

Novel Biocomposites with Feather Keratin

Abstract

This work deals with the preparation and characterisation of cellulose-keratin biocomposites. A method of manufacturing fibrous composite materials by wet spinning is presented. We used natural polymers, biomodified cellulose and keratin obtained from chicken feathers. Keratin waste is a potential renewable starting material. Spinning solutions were prepared from these polymers, and after filtration and aeration they were used for the formation of fibres and fibrils. The investigations included the preparation of biomodified cellulose-keratin spinning solutions of different keratin content, estimation of the influences of formation speed and drawing on the fibre properties, estimation of the sorption properties of the composites obtained. The biomodified cellulose-keratin fibres obtained are characterised by better sorption properties, higher hygroscopicity and smaller wetting angle, than those of cellulose fibres. The introduction of keratin into cellulose fibres lowered their mechanical properties, but they reach a level which enables the application of these fibres for manufacturing composite fibrous materials. Composting tests, carried out at 50°C, showed the better biodegradability of composite fibres than that of cellulose fibres. The biomodified cellulose-keratin fibrils are also characterised by better sorption properties than those of cellulose fibrils. As a result of the lyophilisation of composite fibrils cellulose-keratin sponges were obtained.

Key words: keratin, biomodified cellulose, composite fibres, fibrils, sponge, biodegradation.

Introduction

The strive to use less popular biopolymers, has, amongst other, increased interest in feather-derived keratin. Vigorous expansion in the manufacture of pharmaceutical and sanitary products has fostered a market demand for textile materials which manifest specific features like the ability to absorb and retain humidity. The keratin contained in feathers seems to be a promising candidate as raw material in the preparation of composite hygiene products.

Many publications identify innovative products, which include feather fiber keratin in their compositions [1 - 7].

The aim of our research work was to obtain different fibrous forms, such as fibres and fibrils, with a content of keratin extracted from chicken feathers. We chose cellulose already used to manufacture biocomposites for medical and hygiene applications as the second component. An assumption was made that by using the hydrophilic properties of keratin, the application of this biopolymer should result in the manufacture of fibrous composite materials with increased sorption properties.

The investigations included:

- preparing stable keratin solutions with an addition of cellulose,
- estimating the properties of the composites obtained.

Materials and reagents

Keratin

The raw material for obtaining keratin came from chicken feathers, which were characterised by the following contents:

- a sulphur content of 2.9%,
- a nitrogen content of 15.5%,
- an ash content of about 1%.

The method of obtaining keratin from chicken feathers is described in [8], whereas the properties of the keratin we used in this research are presented below:

- a sulphur content of 2.3%,
- a nitrogen content of 15.2%,
- a cystein content of 16,94 %
- a WRV of 155.5 %
- a sorption factor 188.5%
- an Mw of 144.6 kDa
- an Mw/Mn of 2.6
- colour, shape white powder.

Biomodified cellulose

The cellulose pulp used for obtaining biomodified cellulose is characterised by an polymerisation degree of DP = 670.

A commercial enzymatic preparation produced by AB Enzymes Oy (Finland) under the trade name of Econase CE was used as the bio-modifying agent.

The properties of the biomodified cellulose we used in this research are presented below:

- Solubility of cellulose Sa 99.7%
- Content of α -cellulose α_{cel} 93.9%
- Water retention value WRV 78.0%
- Average polymerisation degree DP 349.0.

The biomodification process is described in more detail in the European Patent [9].

The chemical agents used for obtaining the keratin were of analytical purity.

Methodology

Preparing biomodified cellulose spinning solution

The solution prepared was used for tests consisting of the formation of cellulose fibres and films [10]. To prepare an alkaline spinning solution, a biomodified cellulose pulp containing 75% of water is put into a 10.2% aqueous solution of sodium hydroxide, which also contains zinc oxide, urea and surfactants. The biomodified pulp is dissolved in a mixing tank equipped with a high-speed agitator and cooling jacket. The process is completed over 30 minutes at a temperature rising from 0 to 13 °C. The spinning solution obtained is filtered on a frame press through a standard filter cloth, as used in the viscose fibre industry, and then deaerated.

Preparing cellulose-keratin spinning solutions for fibres

Cellulose-keratin solutions were prepared by mixing the filtered and aerated alkali (6.24%) biomodified cellulose solution with an alkali keratin suspension. Alkali keratin solutions with different concentration within the range from 5% to 20% were also prepared. The keratin suspension was mixed with different ratios of the biomodified cellulose spinning solutions. In order to perform this, a keratin

suspension was added stepwise to the bi-modified cellulose solution, which was stirred by a low-speed agitator at 60 r.p.m for 30 min at a temperature of 20 °C.

Preparing cellulose-keratin spinning solutions for fibrils

The cellulose-keratin solutions were prepared by mixing the filtered and aerated alkali (6.24%) bi-modified cellulose solution with an alkali keratin suspension. The concentration of keratin suspension was 1.0 %. The keratin suspension was mixed with the bi-modified cellulose spinning solutions. In order to achieve this, a keratin suspension was added stepwise to the bi-modified cellulose solution, which was stirred by a low-speed agitator at 60 r.p.m for 30 min at a temperature of 20 °C.

Forming cellulose-keratin fibres

Cellulose-keratin fibres were manufactured using a laboratory spinning machine for wet spinning. An alkaline solution containing a mixture of cellulose and keratin was placed in a pressure container, and next fed to a spinning head with a gear pump of 1.2 ml/min yield. A polymer solution was introduced into a coagulation bath with a yield of 18.6 cm³/min through the spinning head, which equipped with a 300-hole platinum-rhodium spinneret and with hole diameters of 80 µm. The fibres were spun in the coagulation bath, containing H₂SO₄, with a concentration of 120 g/l and Na₂SO₄ with a concentration of 75 g/l at a temperature of 25 °C.

The fibres were spun at a speed of 29.4 m/min, and at a drawing degree from 26% to 40% in air, or water at a temperature of 25 °C and 35 °C. The fibres, after conducting through a washing bath, were taken out in the shape of a hank, and then processed by introducing a preparation containing Honol with a concentration of 7 g/l in water. The fibres were next dried in a free state at room temperature. The

Table 1. Spinning speeds and drawing conditions of the cellulose-keratin fibres; Cel 10 – control test – forming pure cellulose fibres; Rkn/m – cellulose-keratin fibres, drawing in water at a temperature of 25 °C (I) or 35 °C (II).

Fibre symbol	Spinning speed, m/min	Drawing conditions	
		Drawing, %	Medium
Cel 10	29,4	27,3	water
Rk-27/1	29,4	29,1	air
Rk-27/2	29,4	27,3	water (II)
Rk-28/1	29,4	40,1	water (I)
Rk-28/2	20,4	26,0	water (I)

spinning speeds and drawing conditions of the cellulose-keratin fibres are presented in Table 1.

Manufacturing cellulose-keratin fibrils

In order to obtain fibrils at laboratory scale, we used a stand composed of a pressure container, a spinning head with a spinneret, an agitator and a container with a coagulation bath. The aerated spinning solution was placed in the pressure container, from which it was fed to a gear pump with a yield of 0.6 cm³/rotation and 1.2 cm³/rotation; this ensured constant and regular feeding of the solution to the spinneret. A 600-hole spinneret with holes of 60 µm diameter was used. The polymer solution flowed from the spinneret, which is placed in the spinning head into the coagulation bath. The coagulation bath contained H₂SO₄, with a concentration of 80 g/l, an addition of Na₂SO₄ and a concentration of 100 g/l.

The agitator of a Turax-type homogenisation device, with rotary speed of 4,000 r.p.m, was positioned at a specified distance above the spinneret in order to guarantee a speed of the coagulation bath flow which could force the breaking of the solidifying spinning solution stream. The fibrils obtained were separated from the coagulation bath, put into methyl alcohol for about 1 hour, and next after centrifuging it, washed several times in water and lyophilised.

The lyophilisation of cellulose-keratin fibrils in sponge form

Lyophilisation was carried out over 25 hours with the use of an Alpha 1-4 type lyophilisator from Christ Co., at an initial plate temperature of -20 °C and a final temperature of 10 °C, whereas the preparation temperature was within the range of 2 °C to 6 °C.

Biodegradation test of the fibres

Studies of the biodegradation of the samples were done in compost medium in oxygen conditions. Determinations were carried out according to the procedures elaborated at IBWCh on the basis of international standards [11, 12].

The compost used in the experiment was taken from a municipal compost plant after a period of turbulent maturing. The process was conducted at lab-scale in a container of 120 l, at 55 °C, 65% RH with periodic aeration. Air was introduced once a day for 1 hour, at a flow rate of 10 l/min. After a defined time of biodegradation, the samples were sub-

jected to sterilisation in a 3% hydrogen peroxide solution. The samples were next washed with distilled water and dried until constant weight. Finally the samples prepared were measured for loss of weight.

Analytical methods

Microscope analysis of the spinning solutions

The solutions of cellulose, keratin, and cellulose-keratin were assessed with the use of a Biolar-type polarisation microscope from ZPO Warsaw, with an adapter which enables photos of the images observed to be taken. A system of digital image analysis from IMAL was used to monitor the images.

Assessing the dynamic viscosity of the solutions

The dynamic viscosity of the spinning solutions was assessed with the use of a LVF Brookfield viscometer.

Assessing the water retention value (WRV)

The water retention value was assessed according to the standard method [13].

Assessing the sorption coefficient

The sorption coefficient was assessed according to the standard method [14].

Testing the moisture absorption

Testing the moisture absorption of cellulose and cellulose-keratin samples was carried out by placing them in an exsiccator of 65% moisture (NH₄NO₃) at a temperature of 20 °C. The sample mass was assessed as a function of the time served to monitor the moisture sorption. After stabilising the sample mass at an approximate constant level, which means full saturation of the samples by moisture under the given conditions, the samples were placed in an exsiccator with a relative humidity of 93% (KNO₃), and changes in the sample masses over time were assessed. Next, after stabilising the sample masses at an approximately constant level for the second time, they were again placed in the 65% moisture exsiccator, and the moisture desorption of the samples tested were determined.

Determining the content of sulphur and nitrogen

The nitrogen content was determined by the Kjejdahle method, whereas the sulphur content was determined by the Sheniger method [15, 16].

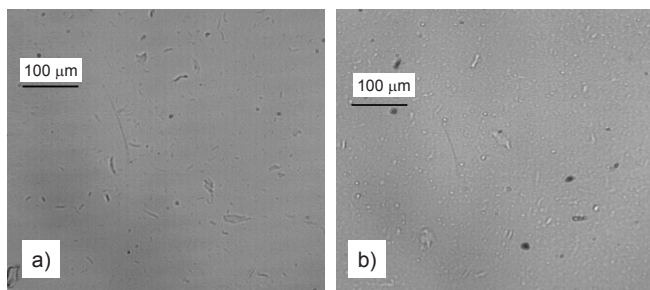


Figure 1. Microscopic photos of: a) alkaline keratin solution, b) cellulose-keratin solution (RK 27) used for manufacturing fibres.

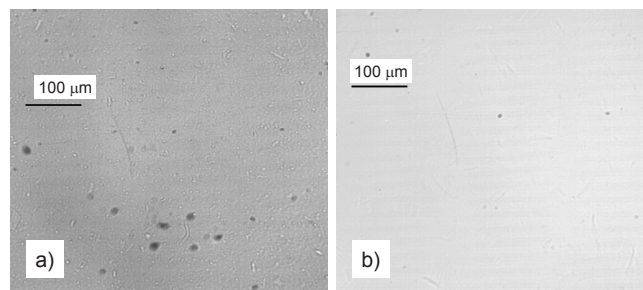


Figure 2. Microscopic photos of: a) keratin solution after dialysis, b) cellulose-keratin solution for manufacturing fibrils (Fib CK 4).

Evaluating the surface of the cellulose-keratin composite materials by scanning electron microscopy (SEM)

SEM observations were carried out with the use of a Quanta 200 SEM from FEI at a magnification of 2,000×. Structural investigations were performed under a high vacuum, in a natural state, without gold sputtering. The area of the fibres and cross-section surface were measured with the use of an analySIS Docu software program from Soft Imaging System.

Assessing the wetting angle of the fibres

Tests to determine the wetting angle of the fibres were performed in relation to glycerol, whose polar properties and surface tension are similar to those of water. The wetting angle measurements were conducted after a time of 60s from the moment of deposition of the drop [17].

Determining the hygroscopicity of the fibres

The hygroscopic properties of the fibres manufactured were determined at the IBWCh, in the Analytical Laboratory, which has the Good Laboratory Practice certificate GLP G016, in accordance with Standard PN-80/P-04635:1981.

Estimating the mechanical properties of the fibres

The mechanical properties of the fibres manufactured were determined at the IBWCh, in the Laboratory of Metrology, which has certificate Nr. AB 388 of the Polish Accreditation Centre (PCA), in accordance with Standards PN-ISO-1973:1997 and PN-EN ISO 5075:1999.

Determining the amount of free thiol groups of cysteine residues (-SH)

The amount of free thiol groups of cysteine in a/the solution of feather keratin was measured by using a DTNB-assay (Ellman's reagent or 5,5'-dithio-bis(2-nitrobenzoic acid). This is spec-

trophotometric analysis. The absorbance was measured at 412 nm [18]. A molar extinction coefficient of 13600 M⁻¹ cm⁻¹. was used to calculate the amount of free thiol groups according to

$$A = \epsilon \times c \times l$$

where: ϵ - molar extinction coefficient [M⁻¹ cm⁻¹], c - concentration, l - thickness of cuvette.

Results and discussion

Obtaining the cellulose-keratin spinning solutions

The cellulose-keratin spinning solutions with different keratin contents were prepared according to the procedure described. The properties of the solutions which were dedicated to fibre formation are presented in Table 2, whereas those of the cellulose-keratin solutions which were applied for composite fibril manufacture are shown in Table 3.

Microscopic photos of the solutions used for manufacturing cellulose-keratin fibres are presented in Figure 1, whereas Figure 2 presents microscopic photos of keratin solution after dialysis and cellulose-keratin solution for manufacturing fibrils.

The keratin content influenced the properties of the spinning solutions in a different way.

It should be stressed that irrespective of the keratin content introduced into the spinning solutions, the keratin particles did not dissolve, which is visible in the photo in Figure 1. Adding the aqueous keratin suspension to the spinning solution caused a drastic drop in viscosity in the cellulose-keratin spinning solutions. Assessing the dynamic viscosity, these solutions were impossible.

Microscopic analysis of the cellulose-keratin spinning solutions

Alkaline keratin suspensions of different polymer concentrations were prepared, and in this way, keratin, in the shape of a suspension, was introduced into the cellulose spinning solution in different proportions. Previous investigations proved that solutions prepared for fibril formation should be characterised by a polymer concentration of about 1.0%. In order to estimate the quality of the cellulose-keratin solutions prepared, they were all analysed with the use of an optical microscope (Figures 1 and 2).

Table 2. Properties of cellulose-keratin spinning solutions used for fibre formation; Cel 10 - cellulose spinning solution, RK 27, RK 28 - cellulose-keratin spinning solutions.

Symbol of spinning solutions	Total polymer content, wt. %	Keratin content, wt. %	NaOH content, wt. %	Brookfield viscosity, cps
Cel 10	6.22	0.0	7.72	6500
Rk 27	6.28	3.0	7.12	4750
Rk 28	6.06	2.6	7.15	5250

Table 3. Properties of cellulose-keratin spinning solutions dedicated to fibril manufacturing; Cel 11 - cellulose spinning solution, FibCK2 ... 4 - cellulose-keratin spinning solutions.

Symbol of spinning solutions	Total polymer content, wt. %	NaOH content, wt. %	Brookfield viscosity, cps	Keratin content wt. %
Cel 11	6.36	7.80	-	0.0
FibCK 2	1.06	5.05	13.0	0.13
FibCK 3	1.26	5.15	21.3	0.15
FibCK 4	1.59	5.28	36.0	0.25

Table 4. Mechanical properties of cellulose-keratin fibres.

Parameter tested	Fibre symbol			
	Cel 10	CK27/1	CK27/2	CK28/2
Linear density, dtex	1.91	2.78	3.28	3.61
Coefficient of variation of linear density, %	3.04	1.01	3.45	3.19
Breaking force of fibres in conditioned state, cN	2.56	1.84	2.13	3.07
Coefficient of variation of breaking force in conditioned state, %	7.36	20.2	16.3	18.2
Tenacity in conditioned state, cN/tex	13.4	6.62	6.49	8.50
Elongation at break in conditioned state, %	32	14	16	22
Coefficient of variation of elongation at break in conditioned state, %	17.4	33.6	21.4	28.3

Investigation into the process of cellulose-keratin fibre formation

A laboratory spinning machine for wet spinning was used for manufacturing cellulose-keratin fibres according to the procedure described in methodology. The conditions for cellulose-keratin fibre formation are presented in Table 1. Next the fibres obtained were tested by assessing the mechanical properties, estimating the sorption properties by measuring their hygroscopicity and wetting angle, and evaluating these composite fibres using the SEM method. Also, studies of biodegradation of the cellulose-keratin fibres were done.

The mechanical properties of cellulose and cellulose-keratin fibres are presented in Table 4. The process of cellulose fibre formation was stable, and the fibres obtained were characterised by the following mechanical properties: a tenacity of 13.4 cN/tex and elongation at break of 32%.

The processing of cellulose-keratin fibres was not so stable, compared to that of cellulose fibres: fibre breaks appeared periodically during the drawing process, as well as disturbances consisting of elementary fibre breaks within the spinneret range. With the increase in the keratin content in the spinning solution, we noted a worsening of the fibre formation process conditions, and also, as a result, a decrease in the tenacity and elongation at break, as well as a worsening of the coefficients of variation of these parameters.

The increase in linear density in relation to the value assumed (2.0 dtex) in the case of some samples may be caused by the chocking of a number of the spinneret holes during fibre spinning (we indicated a pressure increase in the spinning solution before the spinning nozzle), and by worsening finish process conditions; we noticed that parts of the monofilaments

were difficult to separate. The drawing process of the cellulose-keratin fibres was carried out in two variants, in water and in air, as we expected that the manner of conducting the drawing process may influence the mechanical properties of the fibres obtained, as well as the degree of retaining keratin in the fibres. From the data presented in Table 4, we can conclude that the fibres drawn in water and air have similar tenacity and elongation at break, but the fibres drawn in water have greater linear densities, which may be the result of a higher tendency of these fibres to glue to each other, caused by greater difficulties in conducting the process of finishing them.

Summarising, it should be stated that the mechanical properties of the composite cellulose-keratin fibres were essentially

Table 5. Hygroscopic properties of cellulose-keratin fibres; Cel - cellulose fibres, CK - cellulose-keratin fibres.

Fibre symbol	Nitrogen content, wt. %	Hygroscopicity, %	Wetting angle, deg
Cel 10	0.0	40.4	27.3
CK 27/1	1.7	43.7	26.8
CK 27/2	2.6	44.7	25.8
CK 28/2	2.7	45.9	25.0

worse in comparison to the properties of non-modified cellulose fibres. The cellulose-keratin fibres manufactured were characterised by the following mechanical properties:

- a linear density of 2.78 – 3.61 dtex,
- tenacity in conditioned state from 6.49 cN/tex to 8.5 cN/tex,
- elongation at break from 14% to 22%.

Table 6. Properties of cellulose-keratin fibrils.

Fibril symbol	Symbol of spinning solutions	Nitrogen content, wt. %	WRV, %
Cel 11		0.0	98.87
F - CK 12	FibCK 2	0.95	133.50
F - CK 19	FibCK 3	1.95	177.0
F - CK 20	FibCK 4	2.38	186.47

On the basis of the results obtained (Table 5), it can be stated that the modification of cellulose fibres evaluated on the basis of nitrogen content, changes in hygroscopicity, and values of the wetting angle can be observed for all cellulose-keratin fibres. The cellulose-keratin fibres obtained are characterised by better sorption properties: higher hygroscopicity (45.9%) and smaller wetting degree (25 deg), compared to cellulose fibres, for which the hygroscopicity is equal to 40% and the wetting angle is 27.3 deg. The property changes differ depending on the keratin content added.

Evaluation of the cellulose-keratin fibrils

The properties of the cellulose-keratin fibrils were evaluated by assessing the nitrogen content, estimating the sorption properties (Table 6), and by analysing SEM photos. Depending on the keratin content in the ready-to-use spinning solution, the nitrogen content in the cellulose-keratin fibrils varied within the range of 0.95% to 2.38%.

The WRV coefficient changed within the range of 133% to 186%; for comparison, the WRV of cellulose fibrils is 98.9%. A different method of evaluating the sorption properties is testing the moisture absorption. The kinetics of this process was tested for selected cellulose-keratin fibril samples, and for comparison with cellulose fibrils. The sorption and desorption curves are presented in Figure 3. The sorption process under the condition of 65% RH is not intensive, and a greater jump does not appear until the samples are placed in an exsiccator of 93% RH. The highest absorbing capacity was observed for the cellulose-keratin fibril sample

Evaluating the cellulose-keratin fibrous composite materials by the SEM method

The cellulose-keratin fibrils in sponge form are presented on Figures 3.

In order to evaluate the surfaces and cross-sections of the cellulose and cellulose-keratin fibres and the general view of the fibrils obtained, microscopic ob-

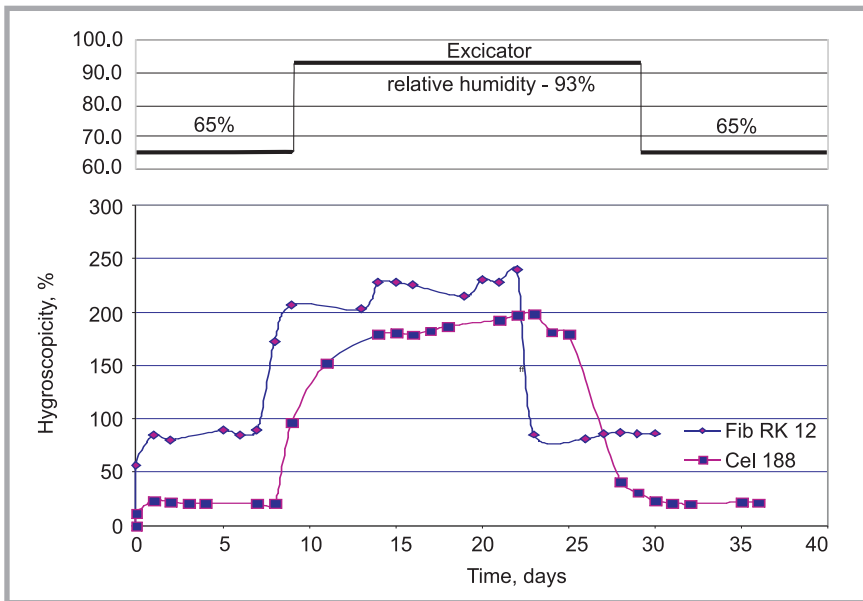


Figure 3. Sorption and desorption curves of cellulose and cellulose-keratin fibrils.

servations were carried out by the SEM method. The photos are presented in Figure 4 - 7.

Numerous longitudinal grooves are visible on the surfaces of cellulose fibres (Figure 6a), at least some on each fibre.

The character of these grooves on the cross-sections of cellulose fibres is readily apparent (Figure 5.a). The average area of fibre cross-section is $124 \mu\text{m}^2$. Even more numerous (up to several dozen) are the grooves on the surfaces of the cellulose-keratin fibres, but they are not as deep (Figure 6.b). On the other hand, a smaller amount of greater flat depressions is visible on the

photo of the cross-section of cellulose-keratin fibres (Figure 5.b), compared to the cross-section of cellulose fibres (Figure 5.a). The average area of the fibre cross-sections of cellulose-keratin fibres is $192 \mu\text{m}^2$. Nevertheless, it can be stated that cellulose-keratin fibres have a more developed surface than cellulose fibres. Spots darker than the background are visible (Figures 5.b) on the surfaces of the cross-sections of cellulose-keratin fibres. These spots are keratin which had been added to the spinning solution in the form of a suspension.

The differences between cellulose and cellulose-keratin fibrils are clearly visible on the photos presented in Figure 7.

Cellulose-keratin fibrils are thinner and shorter than cellulose fibrils (see the numerous short and thin fibrils in Figure 7.b).

Biodegradability

Acomposting environment is very interesting as a biodegrading medium for many reasons, such as the presence of a wide spectrum of microorganisms and the relatively high temperature of biodegradation. Besides this, composting treatment at adequately matched conditions seems to be an appropriate method of organic waste and biodegradable polymer utilisation.

An initial sample of cellulose/keratin fibrils was divided into three comparable parts and exposed to biodegradation. The results obtained after 3 weeks of the process are collected in Table 7. The changes in the external appearance of the samples caused by biodegradation are given in Figure 8. As can be seen very easily, the results are very similar. After 22 days of biodegradation, the process of the two component fibrils was almost totally complete. Conversely, fibrils produced of cellulose were much more durable. A similar level of biodegradation was reached only after 6 weeks. Such results are in good agreement with our previous work [19].

Summary

Cellulose-keratin biocomposites in the shape of fibres and fibrils were obtained as a result of our investigations. It was

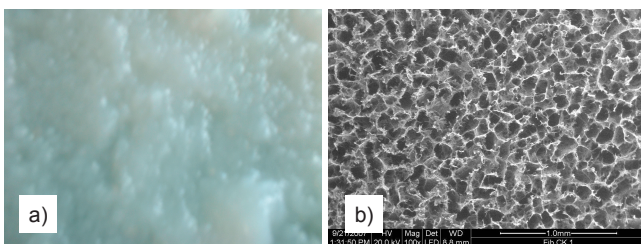


Figure 4. a) Photos of wet cellulose-keratin fibrils (never dried) b) SEM photos of the cellulose-keratin sponge.

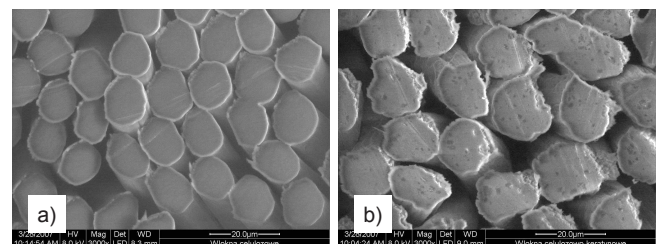


Figure 5. SEM photos of the fibre cross-sections: a) cellulose fibres, b) cellulose-keratin fibres.

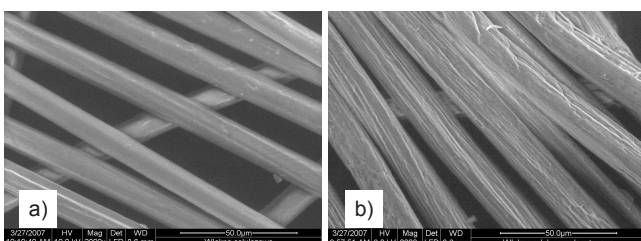


Figure 6. SEM photos of the fibre surface: a) cellulose fibres, b) cellulose-keratin fibres.

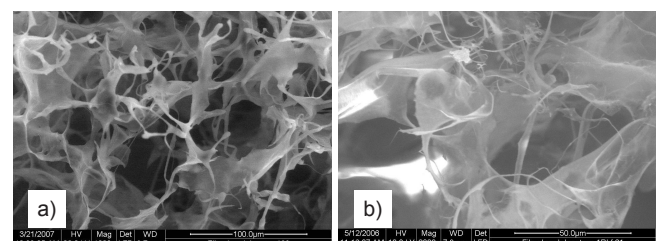


Figure 7. SEM photos of the fibrils: a) cellulose fibrils, b) cellulose-keratin fibrils.

Table 7. Compost biodegradation of cellulose and composite cellulose-keratin fibres.

Fibres symbol	Time of biodegradation, weeks	Weight loss, %
Cellulose fibres	6	94.1
Cellulose-keratin fibres	3	100.0

demonstrated that adding keratin improves the hygroscopic properties.

The cellulose-keratin fibres were characterised by the following mechanical properties:

- a linear density of 2.78–3.61 dtex,
- tenacity in conditioned state from 6.49 cN/tex to 8.5 cN/tex, and
- elongation at break from 14% to 22%.

The modification of cellulose fibres by adding keratin, evaluated on the basis of nitrogen content, the changes in hygroscopicity, and the value of the wetting angle, is evident for all cellulose-keratin fibres. The cellulose-keratin fibres obtained are characterised by better sorption properties: higher hygroscopicity and a smaller wetting angle than those of cellulose fibres. Also, the biodegradability of cellulose-keratin fibres is better than that of cellulose fibres.

Introducing keratin into cellulose fibres lowered their mechanical properties; decreased the tenacity by a factor of nearly two, and a significant decrease in elongation at break took place, but both parameters remained at a level which enables these fibres to be used for manufacturing composite fibrous materials. However, a further increase in the amount of keratin in the cellulose spinning solution over the values used in this research work

may essentially hinder the fibre formation process.

Depending on the keratin content in a ready-to-use spinning solution, the nitrogen content in cellulose-keratin fibrils varies within the range of 0.95% to 2.38%. The water retention value changes from 133.5% to 186.47%, as compared to cellulose fibres for which it is 98.87%.

Evaluating the view of cellulose-keratin fibrous composite materials by the SEM method, we noted that cellulose-keratin fibres have a more developed surface than that of cellulose fibres, whereas cellulose-keratin fibrils are thinner and shorter than alginate fibrils. Studies in progress indicate that this approach is highly promising and may lead to the production of a new range of fibrous composite materials with innovative properties and based on renewable natural resources.

Improving the sorption properties of the biocomposites obtained, creates opportunities to use them as hygienic fabrics.

Acknowledgment

The investigation presented in this paper was carried out as part of research project No. 3 T08 E 078 27 financially supported by the Polish Ministry of Science and Higher Education over the years 2004–2007.

References

1. Kar, P. „Keratin protein fiber for removal of heavy metals from solutions. M.Sc. Thesis. Reno, Nevada: Univ. of Nevada Reno, 2003.
2. Misra M., Kar P. “Novel approach to fabricate keratin sponge scaffolds with

controlled pore size and porosity”, *Biomaterials*, Vol. 25, Issue:18, August, 2004, pp. 4255-4262.

3. Barone, J.R.; Schmidt, W.F., “Polyethylene reinforced with keratin fibers obtained from chicken feathers” *Compos Sci Technol* 2005 pp. 173-181.
4. Papenburg, Bernke J.; Vogelaar, Laura; Bolhuis-Versteeg, Lydia A.M.; Lammer-tink, Rob G.H.; Stamatialis, Dimitrios; Wessling, Matthias, “One-step fabrication of porous micropatterned scaffolds to control cell behavior” *Biomaterials* 2007 pp. 1998-2009.
5. Barone, Justin R.; Schmidt, Walter F.; Liebner, Christina F.E., “Compounding and molding of polyethylene composites reinforced with keratin feather fiber” *Composites Science and Technology* 2005 pp. 683-692.
6. Wrześniewska-Tosik K., Wawro D., Stęplewski W., Szadkowski M., „Fibrous Products with Keratin Content”, *Fibres & Textiles in Eastern Europe*, Vol. 15(2007) No. 2 (61) pp. 30-35.
7. Barone, Justin R.; Schmidt, Walter F., “Effect of formic acid exposure on keratin fiber derived from poultry feather biomass” *Bioresource Technology* 2006 pp. 233-2428.
8. Wrześniewska-Tosik K., Adamiec J., “Bio-composites with a Content of Keratin from Chicken Feathers”, *Fibres & Textiles in Eastern Europe*, January / March 2007, Vol. 15, No. 1 (60) pp. 106-112.
9. European Pat. EP 122 8098.
10. Polish Pat. P. 340715, ‘Method for manufacturing fibres, films, and other products from modified dissolved’.
11. PN-EN ISO 14 855.
12. ASTM D 5338 – 98.
13. R Ferrus, P. Payes., „Water Retention Value and Degree of Crystallinity by Infra-red Absorption Spectroscopy in Caustic-Soda Treated Cotton”, *Cell.Chem.Techn.* 11,633, 1977.
14. ‘Testing the possibilities of manufacturing new composite biomaterials with keratin content’ (in Polish): Research report P-41, IBWCh, Łódź, 2004.
15. Common work, ed. Kłyszewko-Stefanowicz L., ‘Ćwiczenia z biochemii’, PWN, 1999.
16. Majewska J., ‘Sulphur assessing methods in fibre-grade polymers and co-polymers’ (in Polish): *Włókna Chemiczne, Chemia Analityczna, IWCh*, vol.13, No.29, 1968.
17. *Metrologia Włókiennicza*, ed. W. Szmelter, vol. 4, chapter 2, p. 67, WNT, Warsaw, 1973.
18. Peter M. M. Schrooyen, Piet J. Dijkstra, Radulf C. Oberthür, Adrian Bantjes, and Jan Feijen, „Partially Carboxymethylated Feather Keratins. 1.Properties in Aqueous Systems”, *J. Agric. Food Chem.* 2000, 48, 4326-4334.
19. M. Ratajska, S. Boryniec: “Physical and Chemical Aspects of Biodegradation of Natural Polymers”; *Reactive Polymers* 18 (1998) 35 - 49.

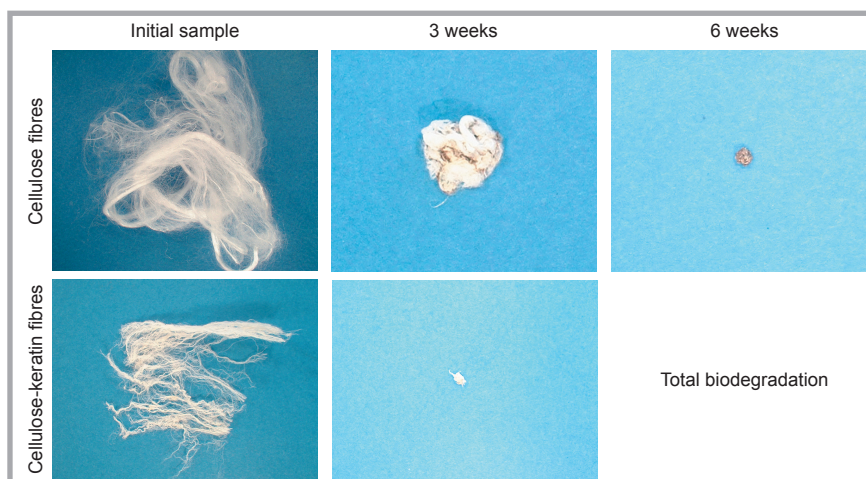


Figure 8. Compost biodegradation of cellulose and composite cellulose-keratin fibres.

Received 10.12.2006 Reviewed 16.11.2007