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OPTICAL PROPERTIES OF MODIFIED FABRICS INTENDED FOR PROTECTION AGAINST UV RADIATION

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ABSTRACT: *In recent years, there has been a progressive increase in the impact of ultraviolet (UV) radiation on human skin, caused by the depletion of the ozone layer in the Earth's atmosphere. Since long-term exposure to UV rays can lead to a number of negative consequences for human health, the development of textile products with the function of protection against UV radiation is relevant and widely developed among scientists and manufacturers. The paper proposes and investigates the method of "modification with metal nanoparticles", which consists in the chemical reduction of metal ions to metals directly in the structure of the textile material and on its surface. The research was carried out with copper sulfate. The optical absorption spectra of the textile samples were measured using a UV-Vis spectrophotometer (Cary 50, Varian, Australia) in accordance with the EN 13758-1:2002 standard with determination of the UV protection factor (UPF). The characteristics of the optical properties of unmodified and modified textiles were evaluated in the Commission Internationale de l'Eclairege L*a*b* (CIELab) color space using a 3NH NR-20XE colorimeter at D-65/10 radiation.*

Keywords: *UV radiation, textiles, optical parameters, UV protection factor.*

OPTIČKA SVOJSTVA MODIFIKOVANIH TKANINA NAMENJENIH ZAŠTITI OD UV ZRAČENJA

APSTRAKT*: Poslednjih godina primetno je progresivno povećanje uticaja ultraljubičastog (UV) zračenja na ljudsku kožu, izazvanog oštećenjem ozonskog omotača u Zemljinoj atmosferi. Budući da dugotrajno izlaganje UV zracima može dovesti do niza negativnih posledica po zdravlje ljudi, razvoj tekstilnih proizvoda sa funkcijom zaštite od UV zračenja je relevantan i široko razvijen među naučnicima i proizvođačima. U radu se predlaže i istražuje metod „modifikacije nanočesticama metala“, koji se sastoji u hemijskoj redukciji metalnih jona na metale direktno u strukturi tekstilnog materijala i na njegovoj površini. Istraživanje je sprovedeno sa bakar sulfatom. Optički apsorpcioni spektri uzoraka tekstila mereni su UV-Vis spektrofotometrom (Cari 50, Varian, Australija) u skladu sa standardom EN 13758-1:2002 uz određivanje UV zaštitnog faktora (UPF). Karakteristike optičkih svojstava nemodifikovanih i modifikovanih tekstila su procenjene u prostoru boja Komisije Internationale de l'Eclairege L*a*b* (CIELab) korišćenjem kolorimetra 3NH NR-20KSE na zračenju D-65/10.*

Ključne reči: UV zračenje, tekstil, optički parametri, UV zaštitni faktor.

1. INTRODUCTION

In recent years, there has been a progressive increase in the impact of ultraviolet radiation on human skin, caused by the depletion of the ozone layer in the Earth's atmosphere. As prolonged exposure to UV rays can lead to a number of negative consequences for human health, the development of textile products with the function of protection against ultraviolet radiation is relevant and widely developed among scientists and manufacturers.

Fabrics differ in their ability to attenuate UV radiation. Many factors influence this ability. The most important factors include the following: type of fiber, dye and decoration, type of weaving, porosity of the fabric, moisture content, as well as the degree of wear of the fabric [1, 2].

One way to improve the UV barrier properties of cotton fabrics is their modification. Recently, many studies [3, 4] have reported the functionalization of cotton fabrics by treating them with semiconducting metal oxides, such as titanium dioxide (TiO_2), zinc oxide (ZnO), and others. Numerical studies proved that cotton fabrics treated with TiO_2 and ZnO nanoparticles showed high and long-lasting protection against harmful UV radiation.

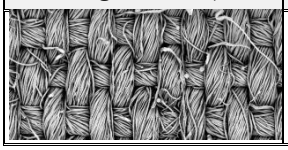
Taking into account the above, the aim of the study was to study the effect of the optical properties of non-modified and modified textile materials (TM) on their shielding ability against UV radiation.

2. MATERIALS AND RESEARCH METHODS

2.1. Non-modified textile materials

For the modification of textile fabrics, bleached cotton fabric of plain weave was chosen. The structural characteristics of the non-modified fabric are given in Table 1.

Table 1: Structural characteristics of non-modified TM «Cotton»

TM structure (SEM with ×100 magnification)	GSM, gram per sq. meter	Thickness, mm	Stitch density per 100 mm		Fineness of yarn (linear mass), tex	
			$П_{warp}$	$П_{weft}$	warp	weft
	110	0,37	300	200	20,0	26,3

2.2. Modified textile materials

For TM modification, the method of metal nanoparticle modification was used, which

consists in the chemical reduction of metal ions to metals directly in the structure of TM and on its surface. Studies were conducted with copper sulphate. The sequence of stages of the process of reduction of copper sulphate with glucose can be presented in the form of a scheme:

$$Cu^{2+} \xrightarrow{C_6H_{12}O_6;NaOH;t^\circ} Cu_2O \xrightarrow{NaOH;t^\circ} Cu$$

A detailed method of TM modification is given in [5].

2.3. Methods

Microscopic studies of unmodified and modified TM were carried out using a Tescan Vega 3 scanning electron microscope at the Technical University of Liberec, Czech Republic.

The optical absorption spectra of the textile samples were measured by UV-Vis spectrophotometer (Cary 50, Varian, Australia) in accordance with the EN 13758-1:2002 standard with determination of the UV protection factor (UPF) at the National Research & Development Institute for Textiles and Leather, Romania.

The characteristics of the optical properties of unmodified and modified TM were evaluated in the Commission Internationale de l'Eclairege L*a*b* (CIELab) color space [6] using a 3NH NR-20XE colorimeter under D-65/10 radiation. The CIE Lab system is a colour space of chromatic values that allows you to measure value and saturation along three coordinates (Fig. 1):

- L* – lightness. The vertical axis represents lightness; 100 represents a perfect white sample and 0 a perfect black;
- a* – The axis in the plane normal to L* represents the redness–greenness quality of the colour. Positive values denote redness and negative values denote greenness;
- b* – The axis normal to both L* and a* represents the yellowness–blueness quality of the colour. Positive values denote yellowness and negative values denote blueness.

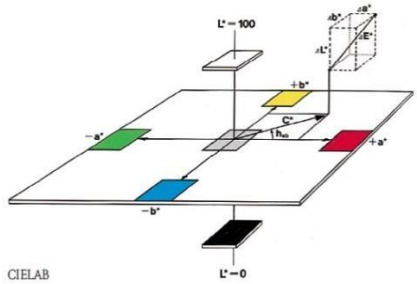


Figure 1: CIELab three-dimensional system [6]

A differentiated analysis of the total colour difference of non-modified and modified TM was carried out in the CIELab system according to colorimetric indicators:

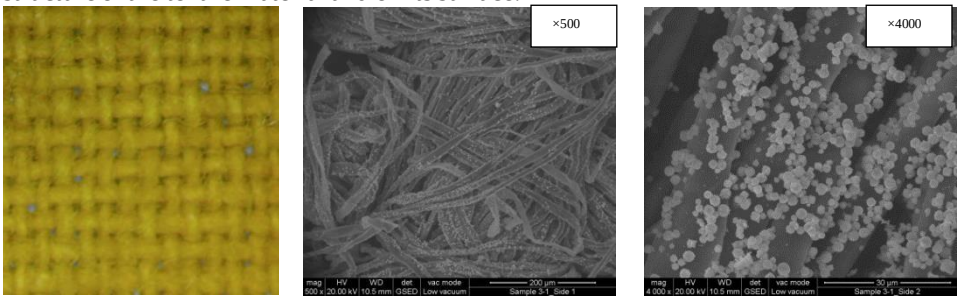
- Chroma: $C = [(a^*)^2 + (b^*)^2]^{1/2}$
- Hue angle: $H = arctg(a^*/b^*)$

– Lightness: $L^* = 25\left[100(y/y_0)^{1/3}\right] - 16$

– Colour difference: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$

3. RESEARCH RESULTS

Electron microscopy shows (Fig. 2) that impregnation of TM in a solution of metal salts with subsequent reduction of metal ions ensures the formation of metal nanoparticles in the structure of the textile material and on its surface.



a b c

Figure 2: The appearance of the modified TM::
a - «Cotton+Cu»; б - «Cotton+Cu» (SEM ×500); c - «Cotton+Cu» (SEM ×4000)

The UPF values of the investigated textile fabrics are shown in Table 2. It was established that the method of modification with metal nanoparticles allows obtaining TM with excellent protection against ultraviolet radiation (UPF 50+).

Table 2: UV protection factor (UPF) of the studied TM

Sample of TM	Transmission coefficient (T,%) in the region		Average value of UPF	UPF level	Characteristics of the textile according to the standard AS/NZ 4399:1996
	UVA	UVB			
Non-modified «Cotton»	10,142	16,855	5,81	5	«not protect»
Modified «Cotton+Cu»	-2,202	1,302	110,85	50+	«excellent protection»

The measure of the quality of TM modification and their aesthetics is the quantitative assessment of the colour of experimental textile samples using the CIELab system. In the CIELab system, any colour is defined by lightness (L*) and chromatic components: the parameter a*, which varies in the range from green to red, and the parameter b*, which varies in the range from blue to yellow. Colour characteristics of non-modified and modified TM are shown in Table 3.

Table 3: Colour characteristics of non-modified and modified TM (CIELab System)

Characteristics	Non modified TM «Cotton»	Modified TM «Cotton+Cu»	
Lightness, L*	93,30	50,07	Δ=-43,23
Green-red colour component, a*	0,18	19,67	Δ=19,49
Blue-yellow colour component, b*	0,65	45,99	Δ=45,34
Chroma, C*	0,68	50,02	Δ=49,34
Hue angle, H*	74,29	66,84	Δ=-0,76
Colour difference, ΔE			65,61

From the experimental data, it was established that for the non-modified TM «Cotton» the colour is characterized by the values of components a* and b* as yellow-red. In turn, it should be noted that the ratio a*/b*, which characterizes the main colour tone (H) for the TM «Cotton» sample, characterizes the colour as yellow with a red shade (the contribution of yellow is 3.6 times greater). The L* parameter for the non-modified «Cotton» sample is 93.30, which is close to 100 in value, and indicates a rich white colour of the original fabric.

In turn, the modification of the «Cotton» sample led to a significant change in the colour of the modified «Cotton+Cu» fabric. The modification of the fabric led to a significant darkening of the TM sample (L*=50.07). In the CIELab system, the determining factor is the value of two colour components: green-red and blue-yellow, the changes of which for the TM sample after the «Cotton+Cu» modification are given in Table 3. As can be seen from Table 3, for the modified "Cotton+Cu" sample, a significant increase in colored components is observed, which is due to the formation of copper nanoparticles in the structure and on the surface of TM (Fig. 2). The modification of the «Cotton» sample leads to an increase in the green-red component (a*) in the direction of an increase in the share of the red component colour, while the value of the blue-yellow component (b*) - in the direction of a significant increase in the share of the yellow component colour. For the sample TM «Cotton+Cu» a*=19.67 and b*=45.99, their ratio characterizes the colour as yellow with a red tint, which is why a decrease in L* is observed for this sample. Studies of the change in the saturation (chromaticity) of the C* sample showed that there is an increase in chromaticity from 0.68 (non-modified TM) to 50.02, which indicates, in combination with a decrease in L* and an increase in the values of the colour components (a* and b*) on significant yellowing of the sample, which is observed visually (Fig. 2).

The most complete information about the colour change in the CIELab system is provided by the "colour difference" (ΔE) parameter, which takes into account the change in brightness and two colour components of the sample. At the same time, it is considered that:

- at ΔE=0.0÷1.0 the difference is "invisible";
- at ΔE=1.0÷2.0 the difference is "easily visible";
- at ΔE=2.0÷4.0 the difference is "visible";
- at ΔE=4.0÷10.0 the difference is "clearly visible";

– at ΔE=> 10.0, the difference is "big".

As can be seen from the data in Table 3, the sample of the modified TM «Cotton+Cu»" has a colour that is visually different from the colour of the original unmodified TM «Cotton». At the same time, the colour saturation of the «Cotton+Cu» sample is higher, which indicates a large number of copper nanoparticles that are fixed in the TM structure and on its surface, which is confirmed by electron microscopy (Fig. 2).

4. CONCLUSION

Based on the results of previous studies, it was established that the ability of TM to shield UV radiation is influenced by many factors. The most important factors include the following: type of fiber, dye, type of weaving, porosity of the fabric, moisture content, colour. It was established that as a result of the chemical modification of cotton fabric with copper sulphate, the optical properties of TM change and affect the shielding properties. Thus, the modification of the «Cotton» sample leads to a decrease in L*. Studies of the change in the saturation (chromaticity) of the C* sample showed that there is an increase in chromaticity from 0.68 (unmodified TM) to 50.02, which indicates, in combination with a decrease in L* and an increase in the values of the colour components (a* and b*) on significant yellowing of the sample, which is observed visually. At the same time, the colour saturation of the «Cotton+Cu» sample is higher, which indicates a large number of copper nanoparticles that are fixed in the structure of TM and on its surface, which is confirmed by electron microscopy and provides high shielding properties of TM against the action of UV radiation (UPF 50+).

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