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STRUCTURE AND THERMAL PROPERTIES OF BAMBOO VISCOSE, TENCEL AND CONVENTIONAL VISCOSE FIBER

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Comparative investigations of new regenerated cellulosic fibers, bamboo viscose fiber and Tencel, together with conventional viscose fibers have been carried out to explain the similarity and difference in their molecular and fine structure. The analyses jointly using SEM, XRD and IR reveal that all the three fibers belong to cellulose II. Tencel consists of longer molecules and has a greater degree of crystallinity, while bamboo viscose fiber has a lower degree of crystallinty. TG-DTG-DSC study shows three fibers resemble in thermal behavior with a two-step decomposition mode. The first step is associated to water desorption, suggesting that bamboo viscose fiber holds better water retention and release ability, the second a depolymerization and decomposition of regenerated cellulose, indicating that Tencel is more thermally stable in this process than bamboo and conventional viscose fiber.

Keywords: *bamboo fiber, Tencel, thermal property, viscose*

Introduction

Cellulose is a raw material with a wide variety of uses in the textile and chemical industry for producing man-made fibers. Being a new kind of regenerated cellulosic fiber, bamboo viscose fiber has recently been of great interest due to its several advantages. Its raw material is easy to obtain and thus its cost is relatively low since bamboo is an abundant and fast-growing plant [1], particularly in some countries such as China and Japan where bamboo viscose fiber has been in fact commercially available [2, 3]. Furthermore, there have been numbers of studies showing bamboo viscose fiber possesses antimicrobial function which is inherited from bamboo itself [4, 5]. In addition, bamboo viscose fiber exhibits good dyeability, soft handle and proper moisture absorbility and permeability which result in the fact that its textile is comfortable to ware and favorably received by people [4, 5].

So far as we know, however, there has been little study on bamboo viscose fiber, especially on its thermal property. In the present paper, we investigated the structure of bamboo viscose fiber and Tencel, and compared them with conventional viscose fiber using IR, SEM and XRD. Tencel is the brand name by Courtaulds Plc, Britain for a new sort of regenerated viscose fiber Lyocell [6, 7]. Tencel is nowadays a very important member of the fiber family owing to the facts that it is produced from wood pulp via a more environmental friendly procedure (dissolving cellulose in aqueous solution of N-methylmorpholine oxide (NMMO) [7, 8]) and that it has many interesting properties such as attractive appearance (‘peach skin’ finish) and appealing handle of its fabric [9–12]. Besides, we observed their thermal behavior with the help of TG-DTG-DSC technique and discussed the relationship between their properties and structure. These results, we think, would be helpful to understand the physical, chemical and mechanical properties of the three fibers better and to improve textile processing.

Experimental

Materials

Three types of regenerated cellulosic fibers, bamboo viscose, conventional viscose and Tencel, were obtained from Courtaulds Plc (British), Jilin Chemical Fiber Ltd. (China) and Jigao Chemical Fiber Ltd. (China), respectively. The linear density and length of all of three fibers were 1.67 dtex and 38 mm. The fibers were purified with a nonionic surfactant of polyoxyethylene ether (0.3% W/V) at 85°C for 1 h, then completely rinsed and dried at 60°C for 6 h. The fibers were scissored into powders before SEM, FTIR, XRD and TA analyses.

Methods

SEM analyses were performed on a Hitachi S-570 scanning electron microscope.

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IR spectra were recorded on a FTIR spectrometer (Model Magna-IR550, Nicolet) with a resolution of 4 cm^{-1}. A potassium bromide (KBr) pellet technique was employed. XRD study was performed on a wide-angle X-ray diffractometer (Model D/Max-3C, Rikagu, Japan) with a CuK_{α} (wavelength=1.54 Å) source. The powder sample was then scanned within 2θ=5–45° in steps of 0.02°.

TA study was carried out on thermoanalyzer, SDT 2960, TA instruments [13], which allows simultaneous detection of mass changes and heat effect of decomposition for samples. Alumina crucibles were served as reference and sample cells. The 3–4 mg of samples were subjected to a rising temperature regime over the range of ambient to 500°C at a heating rate of 10.0 K min^{-1}. Moreover, to explore the process of water desorption carefully, we also performed experiments using DSC-2010 within the temperature range of –50 to 200°C at a heating rate of 10.0 K min^{-1}. All studies were performed under a dry and pure nitrogen atmosphere with a flow rate 100 mL min^{-1}.

Results and discussion

Structural of regenerated cellulosic fibers

SEM

The longitudinal and cross-sectional shapes by SEM for bamboo viscose fiber are shown in Fig. 1. Compared with that of Tencel [10, 14] and conventional viscose fibers [15], the differences among them can be clearly reviewed. The cross-section of Tencel is circular and the surface smooth might be due to the fact that in the spinning process, the cellulosic fibers suffer quick and high permeation of solvent which results in uniform coagulation. The different spinning procedure of Tencel from conventional viscose fiber causes the forming of very long crystallites which are very highly oriented in the longitudinal axis of the fiber [14].

For bamboo viscose fiber, the cross-sectional shape and longitudinal surface are similar to those of conventional viscose fibers with cross-sectional shape being irregular and toothed, which could be caused by the coagulation of viscose solution that takes place first on the surface and then further delayed coagulation in the interior during the spinning process [15]. Besides, some striated cracks distribute over the longitudinal surface of bamboo viscose fibers and there are many voids in their cross-section. These imply that bamboo and conventional viscose fibers would possess good water retention power [16], which is also confirmed by the results of TA analysis.

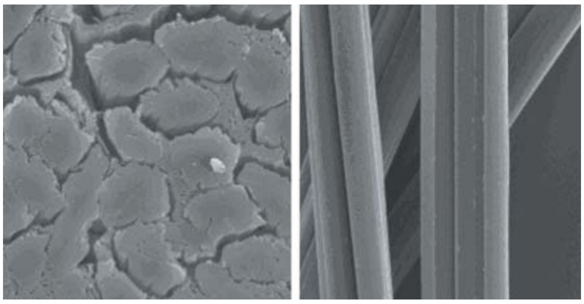

Fig. 1 SEM micrographs of bamboo viscose fiber: left – cross-sectional, magnification: ×1500 and right – longitudinal shape, magnification: ×2000

X-ray diffraction (WAXS)

The X-ray diffraction pattern from the three fibers is given in Fig. 2. Generally, regenerated cellulose fibers with a cellulose II structure have peaks at 2θ=12.2 and 21.8° assigned to (101) and (002) reflection, respectively [17–19]. As we can see in the pattern, all these three fibers have a cellulose II structure. The intensity of peak at 2θ=21.8° is much higher than that of 2θ=12.2° and the intensity of the both peaks increases in the order of Tencel>conventional viscose>bamboo viscose. The crystallinity for all three samples was calculated using the empirical method of Segal *et al.* [20], which is presented in Table 1. The higher degree of crystallinity in Tencel fibers is a consequence of the quick and high orientation of molecular chains during the spinning and drawing, which accelerates crystallization [15, 21]. In comparison with Tencel and conventional viscose fiber,

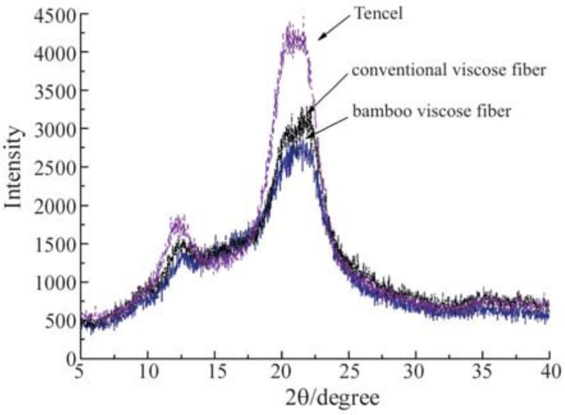

Fig. 2 X-ray diffraction pattern of three fibers

Table 1 X-ray crystallinity index, $\alpha_{1381\ cm^{-1}}/\alpha_{2890\ cm^{-1}}$ infrared peak ratio, and calculated crystallinity index for three regenerated cellulosic fibers

Sample	Crystallinity/% X-ray	Infrared ratio/% $\alpha_{1381\ cm^{-1}}/\alpha_{2890\ cm^{-1}}$
Tencel	69.44	14.56
Bamboo viscose fiber	45.33	13.49
Conventional viscose fiber	53.43	9.533

bamboo viscose fiber has the lowest degree of crystallinity despite of the spinning method resembling that of conventional viscose, which may be attributed to the fact that the performance and spinning parameters of bamboo pulp used for spinning are different from those of conventional wood or cotton linter pulp.

FTIR spectra (KBr)

The IR spectra of Tencel, bamboo and conventional viscose fibers are shown in Fig. 3, which displays the overall situations in the range of 400–4000 cm^{-1}. Three samples exhibit the similar characteristic strong and sharp cellulose II bands at 895 and 1427 cm^{-1}, respectively [22]. Bands at 1161, 1234, 1265, 1319 and 1381 cm^{-1} are also sensitive to cellulose crystallinity and crystal lattice type [23, 24]. This observation is consistent with our interpretation of the X-ray results. Nelson and O'Connor [25] found that a group of IR bands in the region of 1200~1400 cm^{-1} (assigned to C–H and O–H bending and CH_2 wagging motions) appeared to be related to crystallinity and not to lattice type, while certain bands show fewer changes than others. Therefore we chose the 1381 cm^{-1} (C–H bending) among the former as the most suitable for indicating crystallinity and the strongest band of the group (C–H and CH_2 stretching) centered at 2890 cm^{-1} among the latter to calculate the ratio of area $\alpha_{1381\ \mathrm{cm}^{-1}}/\alpha_{2890\ \mathrm{cm}^{-1}}$ [21] which is presented in Table 1, together with the crystallinity calculated using X-ray data for the Tencel, bamboo and conventional viscose fibers. Though the crystallinities determined from XRD and IR do not agree exactly, the trend of the change corresponds quite well, that is, the Tencel shows higher crystallinity than the other two samples.

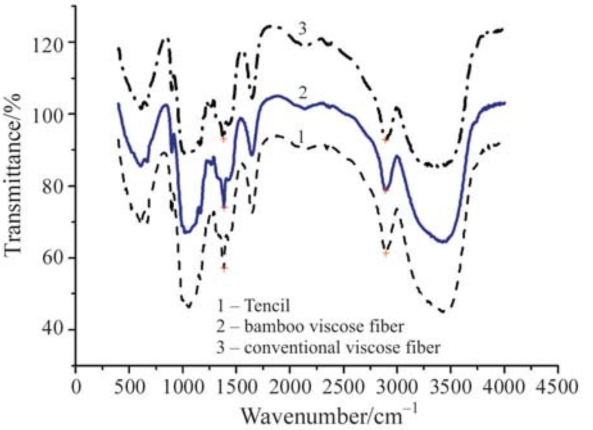

Fig. 3 IR spectra obtained from KBr discs pressed from finely chopped samples

Thermal analysis

The TG-DTG and DSC curves at a heating rate of 10 K min^{-1} for the three samples studied are given in Figs 4 and 5, respectively. The main data obtained by the software of Universal V3.7A TA Instruments are listed in Tables 2 and 3. For all samples, two chief endothermic processes can be attributed to water desorption and decomposition of cellulose, respectively.

The assumption that the stage I is corresponding to water releasing can be further confirmed by the comparison of the DSC curves in Fig. 6a with that in Fig. 6b. The former was recorded during the first heating the samples, while the latter reheating the samples, previously heated until 200°C and cooled to room temperature. It can be seen that the first peak of DSC associated to water desorption disappears in the latter [11]. Both the mass loss (in Table 2) and the ΔH values (in Table 3) show that bamboo and conventional viscose possess better ability of absorbing and releasing water, losing more water and owing higher ΔH in this region due to their higher amorphous phase, while for Tencel, the slightly lower mass loss of 6.108% and ΔH of 267.1 J g^{-1} is coincident with the

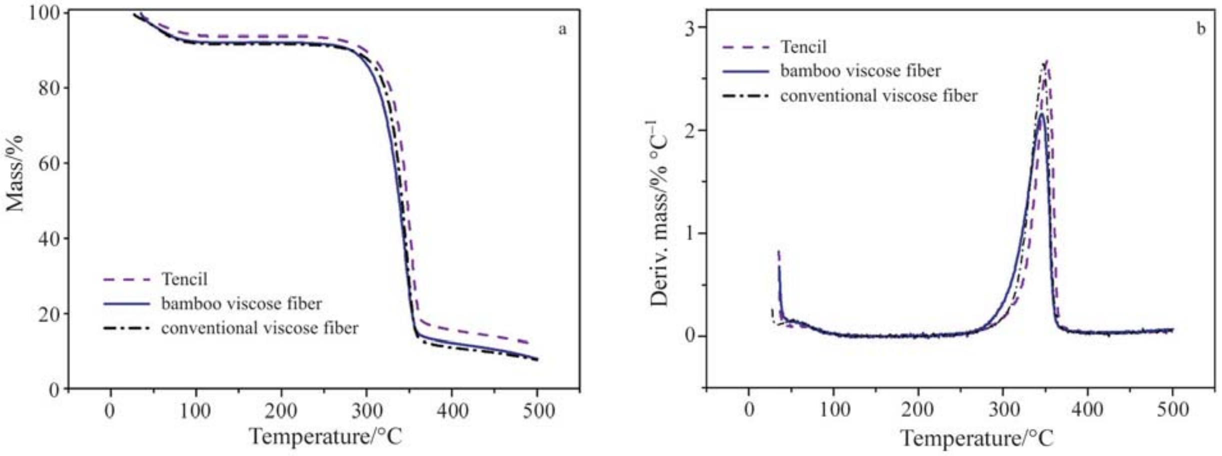

Fig. 4 a – TG curves for three samples, b – DTG curves for three samples

Table 2 Selected TG data of three regenerated cellulose fibers under an atmosphere of dynamic nitrogen (β=10 K min^{-1})

Sample		Tencel	Bamboo viscose fiber	Conventional viscose fiber
Stage I	temp. range/°C	35.25–125.37	35.38–127.39	26.72–126.13
	loss of mass/%	6.108	7.706	8.153
Stage II	temp. range/°C	240.08–438.20	222.42–434.32	230.13–436.08
	loss of mass/%	82.13	84.33	84.16
Residue at 500°C		11.76	7.965	7.685

Table 3 The DSC data of three regenerated cellulose fibers under an atmosphere of dynamic nitrogen (β=10 K min^{-1})

Sample	Water desorption			Decomposition of cellulose		
	T_{onset}/°C	T_P/°C	ΔH/J g^{-1}	T_{onset}/°C	T_P/°C	ΔH/J g^{-1}
Tencel	33.87	61.54	267.1	324.54	355.53	460.3
Bamboo*	37.98	72.07	352.6	301.80	348.85	599.8
Viscose**	31.45	73.86	335.5	312.17	350.47	600.9

*Bamboo – bamboo viscose fiber, **Viscose – conventional viscose fiber

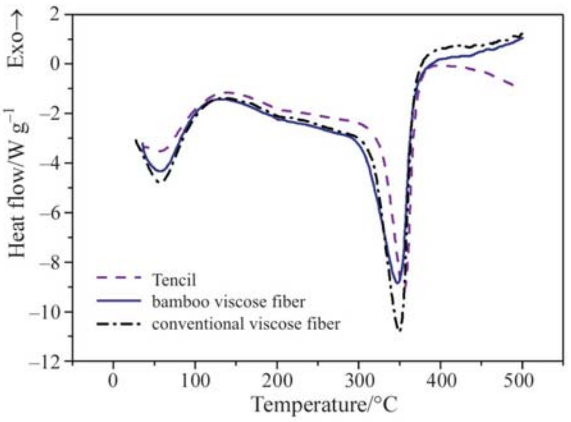

Fig. 5 DSC curves for three samples

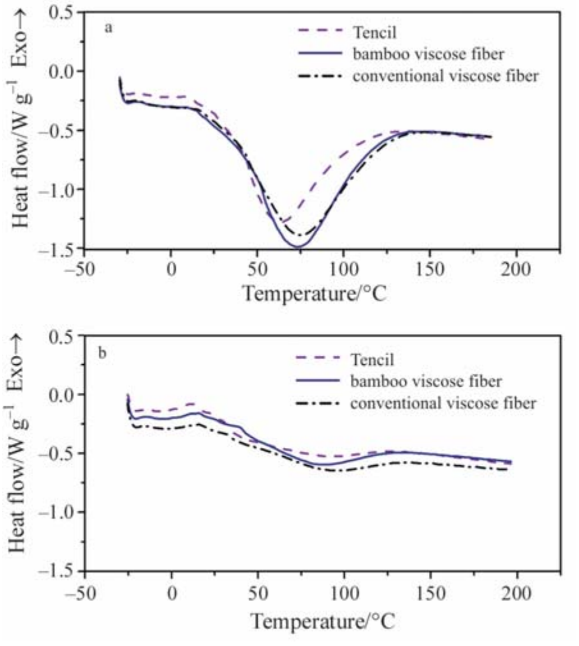

Fig. 6 Partial enlarged view of DSC curves for stage I. a – recorded during the first heating, b – recorded during the reheating

tight structure and high crystallinity of Tencel fibers. The second stage is a strong endothermic process corresponding to the main decomposition of viscose itself. As indicated by Figs 4, 5 this process appears to be in a single-step mode. Actually it may overlap the several successive actions such as the release of other volatile component of samples or the initial stage of thermal degradation at beginning, then followed by the main depolymerization and decompositon of the polymers and at the end, a further carbonization of chain segment with a decreasing slope [26, 27]. The onset temperature of the second stage, that is the T_{onset} of decomposition, symbols the 'thermal stability'. From the data of TG and DSC in Tables 2 and 3, we can see that the thermal stability increases from bamboo to viscose to Tencel, which also may be accounted for by the high crystallinity, the high orientation and polymerization degree of Tencel's molecule chains [21]. Observed from the shape of DSC-TG and the data such as T_{onset}, T_P, mass loss, residue, etc., the Tencel is the most stable all the time, which is in line with the data of structure.

Conclusions

Characteristics of the regenerated fibers depended on the procedure and raw materials, that clearly affected the material structure and, thereby properties. In this paper, bamboo viscose fibers and Tencel are identified as cellulose II, like the conventional viscose fibers. On the other hand, they exhibit different crystallinity and orientation, which is not only corroborated by the result of SEM, XRD and IR, but also confirmed by the thermal properties. The study of thermal decomposition can facilitate to understand the relationship between the properties and structures of new regenerated cellulosic fibers.

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