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New Commercial Fibres Called 'Bamboo Fibres' – Their Structure and Properties

Abstract
Bamboo fibres are gaining more and more attention on the world market. Producers claim that their products are made from natural, ecological material of many exceptional properties characteristic for natural bamboo fibres. There are many obscurities involving bamboo fibres, which lead potential clients to misunderstandings. In the world a campaign is underway to reveal the truth behind these questionable fibres. In this paper, the authors try to prove, by scientific means, that so-called bamboo fibres are in reality man-made viscose fibres made from bamboo cellulose.

Key words: *bamboo fibres, viscose fibres, fibre properties, fibre structure, FTIR, WAXS, SEM.*

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Introduction

In the last few years on the world market, more and more products from so-called bamboo fibres have been appearing. In the media, a campaign promoting their advantages is underway, which encourages companies to elevate the prices of the "new" product.

What is so special about bamboo fibres?

Bamboo is the biggest grass in the world. It belongs to the *Poaceae* family, a subfamily of *Bambusoideae*. There are more than 1250 species within 75 genera of bamboo in the world [1], mainly distributed in tropical and subtropical areas. China is one of the centres of bamboo growth, possessing about 400 species of 50 genera. The area of bamboo growth exceeds 4.21 million ha [2]. As a grass, bamboo can grow in very hard conditions without any need of pesticides and herbicides.

Bamboo is the fastest growing plant in the world - some species grow even one meter per day. It has a great ability to reduce green house gases, absorbing five times more CO_2 than an equivalent stand of trees and producing 35% more oxygen. Bamboo constantly improves its solidity , thereby preventing its erosion. In addition it retains water in its watersheds [3]. The species of bamboo used for fibre production are not eaten by the endangered Giant Panda. Fortunately there is also no information about genetically modified bamboo [4].

Bamboo is known as a very tough and durable plant. It is one of the oldest building materials used by human kind. Bamboo has been widely used in household products and extended to industrial applications due to advances in processing technology and increased market demand [5]. In countries where bamboo is common, it is an inseparable part of people's lives and, hence, treated with great respect.

Annual bamboo fibre production is nearly 40000 tons and is increasing. [6] Bamboo fibres are mainly produced from bamboo Phyllostahys Edulis, called 'Moso', which is the biggest bamboo in the world.

With respect to their structure, natural bamboo fibres (***Figure 1***) are similar to ramie fibres; however, they are finer and shorter. Their length varies from 1 to 5 mm (with an average of 2.8 mm) and the diameter 14-27 μm (average - 20 μm) [7]. They form technical fibres. As can be seen, the length of natural bamboo fibres is very low, and therefore there might be problems with their processing. However, in the industry it is said that many woven and nonwoven products are made from such fibres.

The chemical structure of bamboo fibres is similar to that of wood. The main component is cellulose (about 57 - 63%) with

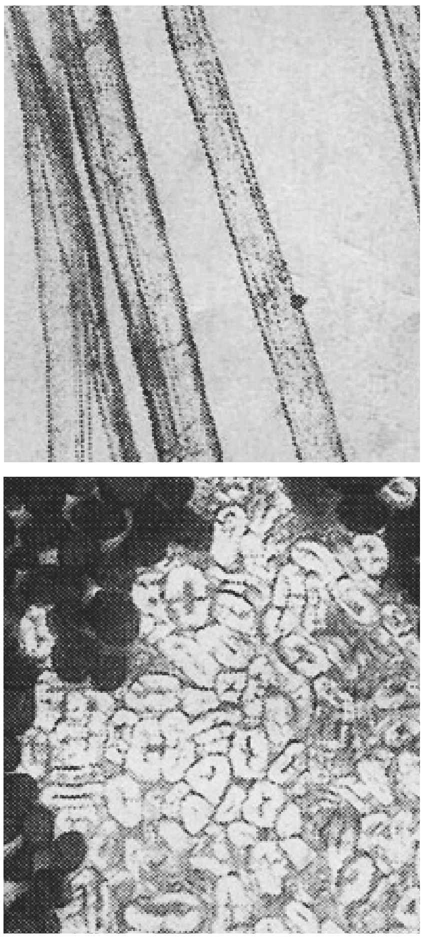

Figure 1. *Longitudinal and cross-section view of natural bamboo fibres [8].*

a α-cellulose content of 36 - 41%, lignins (22 - 26%) and penthosans (16 - 21%) [7]. The most significant components in the bamboo's chemical constitution are those providing its extraordinary fungal and bacterial resistance. The one responsible for bamboo's antibacterial properties is 2.6-bimethoxy-p-benzoquinone [9], called 'Bamboo kun'. The highly distinctive fungal resistance occurs due to a protein – dendrocin [10].

Many producers claim that their products have antibacterial and antifungal properties, smooth hand, UV protection abilities and more. The amount of positive aspects of bamboo fibres is quite exceptional:

- natural antibacterial and antifungal properties, making clothes made from bamboo fibres hygienic and odour resistant. However, this effect starts to wither after fifty washings;
- smoothness, proving bamboo fibres to be non irritating for sensitive skin;
- bamboo fabric is soft and silky with a natural sheen, making it close to natural silk but less expensive and more durable;
- hypoalergic and deodorant properties;
- high water absorption and fast drying caused by a high amount of microcracks and grooves on the fibre's surface;
- higher breathability and thermo regulating properties than cotton and even hemp. They are also said to be 2 - 3 °C cooler than the surrounding temperature ;
- a high durability in comparison to other fibres.
- UV protection abilities (SPF 15);
- a high sorption of dyes and better colour clarity;
- bamboo fabrics have low shrinkage;
- bamboo fibre does not need to be mercerised to receive natural lustre;
- clothes made from bamboo fibre are more wrinkle resistant than cotton and can be ironed at lower temperatures;
- bamboo products are biodegradable and some companies have a utilisation program that allows consumers to return a worn-out product and buy another at a lower price, which is a very good policy for encouraging others to do the same [11].

As a result of the beneficial properties mentioned above, bamboo fibre has found its way into the fashion world. Many well known designers, like Kate O'Connor and Oscar de la Renta have tried their hand at using the new material with good results.

Bamboo fibre has a long list of application possibilities, most of which are shown below.

Because of its antibacterial and temperature-regulating features, bamboo fibre has found its place in the sports clothing industry. With its smooth hand, UV protection abilities and low crumple susceptibility, we receive an ideal material for summer collections [12]. Many companies have spotted these advantages and incorporated bamboo fibre into their products. A most noticeable increase in bamboo fibre application can be seen in yoga and fitness clothing, which are mostly of the women's sports and pro-ecological kind; the oriental touch of bamboo fibre blends well with women's needs.

Except for sports a lot of fashion designers have been driven by the diverse strengths of bamboo textiles. In their collections they often replace more expensive materials like cashmere or silk by their bamboo equivalents. A lot of new stores offering bamboo fibre-based products have started to "spring up" all over the internet market, promising luxurious ecological products for the whole family.

Especially expanded is the market for children's and maternal clothing. Young modern mothers want to give their children what they consider to be the best. And what is better than an ecological, clean and hypoalergical product for their child to wear? As we can see, the whole pro-ecological campaign surrounding bamboo fibres brings very good results.

In Poland the most popular bamboo fibre products are socks and undergarments. In our shops we can find a lot of products made by local manufacturers, amongst which there are various kinds of underwear including special medical socks with an antibinding structure designed for diabetics and people with blood circulation problems in the legs [13].

Unfortunately, there is always a glitch in every case because of the so-called bamboo fibres - the fibres are so short and rigid that it would be hard to spin them, even in the form of technical fibres, into yarn [14]. In this study we are going to take a closer look into the case of bamboo fibres, proving the hypothesis that the bamboo fibres available on the market are in fact not natural but man-made viscose fibres from bamboo cellulose.

Every producer applying bamboo fibres in their textile production asserts their unusual properties, claiming that their products have them all. Ignorance leads to the conclusion that in products made from bamboo fibres, we can find only high-quality ecological material. However, our investigation shows that this kind of thinking is wrong.

Experimental

Materials

An investigation was carried out on "bamboo fibres" from various sources and a comparison made with viscose fibres. The following fibres were used:

a) conventional undyed raw viscose fibres (later termed 'viscose'),
b) dyed "bamboo fibres" from a knitted fabric with a small amount of elastomeric fibres (removed before the research),
c) undyed "bamboo fibres" from the warp and weft of woven fabric coated with polyamide dressing, which was removed,
d) undyed "bamboo fibres" from a yarn.

All the fibres mentioned in b), c), and d) were taken from products manufactured by different producers, who gave no information about the real kind of 'bamboo' fibres used.

Methods

To illustrate similarities in the structure of the "bamboo fibres" investigated and that of man-made viscose fibres, the following measuring methods were used:

- IR absorption spectroscopy - the basis for fibre material identification;
- optical microscopy – showing the macroscopic features of fibres examined (longitudinal and cross-section views);
- scanning electron microscopy (SEM) – to show the differences in the morphological structure of the fibres investigated (a fibrillar structure);
- RTG method – to determine the basic parameter of the fibre's supermolecular structure – the crystallinity degree, with use of the WAXS technique.
- polarisation interference microscopy – to determine the total fibre orientation;
- density measurement of fibres – to highlight similarities in the density of

all fibres examined, which contradicts published data, being the basis for defining the crystallinity degree;
- measurement of the fibre's mechanical properties – tenacity and relative elongation at break;
- evaluation of the fibre's water swelling kinetics;

IR spectroscopic measurements
IR spectroscopic analysis was carried out using the transilluminating technique on tablet specimens containing 1% of powdered fibre, with the use of a FTIR spectrophotometer – Nicolet 6700 coupled with the "The Thermo Scientific" company's control unit. IR absorption spectra were recorded within a wavelength range of 4000 cm^{-1} and 600 cm^{-1} in the following systems: T = f(1/λ), A = f(1/ λ).

Optical microscopy observations
Optical microscopy observations were made on a biologic microscope equipped with a recording unit, using a Lucia aplication. The magnification was 200×.

Scanning electron microscopy observations
For fibre characterisation a scanning electron microscope of the NOVA NanoSEM 230 type (FEI Company) with a field emission gun (FEG) was used. All investigations were carried out in low vacuum ambience – 80 Pa, with the detection of the secondary electron (SE). The beam energy was 10 keV.

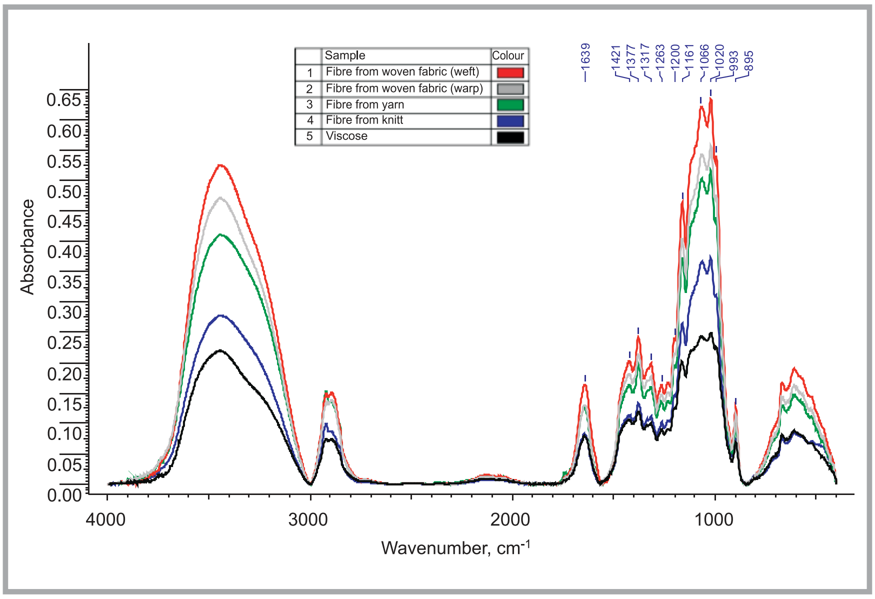

Figure 2. *Set of FTIR spectra for the fibres investigated.*

Table 1. *Characteristic wavenumber values for cellulose II as a pattern compared with the fibres investigated.*

Polymer	Regenerated cellulose [16]	Viscose	„Bamboo fibre" from yarn	"Bamboo fibre" from knitted fabric	"Bamboo fibre" from woven fabric (warp)	"Bamboo fibre" from woven fabric (weft)
Wavenumber cm^{-1}	1635	1647	1647	1647	1639	1639
	1470	-	-	-	-	-
	1420	1422	1423	1417	1421	1421
	1370	1377	1376	1377	1377	1377
	1337	-	-	-	-	-
	1315	1317	1316	1317	1318	1317
	1280	-	-	-	-	-
	1260	1263	1265	1261	1262	1263
	1200	1200	1201	1200	1200	1200
	1160	1163	1160	1161	1161	1161
	1120	-	-	-	-	-
	1070	1066	1064	1065	1066	1065
	1030	1020	1018	1020	1020	1018
	1000	993	993	993	993	993
	900	895	895	895	895	895
	715	715	-	-	-	717

WAXS measurements
The supermolecular structures of the fibres were analysed by wide angle X-ray scattering (WAXS). These investigations were undertaken using an X'Pert Pro diffractometer (PANalitical) with Cu Kα radiation, in which the accelerating voltage was 40 kV and the plate current intensity - 30 mA. X-Ray scattering patterns were obtained at diffraction angles ranging from 12° to 30°, using a semiconducting stripe detector - X'Celerator. The deconvolution of X-ray peaks was performed according to the method proposed by Hindeleh&Johnson, improved and programmed by Rabiej [15]. The degree of crystallinity was calculated as the ratio of the integral intensity from crystalline regions to the integral intensity scattered by the whole sample (over the total domain, from both the crystalline and amorphous regions).

Measurement of the total fibre orientation
The double refraction indices of fibres $n_{\perp}$ and $n_{||}$, being the basis for assessing their total orientation, were determined with polarisation-interference microscopy using the technique of interference stripe field with the separation of the fibre's image into two component views. Based on those images, the directional refraction coefficients $n_{||}$ and $n_{\perp}$ were determined. To illuminate the specimens, monochromatic light was used. Observations were conducted at a magnitude of 150×. For each sample 30 measurements were made. The end result is the mean value of each group of results.

Measurement of fibre density
The fibre density was measured according to Standard PN-P-04752:1984.

Measurements of tenacity and relative elongation at break
The tenacity and relative elongation at break were measured according to Standard PN-EN-ISO 5079:1999, using a tensile instron type 4402.

Evaluation of the fibre's swelling kinetics
This investigation was carried out on an optical biological microscope with a micrometric eyepiece. After evaluating the fibre thickness, they were soaked in a drop of distilled water. After one and five minutes the fibre thickness was measured

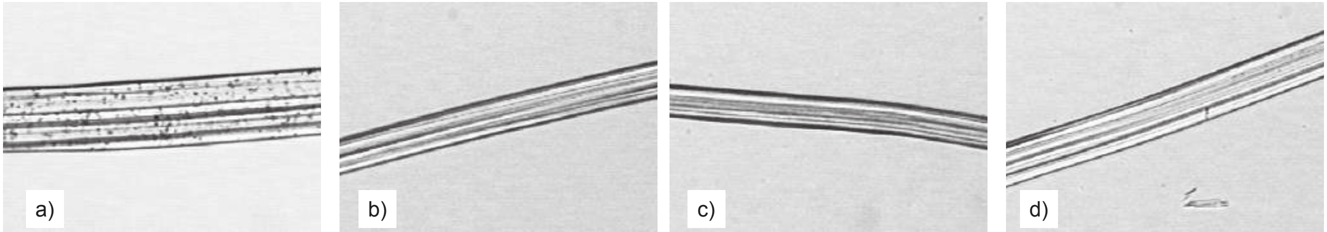

Figure 3. *Longitudinal view of the fibres: investigated a) viscose fibre, b) "bamboo fibre" from yarn, c) "bamboo fibre" from knitted fabric, d) "bamboo fibre" from woven fabric (weft), (magnification 200×).*

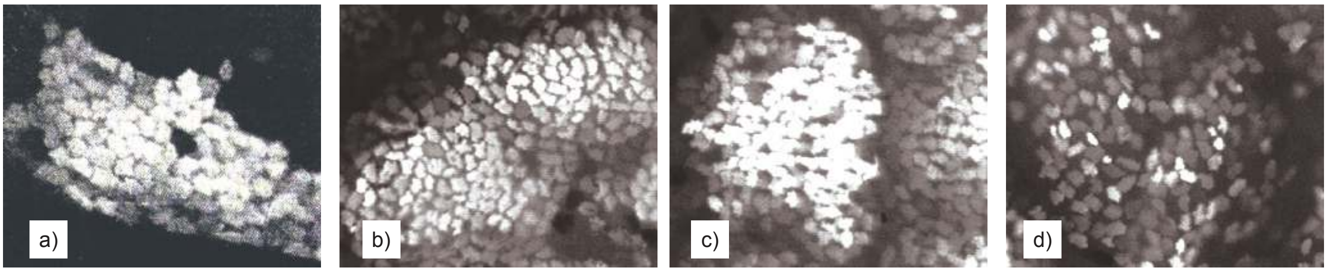

Figure 4. *a) Cross-section of viscose fibres [17], b) Cross-section of "bamboo fibres" from yarn, c) Cross-section of "bamboo fibres" from knitted fabric, d) Cross-section of "bamboo fibres" from woven fabric (magnification 200×).*

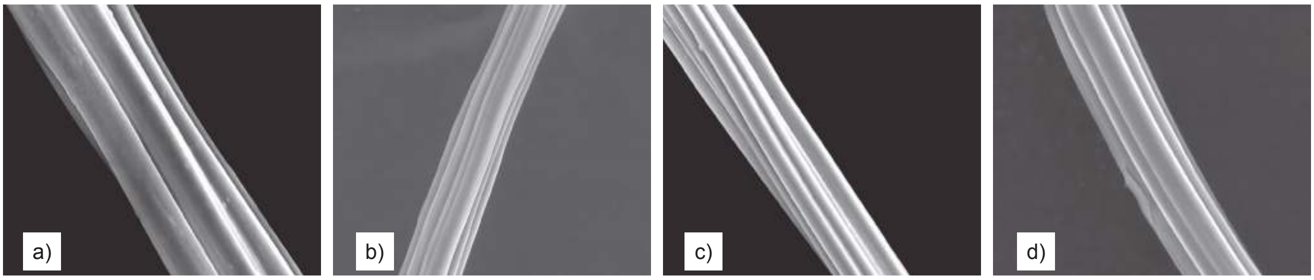

Figure 5. *Longitudinal view of the fibres investigated: a) viscose fibre, b) "bamboo fibre" from yarn, c) "bamboo fibre" from knitted fabric, d) "bamboo fibre" from woven fabric (weft), (magnification 6000×).*

again. The measurements were conducted at a magnitude of 600×. The swelling index was also determined (growth of fibre thickness after swelling in %).

Results and discussion

IR spectroscopic measurements

To determine the fibre's chemical structure, IR spectroscopy measurements were carried out. The results are presented in ***Figure 2*** and ***Table 1***.

Comparison of the IR spectrograms shows that all the fibres investigated were made from regenerated cellulose. Small changes in the intensity of characteristic absorption bands and their slight relocation may result from the different chemical treatment of the fibres during their earlier processing. Peaks, characteristic for regenerated cellulose, within a wavenumber value of 895 and 1421 cm^{-1} appear in the spectra of "bamboo fibres". Peaks of wavelength values in the range 1200-1400 cm^{-1} were found for the scissoring vibrations of groups C-H, O-H and CH_2 , characteristic for cellulose.

Optical microscopy observations

Having been extracted from yarns, the fibres were investigated under an optical microscope to determine their longitudinal and cross-section view. Results of the investigation are shown in ***Figures 3*** & ***4***.

In ***Figure 3*** we can see longitudinal views of "bamboo fibres" compared with viscose fibre. "Bamboo fibres" are visibly finer but very similar to those of viscose. Moreover the cross-section view shows the characteristic shape of viscose fibre (***Figure 4***). "Bamboo fibres" do not show any features of natural fibres.

Scanning electron microscopy observations

SEM investigation of fibres morphology establishes details of the fibre surface as a set of fibrilles, shown on ***Figure 5***. The images of "bamboo fibres" in comparison with standard viscose are very similar.

The surface of "bamboo fibres" is visibly more creased than that of viscose fibres because of the finer fibrillar structure.

WAXS measurements

The crystallinity degree of "bamboo fibres" was measured using the WAXS method. The results of the measurement obtained are presented in ***Table 2*** (see page 22).

The crystallinity degree of "bamboo fibres" was comparable with that of standard viscose fibre.

Measurement of the total fibre orientation

To determine the total orientation of the fibres, polarisation-interference microscopy was used. Results obtained for the "bamboo fibres" investigated are shown in ***Table 3*** (see page 22).

Table 2. Crystallinity degree of the fibres investigated.

Sample investigated	Degree of crystallinity, %
Viscose	36.1
“Bamboo fibre” from yarn	36.9
“Bamboo fibre” from knitted fabric	37.3
“Bamboo fibre” from woven fabric (warp)	38.0
“Bamboo fibre” from woven fabric (weft)	36.8

Table 3. Values of directional refraction indices $n_\perp$ and $n_{||}$ and the double refraction index for the fibres investigated [17].

Indicator	“Bamboo fibre” from		
	yarn	knitted fabric	woven fabric
$n_\perp$	1.512	1.514	1.513
$n_{\|\|}$	1.538	1.538	1.538
Δn	0.026	0.024	0.025

Table 4. Density of the fibres, and related degree of crystallinity.

Fibre/measured quantity	Density, g/cm³	Crystallinity degree, %
Viscose	1.518	46.1
“Bamboo fibre” from yarn	1.509	39.4
“Bamboo fibre” from knitted fabric	1.513	42.0
“Bamboo fibre” from woven fabric (warp)	1.506	37.3
“Bamboo fibre” from woven fabric (weft)	1.505	36.2

Table 5. Tenacity and elongation at break of the fibres investigated [17].

Value measured	Fibre			
	Viscose	“Bamboo fibre” from		
		yarn	knitted fabric	woven fabric
Tenacity, cN/tex	41.00	16.00	15.00	12.00
Elongation at break, %	24.27	17.06	15.18	17.23

Table 6. Increase in the thickness of the fibres under the influence of water over time [17].

Fibre/Time of swelling	“Bamboo fibre” from		
	yarn	knitted fabric	woven fabric
Increase in thickness over t = 1 min, %	31.3	35.0	35.7
Increase in thickness over t = 5 min, %	32.5	38.5	34.3

Analysis of the results obtained proves that the double refraction of the “bamboo fibres” investigated is comparable to the lower limit value of double refraction for standard viscose fibres (Δn = 0.025 - 0.044) [18]. The values of refraction in the transverse direction $n_\perp$ for “bamboo fibres” were slightly lower than for standard viscose ($n_\perp$ = 1.519 - 1.526) [18]. Refraction values for the parallel direction $n_{||}$ were not in the range assumed for viscose fibres ($n_{||}$ = 1.544 - 1.526) [18]; however, they were still very close. Lower values suggest a lower orientation of “bamboo fibres” in comparison with standard viscose fibres.

Measurement of fibre density

Fibre density results are presented in ***Table 4.*** In ***Table 4*** results for the crystallinity degree are also given. These results are based on the density of the fibres investigated and on the densities of the crystalline and amorphous matters of cellulose [19].

The density of the "bamboo fibres" investigated is very similar to that of viscose fibres, which does not confirm information from producers about the much lower density of “bamboo fibres” – 1.32 g/cm³ [20].

Measurements of tenacity and relative elongation at break

Results of the tenacity and elongation at break measurements are shown in ***Table 5***.

As is presented in ***Table 5***, the tenacity of “bamboo fibres” is more than two times lower than that of viscose, and the elongation at break is visibly lower for bamboo fibres than for viscose.

Evaluation of the fibres’ swelling kinetics

The swelling indices of the fibres in water after a swelling time of 1 and 5 minutes are presented in ***Table 6***.

In distilled water the crosswise size of the fibres increased by about 30% on average. Fibre from knitted fabric has the highest swelling value. At the same time the thickness of fibre from woven fabric did not increase. The very quick swelling process (independent of time) of this fibre can be the result of surface modification (molecular reorientation) during its cleaning process (the removing of polyamide dressing).

Conclusions

The investigation carried out proves that the “bamboo fibres” available on the market are not natural fibres derived from bamboo, but man-made viscose fibres from bamboo cellulose. “Bamboo fibres” are visibly finer than those of viscose, and the surface characteristic is also slightly different. Cross-sections of “bamboo fibres” are of a similar shape to that of viscose fibre cross-sections, the longitude view being also comparable. The chemical structure of “bamboo fibres” is close to that of regenerated cellulose. The strength and elongation at break of “bamboo fibres” is lower than for viscose, but the degree of crystallinity is comparable. Moreover their antibacterial properties can be denied. In the work of Wojciechowska and Włochowicz [21], socks made of 97% “bamboo fibres” did not show any antibacterial properties.

As can be seen, so-called “bamboo fibres” are in fact viscose fibres made from bamboo cellulose, which are comparable to viscose fibres in their morphological structure and properties.

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