

Preparation, Composition, Structure and Properties of the *Kosteletzkya virginica* Bast Fiber

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(Received December 15, 2010; Revised May 23, 2011; Accepted June 3, 2011)

Abstract: In this paper, the bast of the *Kosteletzkya virginica* are degummed and separated into fine fibers, the chemical composition, morphology, microstructure and mechanical properties of the *Kosteletzkya virginica* bast fibers are characterized by means of SEM, ART-FTIR, DSC-TGA, XRD and Instron tensile tester. The results show that the surface of the *Kosteletzkya virginica* bast fibers is smooth, and there are many visible grooves along the vertical section. Typical cellulose I in the *Kosteletzkya virginica* bast fibers is confirmed by FTIR and XRD analysis. The crystallinity of the *Kosteletzkya virginica* bast fibers is higher than that of the cotton fibers and lower than that of the castor-oil plant bast fibers. The beginning and maximum decomposition temperature of the *Kosteletzkya virginica* bast fibers are 252 and 347 °C respectively, which indicate that the *Kosteletzkya virginica* bast fibers have an appropriate thermal stability. The *Kosteletzkya virginica* bast fibers have a better mechanical properties and excellent hygroscopicity. All the results show that the *Kosteletzkya virginica* bast fiber is one of an ideal candidate for the new textile material.

Keywords: *Kosteletzkya virginica*, Bast fibers, Morphological structure, Microstructure, Mechanical properties

Introduction

Soil salinity, absence of resource and depravation of environment have gained much attention by our society. Among these problems, soil salinity has become one of the most increasingly serious and costly problem for global agriculture. It is reported by United Nations Educational Scientific and Cultural Organization that the saline soil take up ten precents of the earth. Reduction in yields due to secondary salinization from irrigation, limits to supplies of freshwater, and the growing need in many developing nations for agricultural output from semi-arid and arid maritime regions fed by brackish aquifers have all stimulated widespread efforts to improve salt tolerance in traditional crops and to identify potential new crop plants among wild species native to saline areas [1-3].

Kosteletzkya virginica, seashore mallow, is a perennial dicot which grows in brackish portions of coastal tidal marshes, and it can grow very well by irrigating with brine (from 5 to 15 wt.% concentration), the output (kg/hm²) of the *Kosteletzkya virginica* can reach 1500 by means of irrigating with brine (25 wt.% concentration). A number of studies investigate that *Kosteletzkya virginica* is one of an ideal candidate for the exploitation of coastal tidal marshes [4,5]. Recently, the flowers and seed of the *Kosteletzkya virginica* have gained much attention by the researchers, and *Kosteletzkya virginica* has been suggested as a grain crop for seawater-based agricultural systems in that it produces a relatively large seed with good nutritive value and a mucilage possibly suited to industrial use. The content of

fatty acid, amino acid, microelement and noxious metal were investigated by Ruan *et al.* [6], and they found that there were 9 kinds of fatty acid in the *Kosteletzkya virginica*, and the content of saturated fatty acid was higher than the unsaturated fatty acid. 17 kinds of amino acid in the *Kosteletzkya virginica* were also abundant, and the content of glutamic acid and arginine were relatively higher than other kinds of amino acid. Microelement, such as Ca, K, Me and Fe, were also examined in the *Kosteletzkya virginica* bast fibers.

However, till now, there is no report on the degummed bast fiber of the *Kosteletzkya virginica*. In this paper, the bast fibers of the *Kosteletzkya virginica* were degummed and separated into fine fibers, the chemical composition, morphology, microstructure and mechanical properties of the degummed *Kosteletzkya virginica* bast fibers were characterized by means of SEM, ART-FTIR, DSC-TGA, XRD and Instron tensile tester et al. The structure and properties of the castor-oil plant and cotton fibers were also investigated as controls to display the advantages of the *Kosteletzkya virginica* bast fibers. The results show that the *Kosteletzkya virginica* bast fiber is an appropriate candidate for the new textiles materials which can grow in the brackish portions of coastal tidal marshes.

Experimental

Materials

The *Kosteletzkya virginica* bast fibers (obtained from biotechnology institute of Nanjing University, China), castor-oil plant bast fibers and cotton fibers (purchased from the market, China), were used for this study. Sodium hydroxide,

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sodium sulfite, sulfuric acid, 3-sodium phosphate, soluble glass and hydrogen peroxide were purchased from Shanghai Chemistry Reagent Co., Ltd., China.

Preparation of the *Kosteletzky virginica* Bast Fibers

Compared with other natural fibers (wool and cotton), bast fibers must be degummed and separated into fine fibers before textile processing. The techniques of degumming bast fibers included enzymatic, chemical, or ultrasonic plus mechanical methods, and some new processing strategies have also been proposed [7-10]. In this paper, the *Kosteletzky virginica* bast fibers were degummed by chemical processing. That is, firstly, the *Kosteletzky virginica* bast fibers were immersed into vitriolic solution (0.02 mol/l) at 40~50 °C for 1 h. Secondly, the *Kosteletzky virginica* bast fibers were cooked in sodium hydroxide solution (8 g/l) for 2 h. After alkaline cooking, the *Kosteletzky virginica* bast fibers were sequentially cooked in a mixed solution of sodium hydroxide (10~20 g/l), 3-sodium phosphate (3~5 %, w/w) and soluble glass (4~8 %, w/w) for 2 h. Then the *Kosteletzky virginica* bast fibers were washed, bleached (in hydrogen peroxide solution with concentration of 2 % (w/w) at 100 °C for 45 min) and dried sequentially. All the ratio of the bast fibers and scouring solution were 1/15 (w/w). After degumming, the *Kosteletzky virginica* bast fibers were opened and carded for textile applications. The castor-oil plant fibers were also degummed by chemical processing the same as *Kosteletzky virginica* bast fibers.

Chemical Composition of the *Kosteletzky virginica* Bast Fibers

The cellulose, hemi-cellulose and lignin contents of the *Kosteletzky virginica* bast fibers, as well as some other small quantities of constituents like fats, pectin and aqueous extract etc, were tested according to method of quantitative analysis of ramie chemical components (GB5889-1986, P. R. of China).

Fineness and Diameter Measurements

Fineness of the *Kosteletzky virginica* bast fibers, castor-oil plant bast fibers and cotton fibers were measured according to the method described by Wang [7]. The *Kosteletzky virginica* bast fibers, castor-oil plant bast fibers and cotton fibers were observed by an optical microscope, based on the optical microscope images, the diameter and standard deviations of the bast fibers were analyzed using an image analysis program (Adobe Photoshop 7.0).

Morphological Characterizations

The morphological structures and fracture surfaces of the *Kosteletzky virginica* fibers, castor-oil plant bast fibers and cotton fibers were observed by a Hitachi S-4700 scanning electron microscopy (SEM) operated at an acceleration

voltage of 30 and 5 kV, with the magnification of 20000, 10000, 5000, 2500, 1800 and 1400 *et al.*

Microstructure of the *Kosteletzky virginica* Bast Fibers

The microstructure of the bast fibers were measured by FTIR spectra, TG-DTA and XRD. The FTIR spectrum was obtained by using a series spectrometer (Nicolet 5700, PE LO, USA) in the spectral region of 4000~400 cm⁻¹. TG-DTA curves were obtained through a thermal analysis instrument (Diamond 5700, PE Co. USA) at a heating rate of 10 °C/min, scan range of 40~400 °C and nitrogen gas flow rate of 120 ml/min. The X-ray diffraction of fibers samples were measured by a wide angle X-ray diffractometer (D/max 2027, Rigaku Co. Japan) at a scan speed of 2 °/min. The degree of crystallinity was calculated using the instrument software (Peakfit 4.12).

Mechanical Properties of the *Kosteletzky virginica* Bast Fibers

The mechanical properties of the fibers were characterized using an Instron tensile tester (Model 3365, USA) in ambient conditions. The fibers were measured in tension with a crosshead speed of 15 mm/min by the Instron tensile tester, and the gauge length was set at 15 mm. The ambient conditions were controlled at 20 °C and 70 % relative humidity. All samples were stored under ambient conditions before testing. 30 samples of each material type were tested. Breaking strength and elongation were calculated with equations (1) and (2).

$$\text{Breaking strength (cN/dtex)} = \frac{\text{Breaking tenacity (cN)}}{\text{Fineness (dtex)}} \quad (1)$$

$$\text{Elongation (\%)} = \left(\frac{L_1 - L_0}{L_0} \right) \times 100 \quad (2)$$

where L_0 was the length of sample and L_1 was the length at break.

The moisture regain of the fibers were measured in the oven with constant temperature at 105 °C. The moisture regain was calculated with equation (3). 30 samples were tested, and 30 measurements values taken from the experiments were averaged.

$$\text{Moisture regain (\%)} = \left(\frac{W_0 - W}{W_0} \right) \times 100 \quad (3)$$

Where W_0 and W was the mass of the fibers before and after drying, respectively.

Statistical Analysis

All the data of the physico-mechanical properties was expressed as means±standard deviations (SD). Statistical comparisons were performed by SPSS 13.0 and differences were considered as significant when $p < 0.05$.

Results and Discussion

Chemical Composition of the *Kosteletzkya virginica* Bast Fibers

The chemical compositions of the *Kosteletzkya virginica* bast fiber, as well as the castor-oil plant bast fiber and cotton fiber, were tested according to method of quantitative analysis of ramie chemical components, and the results were shown in Figure 1. As shown in Figure 1, the *Kosteletzkya virginica* bast fiber was a lignocellulosic fiber, which was composed of three main categories of chemical constituents namely cellulose (49.7 %), hemicellulose (17.3 %) and lignin (5.78 %). The content of the cellulose was lower than the castor-oil plant bast fiber (65.8 %) and cotton fiber (92.5 %), however, the content of cellulose was the most major component in the *Kosteletzkya virginica* bast fiber, which was enough fit for the textile uses. The content of hemicellulose and lignin was relatively lower, but they were still higher than that in the castor-oil plant bast fiber (15.64 and 4.39 %) and cotton fiber (1.89 and 0.00 %). The other non-cellulose materials (such as pectin, fats and aqueous extract) were removed from the fibers by treating with sodium hydroxide at boil, and the conditions used in this study to obtain fibers were expected to remove most of the pectin.

We also assumed that lignin was the major binding material in the *Kosteletzkya virginica* bast fibers. In addition, delignification was found to increase the fineness but decreases the strength of the fibers [11]. Complete removal of lignin would result in single cells in the *Kosteletzkya virginica* bast fibers that were too small to be suitable for high quality fibrous applications. The extent of removal of the non-cellulosic substances played a major role in determining the structure and properties of the fibers. Higher lignin content meant a stiffer and weaker fiber, the *Kosteletzkya virginica* bast fibers contained 5.78 % lignin, which was appropriate, lower than that in kenaf (10 %) but higher than that in flax (2~3 %) [12]. In the future research, we will optimize the degumming technology to obtain the *Kosteletzkya virginica* bast fibers with higher cellulose content.

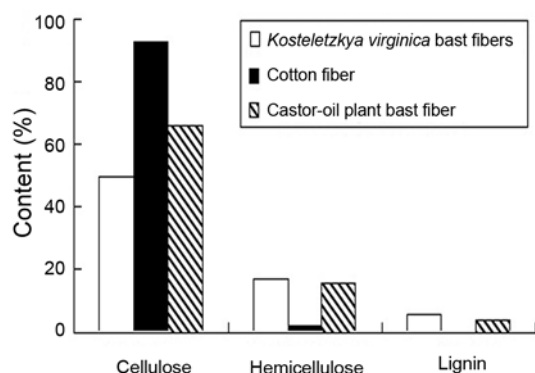


Figure 1. Chemical composition of the fibers.

Fineness of the *Kosteletzkya virginica* Bast Fibers

Fineness and diameter of the fibers was very important for yarn production and quality. In this paper, the fineness and diameter of the degummed *Kosteletzkya virginica* bast fibers, as well as the cotton and castor-oil plant bast fibers, were measured, the results were shown in Table 1 and Figure 2. It could be seen from Table 1 and Figure 2 that the fineness (4.11 ± 0.26 dtex) and diameter ($54.78 \pm 2.06 \mu\text{m}$) of the degummed *Kosteletzkya virginica* bast fibers was remarkably ($p < 0.05$) higher than the cotton fibers (1.68 ± 0.17 dtex and $17.57 \pm 3.69 \mu\text{m}$) and castor-oil plant bast fibers (2.24 ± 0.13 dtex and $24.65 \pm 1.72 \mu\text{m}$). And both the fineness and diameter of *Kosteletzkya virginica* and castor-oil plant bast fibers were significantly ($p < 0.05$) were higher when compared with the cotton fibers. This was due to the delignification of the bast fibers. Although the fineness and diameter of the *Kosteletzkya virginica* and castor-oil plant bast fibers was higher than the cotton fibers, the fineness of the bast fibers was more uniform, and it was in favor of the spinning, and fibers could also obtain a relatively higher strength with a higher fineness and diameter. As shown in Figure 2(a), the surface of the *Kosteletzkya virginica* bast fiber was smooth. While it could be seen that there was irregular distortion in the longitudinal morphology of the cotton fiber (Figure 2(b)), and there were stripes in the longitudinal morphology of the castor-oil plant bast fiber (Figure 2(c)).

Morphological Structure of the *Kosteletzkya virginica* Bast Fibers

In order to clearly observe the morphological structure of the *Kosteletzkya virginica* bast fibers, the longitudinal direction and cross-section of the fibers with different magnification were observed by SEM, and the results were shown in

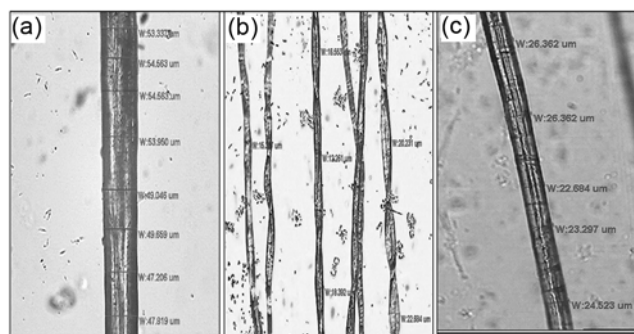


Figure 2. Longitudinal morphology and fineness of (a) *Kosteletzkya virginica*, (b) cotton, and (c) castor-oil plant fibers.

Table 1. Fineness and diameter of the fibers

Fibers	<i>Kosteletzkya virginica</i>	Cotton	Castor-oil plant
Fineness (dtex)	4.11 ± 0.26	1.68 ± 0.17	2.24 ± 0.13
Diameter (μm)	54.78 ± 2.26	17.57 ± 3.69	24.65 ± 1.72

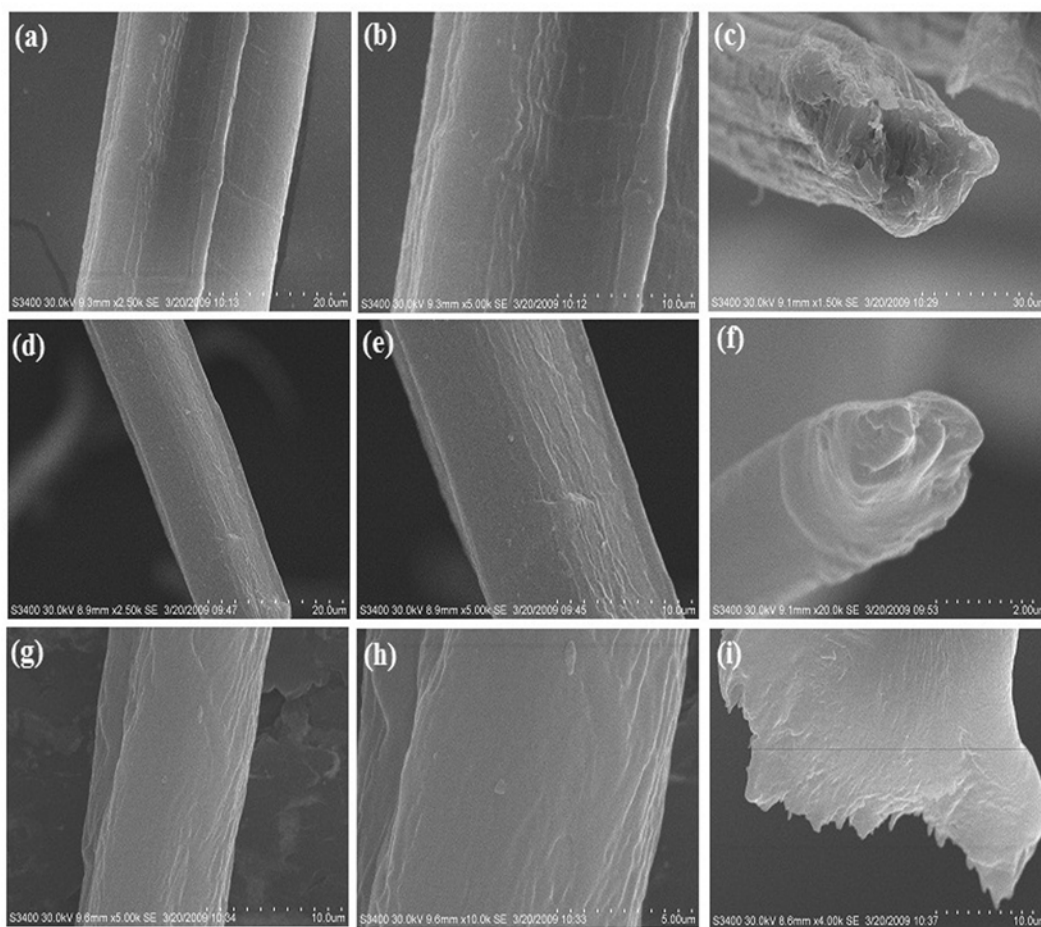


Figure 3. Longitudinal ((a) and (b) with magnification 2500 and 5000 respectively) and cross-sectional ((c) with magnification 1500) SEM micrographs of the *Kosteletzkya virginica* bast fibers. Longitudinal ((d) and (e) with magnification 2500 and 5000 respectively) and cross-sectional ((f) with magnification 20000) SEM micrographs of the castor-oil plant bast fibers. Longitudinal ((g) and (h) with magnification 5000 and 10000 respectively) and cross-sectional ((i) with magnification 4000) SEM micrographs of the cotton fibers.

Figure 3. It could be seen that the surface of the *Kosteletzkya virginica* bast fibers (Figure 3(a) and (b)) was relatively smooth, and there were many visible grooves along the vertical section, which could induce the *Kosteletzkya virginica* bast fibers to have excellent capillary effect, hygroscopicity and air permeability. The results were the same as the castor-oil plant bast fibers (Figure 3(d) and (e)). We could also see that the surface of the bast fibers was covered by a few impurities like hemicellulose, lignin, pectin and waxy substances. This was because although alkali scouring was effective for impurities removal, the impurities could not be totally removed. However, as shown in Figure (g) and (h), the surface of the cotton fibers more smoother when compared with the bast fibers, this was due to that cellulose was the main component of the cotton fibers, and the cotton was not needed to be degummed.

Figure 3(c) and (f) showed the cross-sectional view of the *Kosteletzkya virginica* and castor-oil plant bast fibers. The cross-section is not round but irregularly elliptical, and the

bast fiber was not hollow fiber. The irregular cross-section and fibrillar structure could lead to a higher estimate of the diameter, which was different from the cotton fibers (Figure 3(i)). It was reported that this structure of the bast fibers contributed to high interfacial shear strength with soy protein concentrate (SPC) polymer resin by increasing the mechanical interlocking and interfacial area [13]. Also, this structure of the bast fibers was expected to provide good thermal and sound insulation properties.

Microstructure of the the *Kosteletzkya virginica* Bast Fibers

FTIR Analysis

The components of the *Kosteletzkya virginica* bast fibers, as well as the cotton and castor-oil plant bast fibers, were analyzed using FTIR spectroscopy. Figure 4 showed the FTIR spectra of the three kinds of fibers. As shown in Figure 4(a), the spectrum of the *Kosteletzkya virginica* bast fibers exhibited O-H stretching absorption around 3380 cm^{-1} , C-H

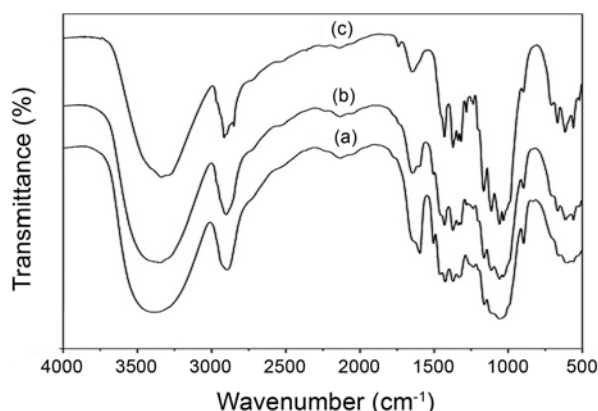


Figure 4. FTIR spectra of (a) *Kosteletzkya virginica* bast fibers, (b) castor-oil plant bast fibers, and (c) cotton fibers.

stretching absorption around 2897 cm^{-1} , C-O-C stretching absorptions around 1059 and 1119 cm^{-1} , and C-O skeletal vibration and the bands at 897 cm^{-1} (glycosidic linkages between sugars). These absorptions were consistent with those of the typical cellulose I backbone [14]. Almost the same absorption peaks as shown in the *Kosteletzkya virginica* bast fibers were observed in the spectrum of the castor-oil plant bast fibers (Figure 4(b)) and cotton fibers (Figure 4(c)). This was due to that the cellulose was the main component of all these three kinds of fiber.

Furthermore, it could be seen from Figure 4(a) and (b) that the disappearance of the absorption peak at 1740 cm^{-1} and the faint peak intensity found at 1253 cm^{-1} indicated the hemicellulose could be partially removed by scouring treatment. In addition, the faint peak intensity found at around 1366 cm^{-1} indicated the partial removal of lignin. The results could also indicate that the alkali scouring was an effective method in removal of the impurities, such as hemicellulose, lignin and pectin. It was accord with the results of chemical components and morphological structure.

XRD Analysis

To investigate the crystal structures of the fibers, the XRD patterns were measured for these samples. The X-ray diffractograms and the crystallinity index of the *Kosteletzkya virginica* bast fibers, cotton and castor-oil plant bast fibers were shown in Figure 5 and Table 2 respectively. The results in Figure 5(a) showed that the *Kosteletzkya virginica* bast fibers exhibited cellulose I structure with the diffraction peaks of the 2θ angles at 16.1° , 22.4° and 34.6° , which were assigned to (101), (002) and (040) planes, respectively [15-17], and this result was accord with the analysis of FTIR. As shown in Figure 5(b) and (c), the castor-oil plant bast fibers (15.1° , 16.2° , 22.7° and 34.4°) and cotton fibers (14.7° , 16.5° , 22.7° and 34.4°) showed the similar diffraction peaks of the 2θ angles when compared with the *Kosteletzkya virginica* bast fibers, which indicated that all the three kinds of fibers had the same crystal structure. Furthermore, when

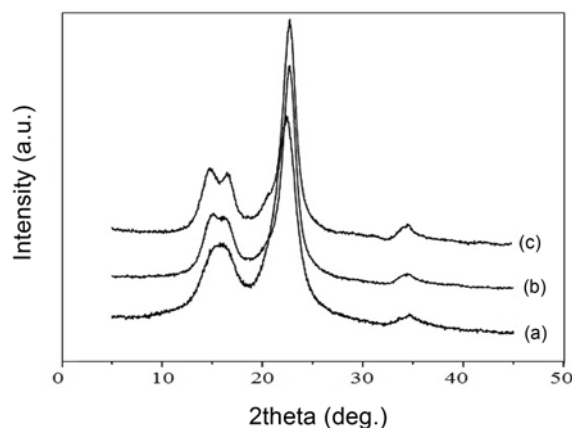


Figure 5. XRD patterns of (a) *Kosteletzkya virginica* bast fibers, (b) castor-oil plant bast fibers, and (c) cotton fibers.

Table 2. Crystallinity of the fibers

Fibers	<i>Kosteletzkya virginica</i>	Castor-oil plant	Cotton
Crystallinity (%)	69	71	65

compared with the cotton fibers, we may conclude that the degummed process (scouring treatment) did not change the crystal structure of the bast fibers [16].

Based on the XRD analysis, the degrees of crystallinity of three kinds of fibers were calculated using equation (4) [18].

$$CI = \frac{I_{\text{crystalline}}}{I_{\text{crystalline}} + I_{\text{amorphous}}} \times 100\% \quad (4)$$

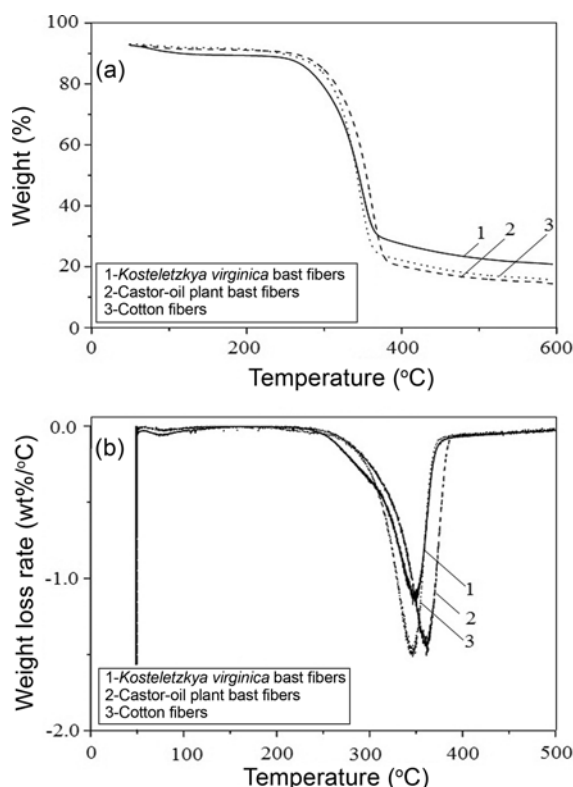
From equation (4) we calculated the *Kosteletzkya virginica* bast fibers' crystallinity index to be 69 %, the castor-oil plant bast fibers' to be 71 %, and the cotton fibers' to be 65 %. The crystallinity of the *Kosteletzkya virginica* bast fibers was higher than the cotton fibers and lower than the castor-oil plant bast fibers. As shown in Table 2, the bast fibers' crystallinity was higher than the cotton fibers. This was due to removal of amorphous materials like hemicellulose, lignin and some other non-cellulose materials during the degumming process. And the longer period of growth of the bast fibers was another reason for the higher crystallinity.

DSC-TGA Analysis

Thermogravimetric analysis was performed to study the decomposition pattern and thermal stability of the *Kosteletzkya virginica* bast fibers, cotton and castor-oil plant bast fibers. The TG and derivative thermogravimetry (DTG) curves of three kinds of fibers were shown in Figure 6 and the data were summarized in Table 3. The TG and DTG curves of the *Kosteletzkya virginica* bast fibers (Figure 6(a) 1 and (b) 1) showed in initial peak between 60 and 100°C , which corresponded to the vaporization of water in the sample [19], and the results were the same with cotton and castor-oil plant bast fibers. As the temperature was increased the mass

Table 3. Thermostability of the three kinds of fibers

Fibers	T_d (°C)	T_{dm} (°C)	Residual mass (wt%)
<i>Kosteletzkya virginica</i>	252	347	20.8
Castor-oil plant	268	361	14.4
Cotton	249	345	15.6

**Figure 6.** Thermogravimetry (a) and derivative thermogravimetry (b) curves of the three kinds of fibers.

remained constant until 252°C, the temperature which corresponds to the beginning of the thermal degradation (T_d), which was due to the thermal depolymerization of non-cellulose materials [20]. And the main weight loss stages corresponded to the decomposition of cellulose [21], with a maximum decomposition temperature (T_{dm}) at 347°C. The T_d and T_{dm} of the *Kosteletzkya virginica* bast fibers were lower than those of the castor-oil plant bast fibers (Figure 6(a) 2 and (b) 2, 268°C and 361°C respectively) and higher than those of the cotton fibers (Figure 6(a) 3 and (b) 3, 249°C and 346°C respectively), this could be explained from XRD analysis section, that is, the crystallinity of the *Kosteletzkya virginica* bast fibers was higher than that of the cotton fibers and lower than that of the castor-oil plant bast fibers. Based on the results, we can state the thermal stability of the *Kosteletzkya virginica* bast fibers was higher than the cotton fibers and lower than the castor-oil plant bast fibers.

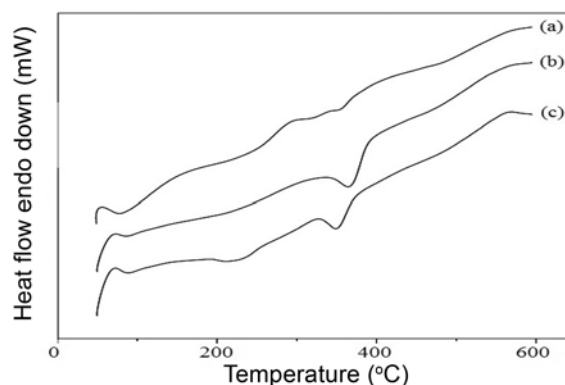
**Figure 7.** DSC thermograms of (a) *Kosteletzkya virginica* bast fibers, (b) castor-oil plant bast fibers, and (c) cotton fibers.

Figure 7 showed the DSC thermograms of the fibers, in the calorimetric study by DSC, several processes associated with water desorption and polymer decomposition were observed. At low temperature (approximately 80°C), an endothermic process was detected, which was associated water desorption. Furthermore, a stronger endothermic peak appeared between 300 and 400°C, which were correlated to the decomposition of cellulose, and the decomposition transition temperature of the *Kosteletzkya virginica* bast fibers (Figure 7(a), 352°C) was lower than that of the castor-oil plant bast fibers (Figure 7(b), 364°C) and higher than that of the cotton fibers (Figure 7(c), 349°C). The results of the DSC were accord with the results of TG and TGA.

Physico-mechanical Properties of the *Kosteletzkya virginica* Bast Fibers

The quality of the *Kosteletzkya virginica* bast fibers or any textile fibers largely depends on the physical and mechanical properties, such as breaking strength, elongation and moisture regain. In this paper, all of these were analyzed to study properties of the *Kosteletzkya virginica* bast fibers. And these properties of the castor-oil plant bast fibers and cotton fibers were also investigated, which were used as controls. The typical stress-strain curves and the physico-mechanical properties of the fibers were shown in Figure 8 and Table 4.

As shown in Figure 8 and Table 4, the breaking strength and young modulus of the *Kosteletzkya virginica* bast fibers were higher than that of the cotton fibers and lower than the castor-oil plant bast fibers significantly ($p < 0.05$), and the elongation of the *Kosteletzkya virginica* bast fibers were higher than the castor-oil plant bast fibers and lower than the cotton fibers significantly ($p < 0.05$). The results indicated that the bast fibers showed a stiff characteristic. However, the cotton fibers showed a relatively flexible characteristic when compared with the bast fibers. The results could be demonstrated by the in situ observation of deformation and fracture of the three kinds of fibers, which was shown in Figure 9. Figure 9 showed the SEM micrographs of the

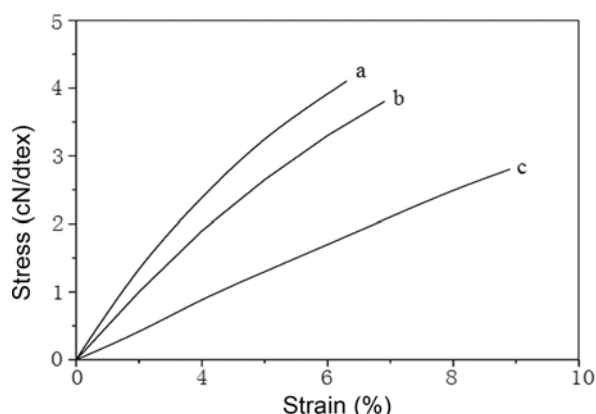


Figure 8. Stress-strain curves of the (a) castor-oil plant bast fibers, (b) *Kosteletzkya virginica* bast fibers, and (c) cotton fibers.

Table 4. Physico-mechanical properties of the fibers

Fibers	<i>Kosteletzkya virginica</i>	Castor-oil plant	Cotton
Breaking strength (cN/dtex)	3.8 ± 0.1	4.3 ± 0.2	2.8 ± 0.2
Elongation (%)	4.9 ± 0.2	4.1 ± 0.4	6.9 ± 0.3
Young modulus (cN/dtex)	77.6 ± 4.4	104.9 ± 4.8	40.6 ± 3.2
Moisture regain (%)	13.2 ± 0.4	12.4 ± 0.2	8.4 ± 0.3

fracture surfaces of the bast fibers and cotton fibers after tensile tests. It could be seen from Figure 9(a) and (a') that the fracture surface of cotton fibers showed that the individual fibrils fracture at different locations. Although the fracture was brittle, the fracture is spread over a large length as a result of fibril fractures. However, as shown in Figure 9(b), (b'), (c) and (c'), both the *Kosteletzkya virginica* bast fibers and the castor-oil plant bast fibers fractured without fibril splitting, which showed a clean and transverse fracture surface with almost no fibrillation. This distinct differences may be explained from the compositions of the fibers. As indicating in the chemical composition section, a higher lignin content meant a stiffer fiber, both the *Kosteletzkya virginica* bast fibers and the castor-oil plant bast fibers had a relatively higher lignin content than that of the cotton fibers. The in situ observation of deformation and fracture of the *Kosteletzkya virginica* bast fibers, as well as the castor-oil plant bast fibers and cotton fibers, explained the mechanical properties' differences of the three kinds of fibers.

The mechanical properties' differences of the three kinds of fibers could also be explained from XRD and TG-DSC analysis sections, that is, the higher the crystallinity and the more thermal stability the higher were the breaking strength and young modulus of the fibers. Nevertheless, the *Kosteletzkya virginica* bast fibers were suitable for direct processing on the conventional textile machinery and also for blending with other common fibers [22]. It can also be seen from Table 4 that the *Kosteletzkya virginica* bast fibers had a high moisture regain ($13.2 \pm 0.5\%$), which was remarkably ($p < 0.05$) higher than the castor-oil plant bast fibers ($12.4 \pm 0.6\%$) and cotton fibers ($8.4 \pm 0.3\%$). The results showed that the *Kosteletzkya virginica* bast fibers had excellent capillary effect, hygroscopicity, air permeability and dyeability, and it was accord with the analysis of the morphological section.

Conclusion

In this study, the bast fibers of the *Kosteletzkya virginica* were degummed and separated into fine fibers. The *Kosteletzkya virginica* bast fibers were lignocellulosic fibers, and the impurities of the bast fibers could be remarkably removed by alkaline scouring. SEM images showed that the surface of the *Kosteletzkya virginica* bast fibers was relatively smooth, and there were many visible grooves along the vertical section. Typical cellulose I in the *Kosteletzkya virginica* bast fibers was confirmed by FTIR and XRD analysis. The crystallinity of the *Kosteletzkya virginica* bast fibers was higher than that of the cotton fibers and lower than that of the castor-oil plant bast fibers. The beginning and maximum decomposition temperature of the *Kosteletzkya virginica* bast fibers were 252 and 347°C respectively, which indicated that the *Kosteletzkya virginica* bast fibers had an appropriate thermal stability. The *Kosteletzkya virginica* bast fibers had a better mechanical properties and excellent

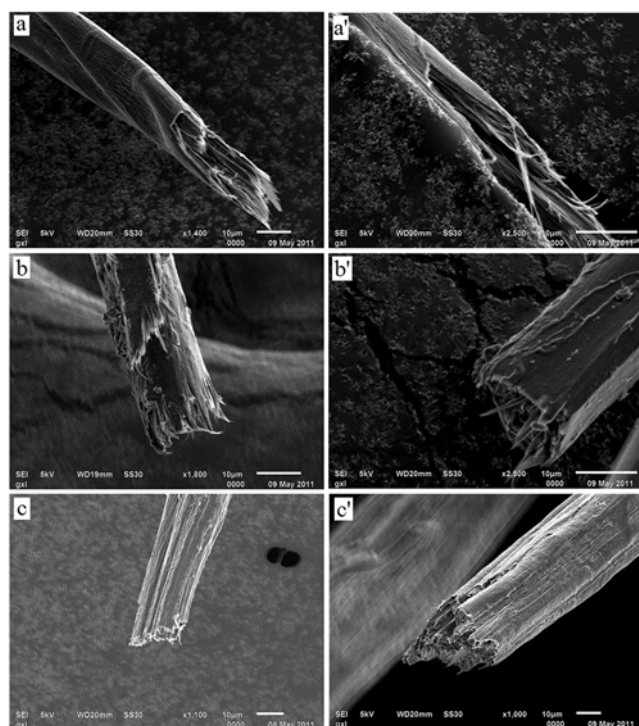


Figure 9. SEM micrographs of the fracture surfaces of the (a) and (a') cotton fibers, (b) and (b') castor-oil plant bast fibers, and (c) and (c') *Kosteletzkya virginica* bast fibers after tensile tests.

hygroscopicity, therefore, it was expected that the *Kosteletzkya virginica* bast fibers would be suitable for direct processing and also for blending with other common textile fibers to produce various products.

Acknowledgements

We thank the fund support of 11.5 National Key Technology R & D Program of China (2006BAD09A04 and 2006BAD09A08) and 2010 Key Technology R & D Program of Jiangsu Province (BC2010469) for this research, and we are indebted to the Testing Center of Soochow University for experimental support.

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