eucalyptus wood chips, which contained ash 0.38%, lignin 24.4%, cellulose 45.1% and hemicellulose 24.9%, were cooked in an 18-l digester using a conventional kraft process. Cooking was carried out under these conditions (maximum temperature of 170 °C, 2 h time to the temperature, 2 h time at temperature, alkali amount 17%, sulfidity 25%, liquor-to-wood ratio of 4/1). The moisture content of unbleached *eucalyptus* pulp was 81.6% by weight in the never-dried state. Use of never-dried pulp was considered important, because a high water content protects cellulose crystallites from mechanical damage (Wijnman, 1954). The fiber morphology parameters of the *eucalyptus* pulp and virgin wood are seen in Table 1.

2.2. PFI beating

PFI beating was carried out according to Tappi T248 wd-97, pulp consistency was 6%, the gap between the opposing refining plates was 0.3 mm distance, the slurry pond spin speed was 1400 r/min and fly cutter spin speed was 1460 r/min. Several different times were used.

2.3. Analyses of the fiber properties and the paper properties

The grammage of the paper was 60 g/m^2. The breaking length, tensile strength and stretch were measured according to ISO standard methods. Fiber length and fines were measured using Kajaani FS200.

2.4. Paper recycling

Repetitive recycling was carried out on handsheets made from beaten pulps. Some handsheets were placed in a humidity-controlled room according to TAPPI T 402 and tested for physical properties 24 h later. The rest of the handsheets were soaked in deionized water for at least 8 h. The rewetted handsheets were then disintegrated for 30,000 revolutions in a laboratory disintegrator. Most of the recycled pulp was then re-made into handsheets and dried according to the described procedure. The recycling procedure was repeated for a total of three cycles.

2.5. Determination of water retention value

The water retention value (WRV) was determined by a centrifugal method with 1.5 g samples (o.d.). The pulp was centrifuged at 3000 × *g* for 15 min and then weighed before and after drying. WRV is calculated as follows:

$$\mathrm{WRV} = \frac{m_1 - m_2}{m_2} \times 100\% \qquad (1)$$

where m_1 is the weight of wet pulp after centrifugation, and m_2 the weight of dry pulp.

2.6. Fourier transform infrared spectrophotometer

Powdered cellulose and pre-ground and subsequently dried KBr were sifted in a sieve with a mesh number of 200. Cellulose (3.5–4.0 mg) and KBr (350 mg) were placed in an agate mortar, mixed well, and pulverized. The mixture was dried at 60 °C for 4 h and then poured into a tabletting mold to obtain completely transparent tablets. Infrared spectra of the samples were obtained by vector-33-type fourier transform infrared spectrophotometer (FTIR). The crystallinity index N.O′KI was obtained by calculating the strength ratio of the two peaks at 1372 cm^{-1} and 2900 cm^{-1}. The crystallinity index was calculated as follows:

$$\mathrm{N.O'KI} = \frac{I_{1372}}{I_{2900}} \times 100\% \qquad (2)$$

where I_{1372} is band intensity of 1372 cm^{-1} assigned to CH bending vibration; I_{2900} is band intensity of 2900 cm^{-1} assigned to CH and CH_2 stretching vibration.

2.7. Low-temperature nitrogen absorption

Prior to testing, the samples were freeze-dried in order to remove free water. This procedure aids in preserving the pore structure of the fiber (Pachulski & Ulrich, 2007). In this study, a pore size distribution detector ASAP2010M (USA, Micromeritics) was used for structural analyses of the fiber pores. High-purity N_2 was used as absorbate and the adsorption–desorption of high-purity N_2 was determined at 77 K in a liquid nitrogen trap using a static volumetric method. This approach was applied to obtain adsorption–desorption isotherms for the non-recycled and recycled fibers. Subsequently, calculations based on the BET equation (Brunauer–Emmett–Teller), using BJH mode, H-K mode, DFT (density functional theory), T-plot, etc., were used to analyze the specific surface area of the porous materials, the sizes of the macropores, mesopores, and micropores, the total pore volume and average pore size, and surface structural parameters.

2.8. Observation of fiber morphology

A Quanta 200 environmental scanning electron microscope (ESEM) was used to examine the fiber surface morphology. Samples were coated with gold for examination in the ESEM. The images were taken in the ESEM mode with gaseous secondary electron detector (GSED) at a temperature of about 23 °C. A low acceleration voltage (10 kV) was used to prevent degradation of cellulose (Blomstedt, Mitikka-Eklund & Vuorinen, 2007). The pressure in the chamber was 6 torr, the condenser tens setting 40%.

3. Results and discussion

3.1. The effect of beating time on fiber length of recycled eucalyptus cellulose fiber

Due to the fiber number-average length is measured according to the number of fiber, so which is affected by fines to a great extent. But the fiber weight length is measured according to fiber weight, so which can more accurately reflect the fiber length and the change during treatment. Therefore, in this work fiber weight length was used to evaluate the effect of beating on the fiber length.

From Table 2 it can be seen that fiber weight length of recycled eucalyptus cellulose decreases lightly with an increase in the beating time. This is mainly due to fiber suffered mechanical shear force is cut during beating. The fiber weight length of first cycle and second cycle beaten pulps cellulose was only decreased by 8% and 8.16%, respectively, compared to the first cycle and second cycle unbeaten pulps. This shows that, in this work, beating has a little influence on fiber cutting at pulp beating consistency of 6%.

3.2. The effect of beating time on fines of recycled eucalyptus cellulose fiber

Due to the eucalyptus cellulose fiber suffered shear force and friction force during beating, the fibrillation developed from fiber surface. The fines content first increased, then leveled off with an increase in beating time (see Fig. 1). The fines number-average content was increased less than 2% for the first cycle pulp when the

Table 1
Fiber morphology parameters of eucalyptus pulp and virgin wood.

Pulp	Fiber length (mm)			Fines (%)	
	Number-average	Weight-average	Weight-weighted	Number-average	Weight-average
Eucalyptus pulp	0.46	0.61	0.85	11.03	2.37
Virgin wood	0.39	0.55	0.68	17.56	4.33

Table 2
The effect of beating on fiber length of recycled cellulose fiber.

Beating time (min)	First cycle fiber length (mm)			Second cycle fiber length (mm)		
	Number-average	Weight-average	Weight-weighted	Number-average	Weight-average	Weight-weighted
0	0.33	0.50	0.56	0.33	0.49	0.55
5	0.33	0.49	0.56	0.33	0.49	0.54
10	0.34	0.49	0.55	0.32	0.48	0.54
15	0.34	0.48	0.55	0.32	0.46	0.53
20	0.33	0.47	0.54	0.33	0.46	0.53
25	0.32	0.47	0.53	0.33	0.46	0.52
30	0.32	0.46	0.52	0.32	0.45	0.51

beating time was 5 min, but the content was increased by 8.45% when the beating time was in the range of 5–15 min. The fines number-average content was only increased by 2.98% for the second cycle pulp when the beating time was in the range of 0–10 min, and the content was increased by 7.59% when the beating time was in the range of 10–20 min. The fines number-average content was increased by 3.91% for the third cycle pulp when the beating time was in the range of 0–15 min, and the content was increased by 10.6% when the beating time was in the range of 15–25 min. Therefore, the degree of fibrillation of the fiber was relatively small at the beating initial stage, the fines content increased slowly. It mainly presented the breaking of the fiber primary wall and second wall, and the time needed for the breaking process made fiber hornification became longer and longer with an increase in recycle numbers (Han, Kwei-Nam & Robert, 2008).

Meanwhile, from Fig. 1 it can also be seen that the number-average fines content of the second cycle pulp was decreased by 8.67%, compared to the first cycle pulp; and the third cycle was decreased by 13.4%, compared to the second cycle. This is because the eucalyptus cellulose fiber itself is one of short fibers, and fines produced during beating process run off during recycling.

Fig. 2 shows the fiber surface morphology seen by ESEM at different beating time after fist cycle. From Fig. 2 it can be seen that the fiber is intact and the fiber surface is smooth when the beating time is 10 min. When the beating time is 20 min, the fibrillation of fiber is obvious, the fibers become more flexible, and the fiber longitudinal direction produces splitting and two ends promote fibrillation. The surface fibrillation makes fine fibers loose, obtains an amount of fine fibers and microfibrils. This results in the fines content fast increase. This result is in accordance with Kibblewhite's reports (Kibblewhite, 1984). Their studies have shown that the surfaces of chemical pulp fibers are progressively removed during the beating process. Some of the surface layers of the fiber are loosed or removed, exposing the P, S_1 and S_2 layers. The fibers become more flexible. The beaten fibers collapse on pressing, giving more intimate contact, stronger bonding and the strength of the paper is increased. The degree of collapse increases with the amount of beating (Lumiainen, 1990). Better conformation plus the presence of some fiber debris arising from beating means that the modified mat drains more slowly on the wire, resulting in a more even sheet of paper.

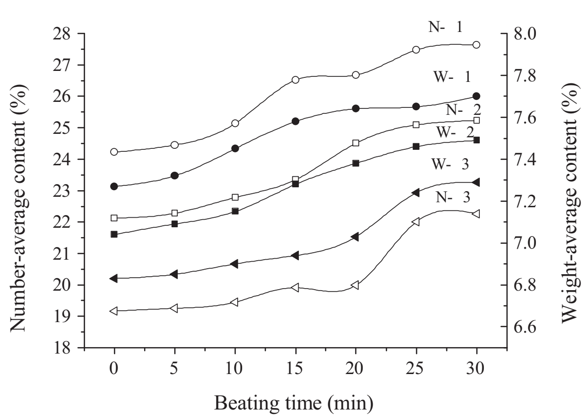
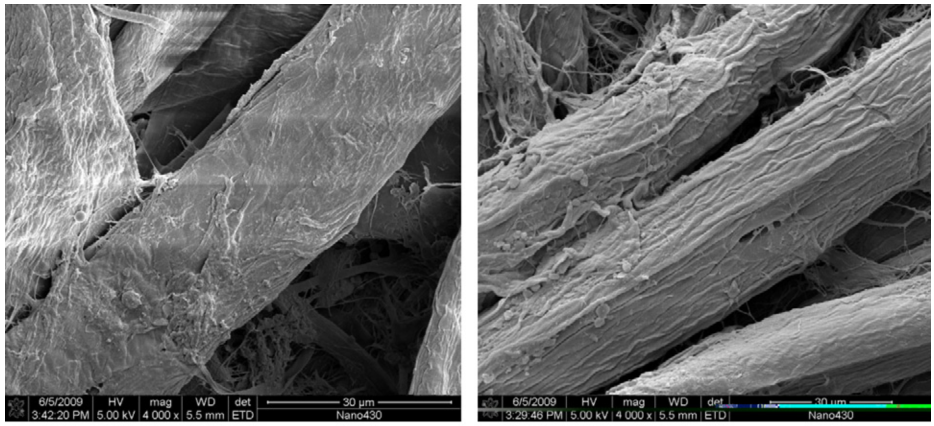


Fig. 1. The effect of beating time on fines content of recycled cellulose fiber. N, number-average content; W, weight-average content; 1, first cycle pulp; 2, second cycle pulp; 3, third cycle pulp.



(a) 10 min (× 4000) (b) 20 min (× 4000)

Fig. 2. ESEM images of fiber after first cycle at different beating time: (a) 10 min (4000×) and (b) 20 min (4000×).

3.3. Changes of beating degree and water retention value of recycled eucalyptus cellulose fiber at different beating time

Fig. 3 shows the changing regularity of the beating degree and WRV of recycled pulps at different beating time. From Fig. 3, it can be seen that the beating degree increased with an increase in beating time. The beating degree increased more fast with an increase in beating time but leveled off remarkably with an increase in beating time. This work showed that the eucalyptus pulp could obtain a more ideal beating degree when the beating time was in the range of 20–25 min. It demonstrates that the degree of fiber surface fibrillation, the fines content and pulp draining resistance increase with an increase in beating time, which improves the beating degree. But the role of mechanical force on fiber fibrillation gradually decreases with a further increase in beating time. Beating cannot further make the fiber fibrillation, and only increase the energy consumption.

The beating degree decreases with an increase in recycle numbers at the same beating time (see Fig. 3). The beating degree of the third cycle pulp was decreased by 36% when the beating time was 20 min, compared to the first cycle pulp. This shows that beating can improve fiber quality and increase beating degree, although there is a certain limitation. This is mainly caused by fines loss, hornification and irreversible phenomena during recycling.

Water retention value (WRV) can reflect the swelling ability of the pulp. WRV increases with an increase in beating time (see Fig. 3). In this work, WRV of the first cycle and the third cycle of beaten pulps was increased by 32.1% and 37.7%, respectively, compared to the first cycle and the third cycle of unbeaten pulp. This demonstrates that the special structure of PFI refining plate makes fiber produce "external effect" (Liu, Li, Lei, Cao, Li, 2002). The phenomena of recycled fiber surface hardening and the cell closure are partly activated, which makes recycled fiber easy swelling and WRV increase (Xia, Zheng & Ma, 2006).

3.4. The effect of beating time on physical properties of sheet from eucalyptus cellulose fiber

Beating time is an important controlling condition in beating process. The long beating time will cause fiber over cut, decrease fiber properties, consume more energy and increase the papermaking cost. However, the short beating time will cause fiber insufficient exerted force, and the improvement of fiber quality is limited. Therefore, in order to obtain the best beating effect, it must be to control a reasonable beating time. Fig. 4 shows the changes of the strength of pulp sheet from first cycle pulp at different beating time.

From Fig. 4 it can be seen that pulp sheet strength increases with an increase in beating time. This is due to the internal friction force produced by the network packet made through recycled cellulose fiber, water and air makes hornified layer of the recycled cellulose fiber surface peel, and the smooth and rigor fiber surface is fibrillated. More hydroxyl groups are fractionated out, which results in the bonding ability of fiber–fiber hydrogen bond is regenerated to

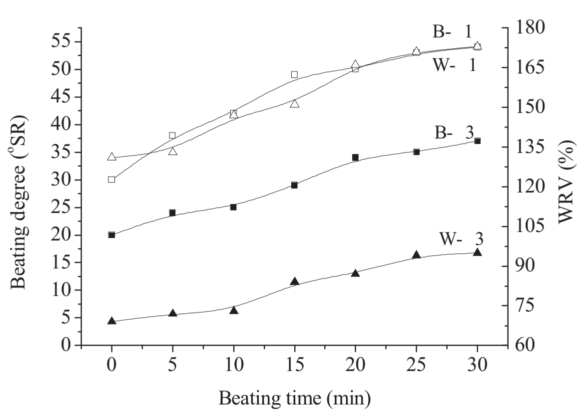


Fig. 3. The effect of beating on beating degree and WRV of pulp fiber. B, beating degree; W, WRV; 1, first cycle pulp; 3, thrid cycle pulp.

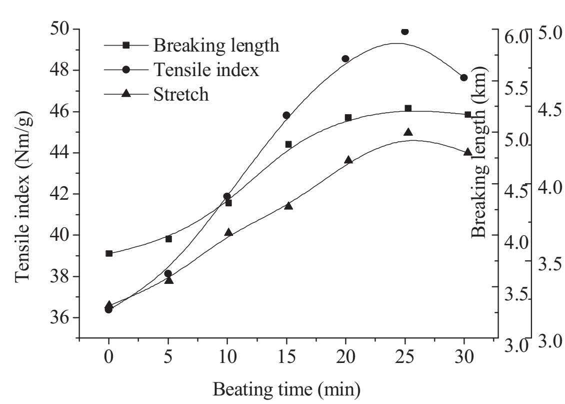


Fig. 4. The effect of beating time on physical properties of pulp sheet from first cycle pulp.

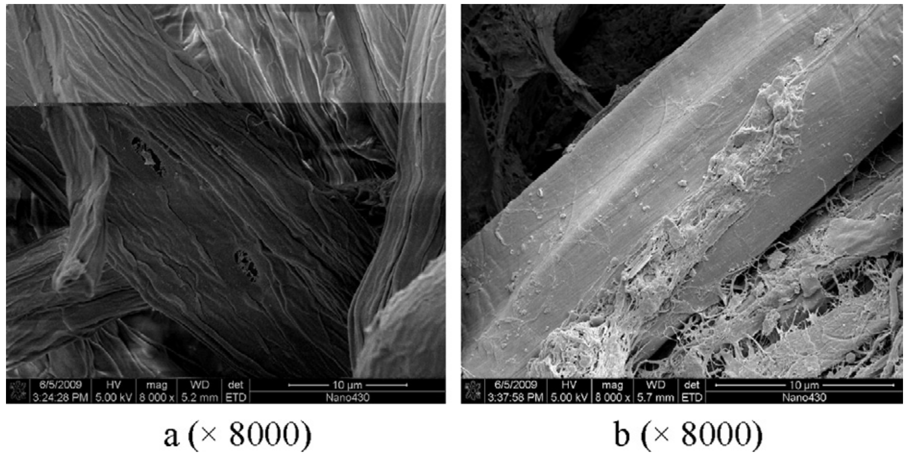


Fig. 5. ESEM images of different recycle numbers fiber at beating time 20 min: (a) the first cycle fiber (8000×) and (b) the third cycle fiber (8000×).

some extent (Bhardwaj, Hoang & Nguyen, 2007). Moreover, due to the special structure of PFI refining plate, fiber external effect and recycled fiber surface hardening and the cell closure are partly activated, which make fiber easy swelling. So, the bending of recycled fiber is increased, the fiber length of beaten pulps obtains retention, the inherent strength loss of fiber is smaller, and the paper strength properties have an upturn. The effect is very obvious using PFI medium consistency beating to improve the recycled fiber properties.

The breaking length, tensile index and stretch of beaten pulps increased markedly, compared to unbeaten pulps. The breaking length, tensile index and stretch were maximally increased by 43.3%, 39.9% and 34.9%, respectively. Paper made from unbeaten chemical pulps is bulky, porous and has less tensile strength than from beaten pulps. This is because the unbeaten fibers tend to be stiffer, springy and resistant to collapse on pressing, so that there is comparatively little inter-fiber bonding in the sheet.

The paper strength increased with an increase in beating time when the beating time was in the range of 0–25 min, but when the beating time was 30 min, the paper strength decreased instead. This is because the fiber length greatly decreases when the beating time is too long, which cause the strength properties decrease (Beg & Pickering, 2006; Harper, Turner, Warrior & Rudd, 2006). That is the strength of paper increase on beating until they reach a plateau, from which they will decline again if beaten excessively.

3.5. *The effect of beating on physical properties of sheet from recycled eucalyptus cellulose fiber*

Table 3 shows the effects of beating on physical properties of sheet from eucalyptus cellulose pulp. From Table 3, it can be seen that the paper strength properties of beaten pulps greatly increased. The breaking length, tensile index and stretch of the first cycle beaten pulp were maximally increased by 43.3%, 39.9% and 34.9%, respectively, compared to the first cycle unbeaten pulp. The breaking length, tensile index and stretch of the second cycle beaten pulp were maximally increased by 29.1%, 27.8% and 24.8%, respectively, compared to the second cycle unbeaten pulp. The breaking length, tensile index and stretch of the third cycle beaten pulp were maximally increased by 23.4%, 18.9% and 15.8%, respectively, compared to the third cycle unbeaten pulp. It demonstrates that beating makes fiber fibrillation, the ability of fiber swelling and the bonding of fiber increases.

But the increasing rate of tensile index decreased from 39.9% of the first cycle pulp to 18.9% of the third cycle pulp, and the increasing rate of the stretch decreased from 34.9% of the first cycle pulp to 15.8% of the third cycle pulp. It can be seen that the role of beating on the recycled cellulose fiber quality improvement becomes increasingly weak with the increase in recycling times. So, the improvement of beating on the recycled cellulose fiber quality has a certain limitation.

Fig. 5 shows the ESEM images of the first cycle fiber and the third cycle fiber. From Fig. 5 it can be seen that fiber surface become smooth and stiffen, and the fiber is difficult to re-fibrillate with an increase in recycle numbers. One reason is that many fines at fiber outside loss resulting in fiber becomes smooth and stiffen. Moreover, the water of the cell wall inner and inter microfibers is removed during sheets drying. When the water goes through the cell wall, the resins are transferred to fiber surface, which cause the fiber swelling decrease (Chen, Wan, Ma, Wu & Wang, 2008). Therefore, it shows that external and internal structures of recycled cellulose fiber produce some harmful papermaking problems. On the other hand, beating will inevitably cut the recycled cellulose fiber itself become brittle and stiff, makes fiber length become short, and the fiber strength is destroyed.

3.6. *The effect of beating degree on crystallinity of cellulose and water retention value of cellulose fiber*

In some degree, crystallinity of cellulose reflects the physical and chemical properties of fiber. In general, tensile strength, stiffness, relative density and size stability increase with an increase in crystallinity of cellulose, however, the softness and chemical reaction

Table 3
The change of physical properties of eucalyptus cellulose pulp at different recycle numbers.

	Breaking length (km)	Tensile index (Nm/g)	Stretch (%)
First cycle pulp			
Unbeaten	3.65	36.4	3.21
Beaten 48°SR	5.14	49.6	4.15
Beaten 52°SR	5.23	50.9	4.33
Beaten 54°SR	5.17	48.6	4.2
Second cycle pulp			
Unbeaten	2.65	25.6	3.06
Beaten 32°SR	3.27	31.8	3.62
Beaten 36°SR	3.42	32.7	3.82
Beaten 41°SR	3.35	31.8	3.75
Third cycle pulp			
Unbeaten	2.22	22.92	2.85
Beaten 29°SR	2.54	26.35	3.19
Beaten 32°SR	2.74	27.25	3.3
Beaten 35°SR	2.66	27.03	3.24

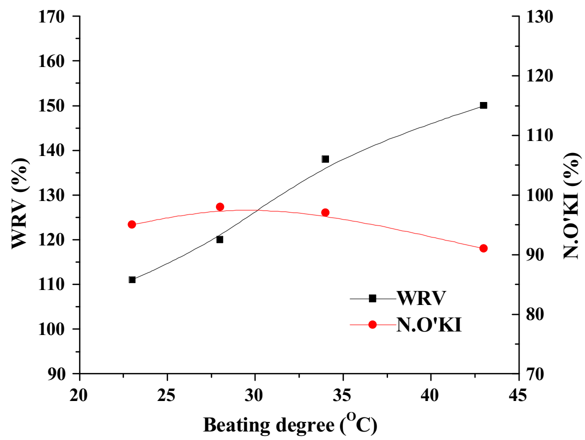


Fig. 6. The effect of beating degree on WRV and crystallinity of cellulose.

decrease. Therefore, the determination of crystallinity of cellulose has a guiding significance to understand fiber decay from structure.

Fig. 6 shows the effect of beating on crystallinity of cellulose and WRV. From Fig. 6 it can be seen that WRV increased with the increase in beating degree. WRV increased by 35.1% when the beating degree was 43°SR. Crystallinity of cellulose increased, and then decreased with an increase in beating degree. This is mainly due to the force acts on the amorphous regions of cellulose in the beating initial phase, then on the crystalline regions of cellulose in the beating later phase. When the beating degree was 43°SR, the crystallinity of cellulose was decreased by 4.2%.

3.7. The effect of beating degree on surface chemical bonds of eucalyptus cellulose

Fig. 7 shows the FTIR spectra of eucalyptus cellulose fiber at different beating degrees. From bottom to top, the spectra are those for pulp that its beating degree was 23°SR, 28°SR, 34°SR and 43°SR, respectively. The absorption bands and the corresponding structure assignments from the infrared spectra are those reported previously (Lu, Shi, Yang, Niu & Song, 2005). From Fig. 7 it can be seen that there were no drastic changes in the functional groups of the sample during beating.

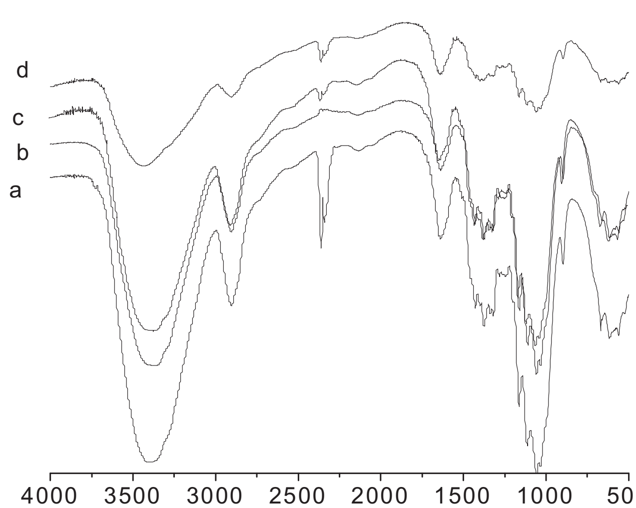


Fig. 7. FTIR spectra of cellulose fiber with different beating degrees: (a) 23°SR; (b) 28°SR; (c) 34°SR; (d) 43°SR.

Table 4
Average pore size and BET surface area of eucalyptus cellulose fiber at different beating degrees.

Beating degree (°SR)	Average pore size (nm)	Cumulative pore volume (cm^3/g)	BET specific surface area (m^2/g)
Unbeaten	4.5	0.0215	12.7
28	5.7	0.0367	16.7
34	6.1	0.0409	17.6
43	6.5	0.0485	19.5

3.8. Effect of beating degree on the average pore size and specific surface area of eucalyptus cellulose fiber

Table 4 shows the average pore size, cumulative pore volume and specific surface area of unbleached eucalyptus cellulose fiber at different beating degrees. The average pore size of the beaten pulp fiber significantly increased, compared with the unbeaten pulp. When the beating degree of pulp was 43°SR, the average pore size of pulp fiber increased by 42.7% and cumulative pore volume increased by 126%, compared with the unbeaten pulp fiber. This is because the force on crystalline regions of cellulose fiber increases with the beating, leading to crystalline regions decrease, resulting in pore increase. The increase of pore volume is beneficial to remain more water, improve fiber swelling ability and fiber quality.

Table 4 also shows the BET specific surface area significantly increased with the increase in beating degree. When the beating degree was 43°SR, BET specific surface increased by 53.8%. BET specific surface area is the complex function of fiber fineness, fiber fibrosis degree and fiber length. During beating, one hand, fiber is tore along the axis under the joint action between mechanical force and fiber–fiber fiction force, and some part of fine are pulled out the fiber surface, resulting in fibrillation of fiber surface. But the diameter of fiber surface fine is small, and specific surface area is large. On the other hand, fiber BET specific surface area is related to the inner surface area of pore of fiber cell wall. The outer of fiber primary wall and second wall is broken after beating, which leads to amount of the water is penetrated into amorphous regions of fiber, resulting in fiber swelling. After fiber swelling, the fiber cohesion decreases and inner organizational structure become loose, which results in the increase in pore volume and BET specific surface area.

3.9. Effect of beating degree on the pore size and pore size distribution of eucalyptus cellulose fiber

Fig. 8 shows the pore size and pore size distribution of unbleached eucalyptus cellulose pulp with different beating

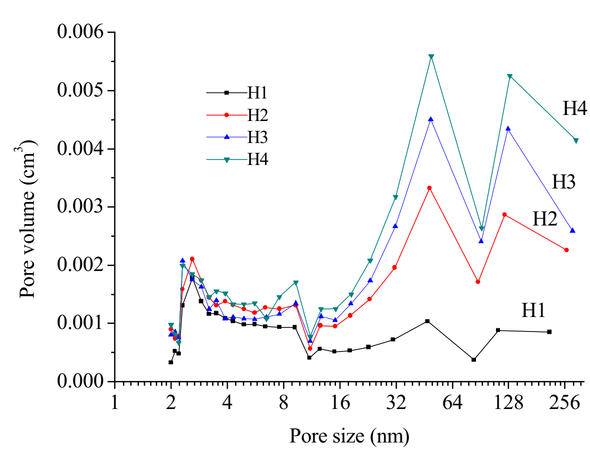


Fig. 8. Pore size and pore size distribution of unbleached eucalyptus cellulose fiber with different beating degrees: H1, unbeaten; H2, 28°SR; H3, 34°SR; H4, 43°SR.

degrees. It can be seen that the mean diameter of fiber pores was in 1.7–300 nm. Fiber pore size was gradually diverted into macropore with the increase in beating degree, resulting in the increase in mean pore volume. This maybe due to the mechanical force acts on the fiber crystalline regions lead to the decrease of crystalline regions, even the closure pore reopen and reform micropore, resulting in the increase of pore volume. This is also due to micropores bond to larger pores and obtain more mesopores and macropores when the removal amount of hemicelluloses reaches a certain amount during beating. Therefore, beating can improve the structure of pore of recycled cellulose fiber, and may become a physical method to effectively resist the irreversible closure of pore of recycled cellulose fiber.

4. Conclusions

The fiber cut is not very obvious at the beating consistency of 6%. For example, the fiber length-weighted of beaten pulp was only decreased by 8% and 8.16%, respectively, compared to the unbeaten pulp. Beating can effectively improve reclamation quality of recycled cellulose fiber. The tensile index of papers of the first cycle beaten, the second cycle beaten and the third cycle beaten pulps was increased by 39.9%, 27.8% and 18.9%, respectively, compared to the unbeaten pulps. Fiber swelling ability was greatly improved after beating. WRV was increased by 32.1% and 37.7%, respectively. The fiber fibrillation during beating might explain the changes in the WRV and could be partly the reason for the increase in tensile strength of the sheet from beaten pulp. The improving role of beating on the recycled cellulose fiber quality gradually decreased with an increase of recycle number. Crystallinity of cellulose increased, and then decreased with an increase in beating degree. The average pore size, cumulative pore volume and specific surface area of unbleached eucalyptus cellulose fiber increased with the increase in beating degree. Therefore, beating can improve the structure of pore of recycled cellulose fiber, and may become a physical method to effectively resist the irreversible closure of pore of recycled cellulose fiber.

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