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Influence of Fabric Constructional Parameters and Thread Colour on UV Radiation Protection

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Abstract
The purpose of the research presented was to analyse the influence of the fabric surface cover factor and fabric colour values on the degree of UV ray transmittance and the UV protective factor (UPF). The research was carried out on lightweight coloured fabrics woven in sateen weave with different densities of warp and weft threads and with different colours in the weft. Measurements of the UPF were performed using the "in vitro" method in the range of UVA and UVB ray wavelengths, from 280 to 400 nm. The results of the research confirm the importance of the fabric surface openness for the UV protective factor and expose the influence of the fabric face and reverse sides as well as of colour values L, C^*_{ab}, h_{ab} of warp and weft threads on the UPF in sufficiently closed woven constructions. Namely, constructions with less than the 5% surface openness offer excellent protection (UPF above 50), whereas constructions with less than 10% surface openness offer good to very good protection (a UPF above 20). At coverage higher than 95%, the fabrics analysed could be generally divided into three groups with respect to the effectiveness of their UV protection: fabrics of darker colours (black, blue) with extremely high UPF values, fabrics of chromatic lighter colours (yellow, red, green) with UPF values half of those of darker colours in general, and white fabrics (bleached) in which the desired UPF values are not reached regardless of the degree of the cover factor.*

Key words: *woven fabrics, constructional parameters, cover factor, thread colour, UPF.*

Introduction

During the last decades, awareness of the effects and consequences of UV radiation, which have become even more damaging (different degrees of skin damage, including skin cancer) due to the thinning of the ozone layer, have led to an increased number and better quality of researches focused on protection against UV rays. Today, preventive measures are mostly recommended for defence and protection, such as avoiding exposure to UV rays (especially when their intensity is the highest), using natural and artificial protective shades, wearing suitable clothing, and last but not least, applying sunscreens. Effective protection can be the result of the activity of only one protective factor or of a combination of more factors. The paper is focused on UV protection obtained by wearing lightweight summer clothing, which would be fashionable, coloured or figured, comfortable to wear, and at the same time offer protection against UV rays. The researches which have been carried out in this area have proved that the protective efficiency of such clothing depends on several factors, such as the type of fibres, constructional parameters of the textile material, the colour of the material or fibres, as well as certain mechanical parameters, such as elasticity, moisture content, after-treatments and treatment of the fabric with UV absorbents [1, 2].

The investigations of various types of fibre carried out by the scientists Cox Crews et al., Curiskis & Pailthorp, and Davies et al. showed that, in general, cotton and viscose have a low ability to absorb UV rays. Among natural materials, wool had slightly better protective properties, whereas the protective properties of silk are, even compared to those of synthetic fibres, due to its low UV ray transmittance. There are, of course, differences between synthetic materials too. Thus, polyester fibres, which are made of aromatic components, have high absorbance, whereas polyamide fibres (PA 6 and PA 6.6) have lower absorbance [3 - 7].

The research presented in this paper focused on the analysis of cotton, which is the most suitable material for woven and knitted summer clothing. However, due to its low weight, cotton clothing does not have a sufficient protective function without subsequent treatment with the so-called UV blockers. Our study was based on the following findings of other researches:

- The construction of protective clothing should include an optimal combination of the following parameters: thickness, density, mass per unit area, weave and type of yarn used, which all together influence the most important property of textiles, i.e. their porosity (cover factor) [3, 4, 7, 8]. The weight and thickness of the material are another two factors which should be monitored. As a rule, fabrics with a higher weight and thickness absorb a higher amount of UV rays and, as a result, provide better protection. This fact is in contradiction with our purpose of making lightweight and thin clothing which would be able to block UV rays in summer time when UV radiation is the most intense. It should be noted that a higher weight and thickness do not always mean the higher compactness and closeness of a textile material.
- Researches have shown that fabrics woven in sateen weaves provide the best UV protection (in comparison with twills and weaves similar to plain weave) [9]. This can be explained by the composition of sateen weaves, which have the highest cover factor due to the specific arrangement of interlacing points, and also a different

shape of pores from twills and weaves similar to plain weave.

- The UV protection of differently coloured textiles or fibres is primarily influenced by the absorbing properties of dyestuffs within the UV range, which also depend on the dyestuff concentration. Thus, darker textiles are better absorbers than lighter textiles of the same construction [1, 10 - 12].
- Besides dyeing, there are other additional processes for textiles which have an impact on the chemical structure of fibres. The already mentioned studies of scientists Crews et al. [5] and Curiskisa, J. & Pailthorpe M. [6], in which they investigated the effect of bleaching, prove that bleaching considerably increases the transmittance of cotton textiles and aggravates their UV protection.
- On the basis of these findings, the aim of the research presented was to analyse, the possibility of imparting efficient UV protective properties to cotton textile products by selecting an adequate construction and proper colour. Experiments were performed on lightweight fabrics of sateen weave. By changing the warp and weft density and the weft colour, we changed the mass per unit area and openness of the samples and, consequently, influenced the change in the colour values of the woven fabrics. Our intention was to find out:How and to what degree the surface openness (opposite to the cover factor) influences UV radiation protection.
- At what degree of the surface openness/closeness sufficient protection is achieved, and at what degree excellent protection is achieved.
- At what degree of the surface openness/closeness the effects of differently coloured threads are manifested
- To what degree the colour effect of differently coloured threads influences UV radiation protection, which is also important for designing two- or multi-colour jacquard patterns?

Theoretical part

UV radiation

Ultraviolet rays (UV), the natural source of which is the sun, represent light of wavelengths from 100 to 400 nm of the electromagnetic spectrum. Ultraviolet spectral bands (UVA: 315 - 400 nm, UVB: 280 - 315 nm, UVC: 100 - 280 nm, far UV radiation and vacuum UV radiation), which all together represent the total UV radiation, differ in wavelength, energy and the effects they have on the cells of living beings. Vacuum, far UV and UVC radiation are energetically the most intensive; however, they do not reach the earth but are completely absorbed by the layer of atmosphere. The most important for research are the UVB and UVA bands, which are partly absorbed by the atmosphere - more UVB than UVA. This part of radiation reaches the earth and has by far more negative effects, such as photochemical damages to cellular DNA (UVB), erythema (sunburns), skin toughening and ageing, cataracts, and various types of skin cancer than positive effects (synthesis of vitamin D) [1, 13].

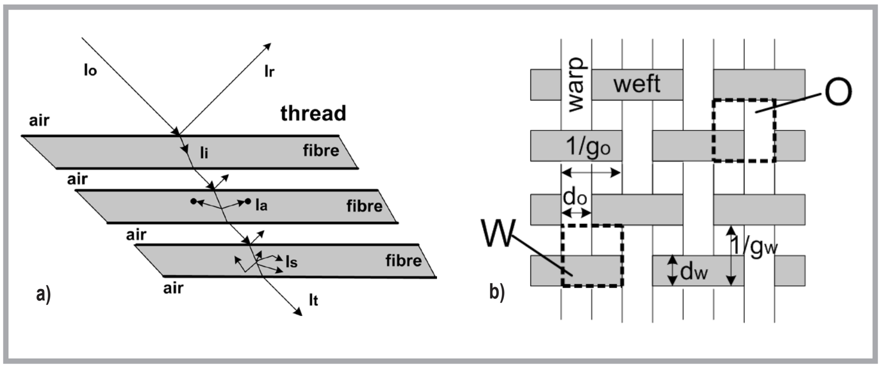


Figure 1. Interaction of light and textile material (a) [17] and scheme of the cover factor and open surface (b) [14, 15].

Cover factor and UV ray transmittance of textile material

Protective clothing is deemed a basic and the most advantageous method of protection against UV radiation, which protects a large part of the human body and has practically no side effects. Protective clothing should have as high UV ray reflecting and/or absorbing properties as possible so that it prevents UV rays from reaching the skin and threatening the human body. The key property for determining the quality of clothing protection (textile) is its transmittance. The transmittance of UV rays through textile material is defined as the ratio of the total amount of incidental UV rays in a defined wavelength range to the amount of transmitted UV rays reaching the skin.

Absorbing, transmitting and reflecting the properties of fabrics are determined primarily by the constructional parameters of textiles, such as the thickness, density, mass per unit area, weave and type of yarn, which all together influence the most important parameter – the porosity of fabrics or their cover factor [3, 4, 7, 8]. The cover factor is defined as the percentage of the fabric surface covered with warp *O* and weft *W* threads, or as a sum of the cover factor (share) of warp threads U_o and weft threads U_w threads ($U_o + U_w$), decreased for their cover section ($U_o \times U_w$). The cover factor is calculated from the diameter of the warp and weft threads (d_o and d_w) and distance between warp and weft threads $1/g_o$ and $1/g_w$ [14 - 16]. ***Figure 1.a*** shows the phenomena which might occur during the interaction between light and textile material, in which case Equation (1) applies. Incidental light I_o, which is refracted in fibre I_i, is the sum of reflected light on surface I_r, absorbed light in fibres I_a, and scattered light on particles I_s and transmitted light I_t [14]. ***Figure 1.b*** shows the scheme of the cover factor and contents of individual colour threads, which can be calculated with Equation (2) [14 - 16]. The sum of all shares of individual colour threads results in the cover factor of woven fabrics. Meanwhile, the open surface of the fabric is the one that is not covered with warp and weft threads.

$$I_o = I_r + I_a + I_s + I_t \qquad (1)$$

$$U_i = \frac{u_{on,ot} \cdot n_{on,wt} + u_{wn,wt} \cdot n_{wt,wi}}{n_{oi}} + \frac{u_{wn,ot} \cdot n_{ot,wi} + u_{on,wt} \cdot n_{wt,oi}}{n_{wi}} \qquad (2)$$

In Equation (2) U_i is the content of individual colour thread (warp *o*, weft *w*); *n* is the number of all points in a colour repeat; $u_{on,ot}$ is the content of warp thread colour at the warp interlacing point; $n_{ot,oi}$ is the number of warp points on the i colour warp threads; $u_{on,wt}$ is the content of warp thread colour at the weft interlacing point; $n_{wt,oi}$ is the number of weft points on the *i* colour warp threads; n_{oi} is the sum of warp and weft points on the *i* colour warp threads = $n_{ot,oi} + n_{wt,oi}$; $u_{wn,ot}$

is the content of weft thread colour at the warp interlacing point; $n_{ot,wi}$ is the number of warp points on the i colour; $u_{wn,wt}$ is the content of weft thread colour at the weft interlacing point; $n_{wt,wi}$ is the number of weft points on the i colour wefts; n_{wi} is the number of warp and the weft points on the i colour wefts $= n_{ot,wi} + n_{wt,wi}$. Equation (2) is actually the transform of the simple equation of cover factor ($d_o g_o + d_w g_w - d_o g_o \cdot d_w g_w$) in the case of different colours of warp and weft threads, and when the calculating cover factor, different colours of warp and weft threads are taken into account [14 - 16].

Ultraviolet protective factor (UPF)

The ultraviolet protective factor (UPF) is a numerical value which represents the degree of protection against UV rays provided by clothing. It is defined as the ratio of the amount of time needed to produce damage on skin protected with a textile material to the amount of time needed to produce such damage on unprotected skin. UPF is calculated by using Equation (3), where E_λ is the relative erythema efficiency, S_λ is the spectral radiation, T_λ is the mean measured transmittance of the sample, $\Delta\lambda$ is the measured wavelength interval in nm, and λ is the wavelength in nm [18 - 20].

$$UPF = \frac{\sum_{280}^{400} E_\lambda \cdot S_\lambda \cdot \Delta\lambda}{\sum_{280}^{400} E_\lambda \cdot S_\lambda \cdot T_\lambda \cdot \Delta\lambda} \qquad (3)$$

Classification of UPF values in conformity with Australian and New Zealand standards is presented in ***Table 1*** [19].

__Table 1.__ Classification of textiles by UPF.

UPF range	Classification	UV radiation transmittance, %	UPF labelling
15 - 24	good protection	6.7 - 4.2	15, 20
25 - 39	very good protection	4.1 - 2.6	25, 30, 35
40 - 50, 50+	excellent protection	< 2.5	40, 45, 50, 50+

__Table 2.__ Constructional and physical parameters, shares of warp and weft threads, and openness of the fabrics investigated.

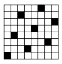
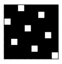
No. of sample	Weave Face Back	g_o, warp thr./cm	g_w, weft thr./cm	m, g/m^2	m, CV, %	Face side U_o, %	Face side U_w, %	Face side U_p, %	Back side U_o, %	Back side U_w, %	Back side U_p, %
1		40.0	59.0	158.0	0.8	0.15	99.85	0.00	61.83	38.17	0.00
2		40.0	42.0	131.2	1.1	23.45	71.08	5.47	67.35	27.18	5.47
3		40.0	35.0	120.0	0.7	31.98	59.24	8.78	68.57	22.65	8.78
4		40.0	29.0	110.4	1.9	39.29	49.08	11.63	69.60	18.77	11.63
5		40.0	24.0	102.4	0.9	45.40	40.62	13.98	70.49	15.53	13.98
6		36.0	28.0	102.4	1.0	36.46	47.88	15.66	62.81	21.53	15.66
7		31.0	24.0	88.0	2.0	35.18	41.56	23.26	54.62	22.12	23.26

__Table 3.__ Colour values and dyestuffs/bleaching agent of the warp and weft threads.

Thread	Colour	L*	a*	b*	Dyestuff/bleaching agent
Warp, Weft	blue	22.82	9.67	-34.55	Cibacron brillantblau FN-G Cibacron rot FN-R
Weft	red	37.63	47.22	16.70	Drimaren orange 4 GL Drimaren brillantrot K-4BL Drimaren rubinol K5 BL
	yellow	83.38	-0.39	79.36	Drimaren brillantgelb K-3GL
	green	38.05	-21.58	9.99	Cibacron gelb F4G Cibacron blau FR
	black	14.66	0.13	-2.03	Cibacron schwarz C-NN Cibacron marine FN-B
	white	96.79	4.56	-17.82	Hydrogen peroxide

Experimental part

Materials

The samples used for the research were designed and woven in eight-end sateen weave - $S\frac{1}{7}Z_3$. Their constructional parameters and some physical properties are given in ***Table 2***. The construction of the yarn used for warp and weft was identical: material – mercerised cotton, fineness - 8 × 2 tex, twists -1140/m S, mean value of the diameter of non-deformed threads - d = 0.187mm (CV = 14.179%).

Constructional and physical parameters of fabrics: density of warp threads g_o in threads/cm and weft threads g_w in threads/cm, theoretical shares of warp threads U_o in %, weft threads U_w in % (for face and reverse side), and open surfaces U_p in %, mass per unit area in g/m^2; which were determined according to ISO 3801 are given in ***Table 2***. The fabric constructional parameter report is based on 5 specimens per sample.

All fabrics in sateen weave with different constructional parameters were made with blue warp and differently coloured wefts: blue, red, yellow, green, black, and white. The colour values L*, a*, b* of the warp and weft threads, and the dyestuffs/bleaching agent used are listed in ***Table 3***.

Work methods

Measurements and calculation of open surface

The values of open surface/shining throughout the area (opposite to the cover factor) of the fabrics was determined theoretically by using a geometrical model and related theoretical equations given in the theoretical part [14 - 16]. The constructional parameters of the fabrics were considered, such as warp and weft thread density, warp and weft yarn thickness (thread fineness), and the weave or the ratio of warp to weft points in the weave repeat. These constructional parameters enabled the calculation of the coverage percentage of warp threads U_o in %, weft threads U_w in %, and surface openness U_p in %, which is given in ***Table 2***. It should be noted that deformations, which occur at threads interlacing, were not considered, therefore it is most probable that the actual value of the open surface was lower than the theoretically calculated one. This particularly applies to the samples with a maximum density in which a mistake in the theoretically calculated open surface would be the largest. The way that threads interlace in sateen weave also provides the maximum cover factor of weft threads, which also occurs due to deformations of these threads, the result of which is an increase in the thickness of the fabric. However, preliminary research on the reliability of this theoretical model gave an excellent correlation between the theoretically predicted cover factor of simple weaves and experimental results determined with image analysis [21].

Measurements of transmittance and reflectance

UV transmittance and reflectance values were measured using a Varian Cary 1E UV/VIS spectrophotometer, following the instructions of the AATCC standard [22]. From the UV transmittance and reflectance values, related values of UV absorbance and UPF were calculated by using Equation (3). The protective efficiency of the samples investigated was measured by the "*in vitro*" method. The transmittance and reflectance were measured by the spectrophotometer at intervals of 2 nm and within a wavelength range from 200 nm to 700 nm. For evaluation of the data concerning UPF values, transmittance, reflectance and absorbance, only values obtained for wavelengths 280 to 400 nm were taken into account. Measurements were carried out on each individual sample on its face side and reverse side in the warp and weft direction (5 measurements for each sample). Further analysis of the results considered the values of transmittance across the entire UV range and mean values of measurements in the warp and weft direction.

Measurements of colour values of surfaces

Colour values of the warp and weft threads of the woven fabrics were determined spectrophotometrically in conformity with the European standard for colorimetry - EN ISO 105-J01 [23] using a Spectraflash® SF 600 Plus-CT (Datacolor) spectrophotometer and Dcshell (Datacolor) software. Measurement parameters were D65, 10°, D/8, mean diameter of the round measuring opening 2 cm, mirror reflection included, 10 measurements.

Results of measurements

Due to a lack of space, the mean values of the measurements of transmittance - T, reflectance – R, the ultraviolet protective factor – UPF calculated for the face and reverse side of the samples and colour values L*, a* and b* evaluated for the face and reverse side of the samples will be given as figures based on the data mentioned in the discussion part. If readers want to see the exact data, they can obtain it from the authors in the form of fairly large tables, also containing the coefficient of variation for every measurement.

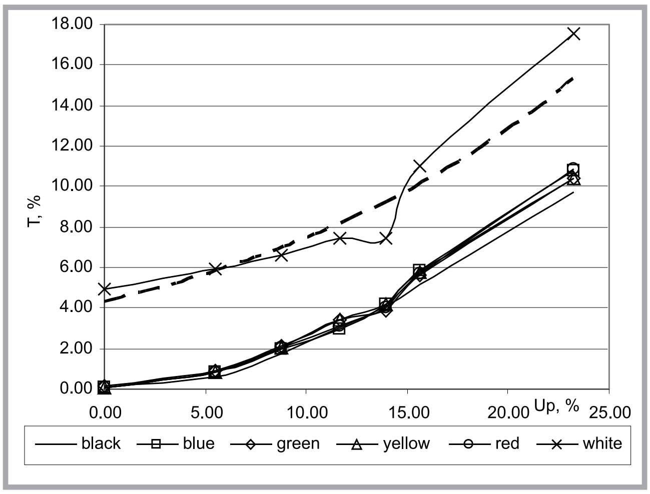


***Figure 2.** UV ray transmittance through samples with differently coloured wefts with dependence on their open surface.*

Discussion

Influence of the surface cover factor on the protective factor value

The influence of the open surface on the UV transmittance of the samples and, consequently, on their UPF is presented in ***Table 4*** and ***Figure 2***. It is evident that all samples made of coloured threads achieve, regardless of the colour, transmittance values lower than 2% at about 9% of the open surface U_p and values of about 1% at 5.5% of the open surface, which means the UPF value is about 100. Due to the non-absorbance of UV rays, the colour white provides insufficient protection across the entire range. The trend line (presented as a disconnected curve) clearly shows the parallel course of the curve of samples with white weft to other curves. The trend lines of other curves are not presented because they would spoil the appearance of the entire figure due to the overlapping of individual curves.

Samples 5 and 6 have the same mass per unit area, i.e. 102.4 g/m^2 (***Table 2***); however, their open surface differs by 1.68%, (13.98% and 15.66%) which results in a difference in transmittance of up to even 1.87% on average and, consequently, in a different protective factor of the samples made of different coloured threads (including fabrics with white weft threads). This proves that an open surface has a predominant influence on UV protection, and that the weight and thickness of a material, just like colours, have an influence only when open surfaces are equal and small enough.

Due to an extremely low degree of UV ray absorbance, the samples with white wefts do not provide sufficient protection, not even in the most tightly woven samples, despite the fact that in the fabric structure white wefts mix with blue warp threads, which have inherently good absorbing properties. The samples with the highest weft density, 59 wefts/cm, achieve 4.94% transmittance or a UPF value of 18.78 on the face side. This proves the importance of colour, its values and the effect of bleaching on UV radiation protection.

The correlation coefficients between the transmittance *T* in % and open surface U_p in % for samples with different colours of weft threads are presented in ***Figure 3***. Correlation coefficients r_{xy} 1 – 7 were calculated from all samples - from sample no. 1 to sample no. 7, while values r_{xy} 2 – 7 were calculated without considering sample no. 1 with the most closed surface (g_o = 40.0 thr./cm, g_w = 59.0 thr./cm, U_p =0.00%).

The correlation coefficients between the UPF and open surface U_p in % for samples with a different colour of weft threads are presented in ***Figure 4***. Correlation coefficients r_{xy} 1 – 7 were calculated for all samples - for sample no. 1 to sample no. 7. Correlation coefficients r_{xy} 2 – 7 and 3 – 7 were calculated without considering samples no. 1 and 2 with the most closed surface (sample no. 1: g_o = 40.0, g_w = 59.0, U_p =0.00%, sample no. 2: g_o = 40.0, g_w = 42.0, U_p = 5.47%), while values r_{xy} 1 – 5 were calculated from measurements of samples no. 1 – 5.

If we compare correlation coefficients between the transmittance and open surface (***Figure 3***), and between the UPF and open surface (***Figure 4***) of all seven samples, we find out that in the first case the correlation coefficients range around a positive value of 0.95, and in the latter

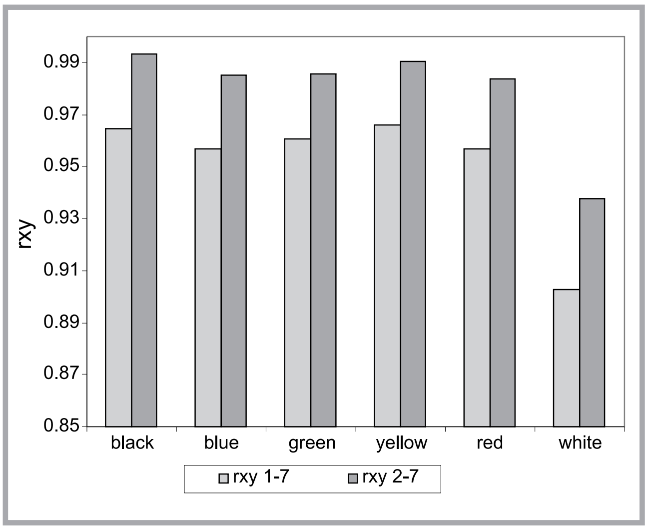


Figure 3. *Correlation coefficient values r_{xy} between UV ray transmittance through samples made of differently coloured wefts and the theoretical value of the open surface U_{p}.*

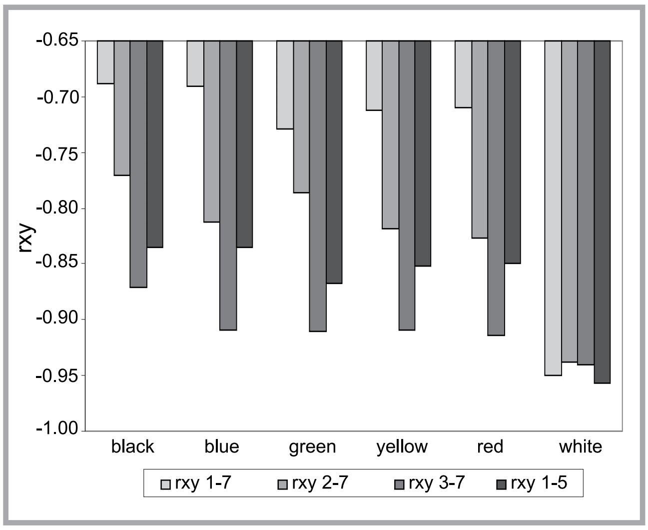


Figure 4. *Correlation coefficients between the UPF on the face side of samples made of differently coloured wefts and the theor. size of the open surface by considering various intervals of the open surfaces.*

case around a mean value of only -0.75. Since the UPF is a direct opposite function of the transmittance, the opposite sign of correlation coefficients is expected; however, we would expect lower differences between the values of correlation coefficients. Such high a difference between the values of correlation coefficients in the case of the transmittance and UPF can be explained by the fact that the real value of the open surface is lower than the theoretically calculated value. Moreover, the difference can also be attributed to the fact that besides the open surface, which has the most important role, it is also the weft colour which contributes to the UPF. Thus, the comparison of correlation coefficients between the transmittance and open surface of samples 1 – 7 and 2 – 7 (***Figure 3***) shows that the value of correlation coefficient increases by approximately 3% of its mean value when samples 1 (with the most closed surface) are excluded from the analysis. By omitting the measurements for sample 1, in which the colour of the material is most pronounced, the correlation between the transmittance and open surface slightly improves, and the correlation between the UPF and open surface improves by 8 to 18% and reaches a mean value of about -0.83. If only samples 3 – 7 are considered, the correlation coefficient between the UPF and open surface increases by a further 12% to the value of about 0.91. By omitting sample 1 first, and then samples 1 and 2, we tried to show how the correlation between the transmittance and UPF increases with an increase in the open surface, and how the UPF becomes less and less dependent on the thread colour. Moreover, it must also be stated that the statistical reliability of the correlation was confirmed by a t-test. In the case of the correlation between the transmittance and open surface, the t-test shows that there is more than 99% statistical certainty, which proves the strong connection between both parameters. On the other hand, the correlation between the UPF and open surface would be further proved with a greater number of measurements.

In ***Figure 4*** only the correlation between the UPF and open surface for samples 1 – 5 is presented. The correlation coefficients are higher than in the case where all samples are considered and achieve a mean value of about -0.87, i.e. very close to the value of the correlation coefficient in the case of samples 2 – 7. In this analysis samples 6 and 7 are omitted as they contain relatively different shares of coloured warp and weft threads than the first five samples - 1 – 5, in which the share of warp threads steadily increases (***Table 2***; values of U_o from 0.15% to 45.40%), and the share of weft threads is decreases (values of U_w from 99.85% to 40.62%). This is further proof that the ratio of colours of warp and weft threads on a fabric surface influences the reflectance, absorbance and transmittance of UV rays. Since only mean transmittance and UPF values, which were calculated on the basis of measurements on the face and reverse sides of fabrics, are considered in the cases presented in ***Table 4*** (see page 52) and ***Figures 3*** & ***4***, we will try to analyse more precisely the influence of colour on the basis of the measurements on the face side and measurements on the reverse side of the samples separately.

Influence of colour values of threads and woven surfaces on the protective factor value

The influence of thread colour and colour surface values on the UPF was investigated in two ways: first, by the integral investigation of all measured data, and second, by the investigation of the data obtained when the open surface of the fabrics is very small, and the protective functions of the colours are more expressed.

Figure 5 deals integrally with all data concerning the transmittance and reflectance of the samples measured on the face side of the fabrics (samples with white weft threads were not included in the analysis). It gives an explanation why in cases where the open surface values are higher than approximately 15.5%, the reflectance of the samples begins to fall, regardless of colour. The reason can be found in the interdependence of the open surface, reflectance and transmittance, which is presented in ***Figure 5***. We can conclude that the curves have practically three zones: the first zone (from 0 to 5.47% of the open surface) where due to the high cover factor of warp and weft threads, the transmittance and reflectance are at first low and then increase; the second zone (from 5.47 to 15.66% of open surface) where the reflectance is almost constant, and the transmittance increases almost proportionally with an increase in the open surface; and the third zone (more than 15.66% of open surface) where the reflectance decreases, and the transmit-

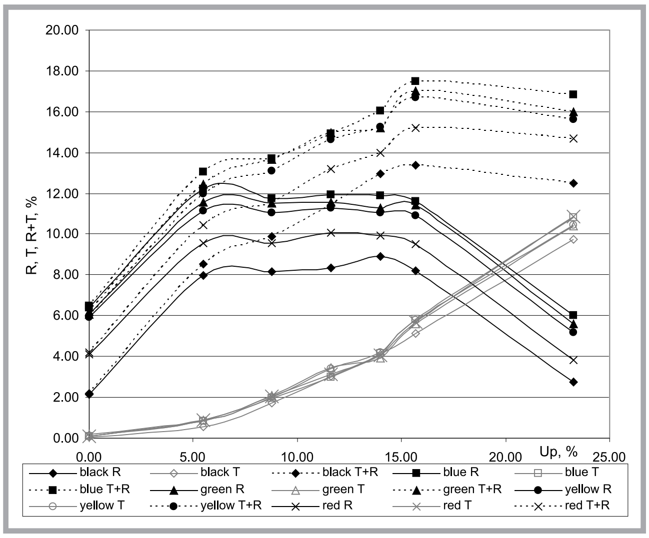


***Figure 5.** Diagram of reflectance R, transmittance T and the sum of the reflectance and transmittance R+T of samples made of coloured threads, measured on the face side with dependence on their open surface U_p.*

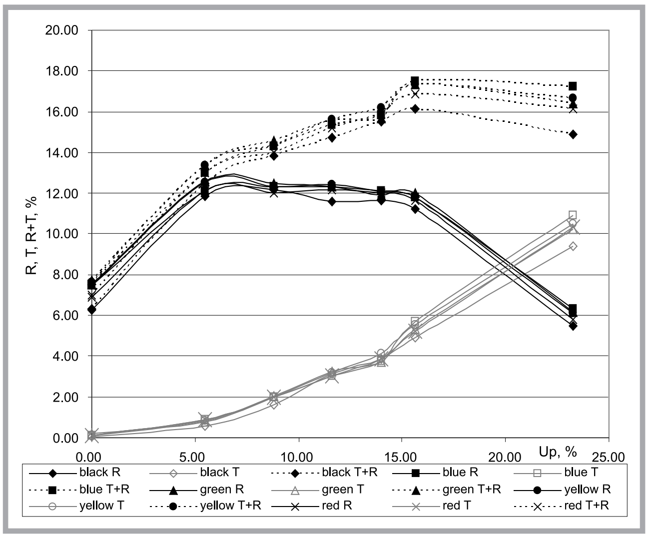


***Figure 6.** Diagram of reflectance R, transmittance T and the sum of the reflectance and transmittance R + T of samples made of coloured threads, measured on the reverse side with dependence on their open surface U_p.*

tance increases at almost the same rate, therefore their sum ($R + T$) remains practically constant all the time with only a slight tendency to fall.

Differences between the reflectance values of samples with different weft colours, which occur in the area of constant reflectance, range, with dependence on the colour, from 8% in the case of black weft to 12% in the case of blue weft. The reflectance values of samples with all other colours in weft are within the interval of 4%. It is very difficult to estimate the influence of an individual colour and its relation to the UPF because reflectance values are mainly influenced by the quality of the surface and shares of colour threads on the face side of a fabric, whereas absorbance values are strongly influenced by threads located deep in the

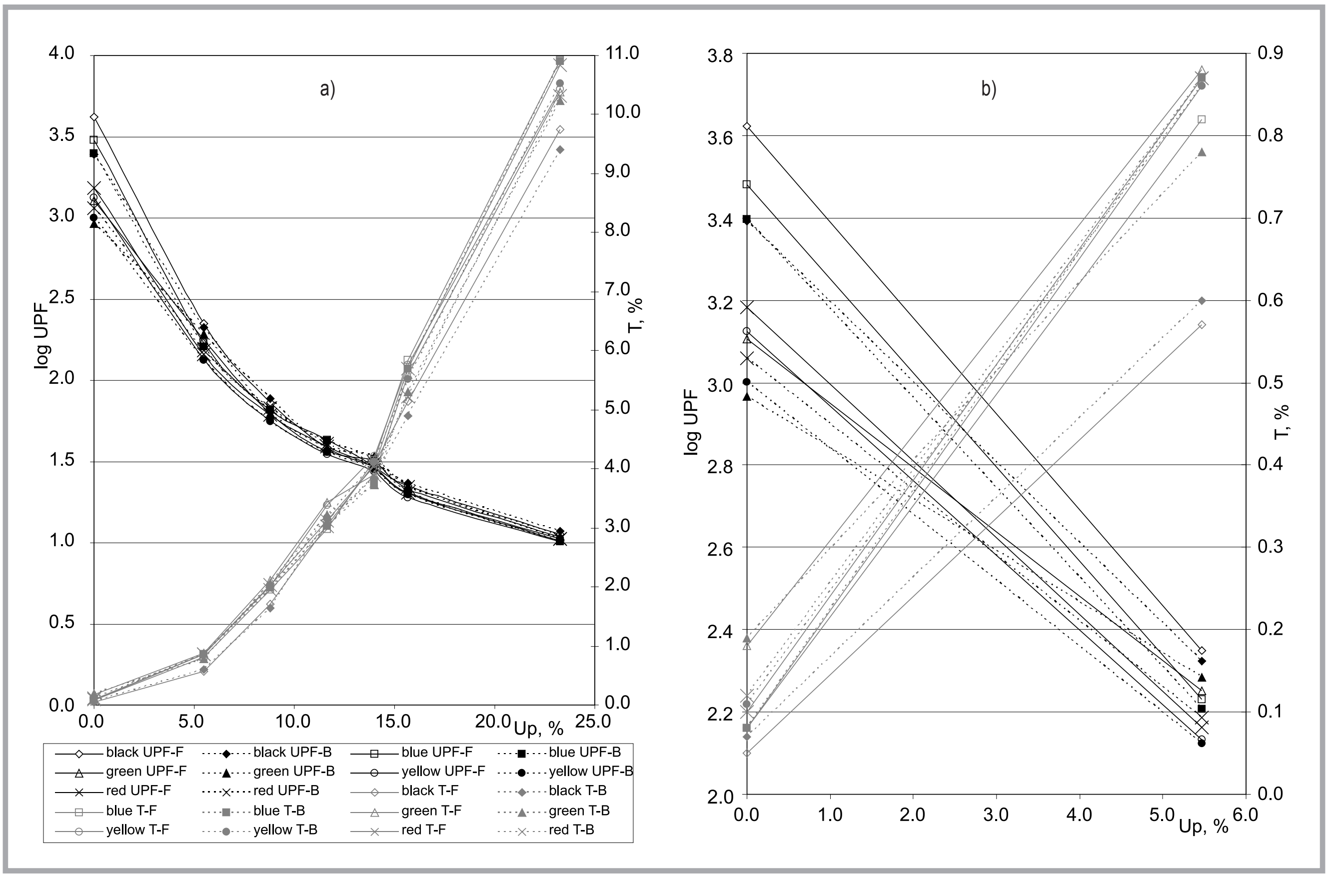


***Figure 7.** (a) UPF (left y axis) and transmittance T (right y axis) of face F and back B side of samples made of coloured threads with dependence on the open surface U_p; (b) UPF (left y axis) and transmittance (right y axis) of samples made of coloured threads within the range of the open surface, from 0 to 5.47% of the open surface.*

fabric and their absorbing properties, provided, of course, that the the difference between 100% radiation and the sum of the measured transmittance and reflectance is taken into consideration. However, it is expected that the extent of the influence of thread colour is exhibited only in the absorbing properties of coloured threads, in which dyestuff molecules have a contribution. The phenomena presented in ***Figure 5*** (see page 51) are repeated in ***Figure 6*** (see page 51) with the only difference that the curves are much closer, because the latter presents the connection between the open surface, reflectance and transmittance on the back side of the fabrics. The total difference in reflectance, which ranged around 4% in the case of the face side (from 5.47 to 15.66% of open surface), is only 1% on the reverse side. The reason is that on the reverse sides of all samples, it is the warp effect with predominating blue warp threads which has the largest share on the surface, from about 54.62 to 70.49%. Thus, these threads uniformly and mostly contribute to the reflectance, absorbance and UPF of all samples, which consequently results in much more equalized values than in the case of the face side.

Figure 7.a (see page 51) presents logarithmic UPF mean values and transmittance of the samples made of coloured threads (without samples of white colour) with dependence on their open surface U_p (results for the reverse side of the samples are presented as a disconnected line). It is evident that the colour of the samples does not contribute substantially to the UPF when the open surface is higher than 5.47%. Differences between colours exist but are not so obvious as in the case of samples with an open surface lower than 5.47%. Anyway, the UPF exceeds 50 (a logarithmic value of 1.69) at 8.78% of the open surface regardless of the colour (the exception being white weft). On the contrary, when values of the open surface are lower than 5.47%, the influence of thread colour increases sharply, and for a completely closed surface, the differences between individual samples on the face and reverse side are more than obvious. This part is separately presented in ***Figure 7.b*** (see page 51), in which the order of individual coloured samples with respect to their UPF is evident.

The changes in the UPF values of samples of different weft colour are significantly below 5.47% of the open surface (depending on the colour). The order of

Table 4. *Colour values L*, C*$_{ab}$ and h_{ab} and correlation coefficients r_{xy} between the colour values and UPF of the samples of groups 1, 2 and 3 with different colours of weft threads.*

Sample	Open surface, %	Weft Colour	Face			Back		
			L*	C*$_{ab}$	h_{ab}, rd	L*	C*$_{ab}$	h_{ab} (rd)
1	0.0	black	16.02	4.25	4.82	39.91	27.73	4.92
		blue	23.51	36.82	4.98	25.44	35.91	4.96
		green	38.70	21.70	2.87	29.65	24.18	4.69
		yellow	72.89	59.81	1.69	38.13	10.31	4.61
		red	37.30	45.25	0.28	27.96	30.07	5.25
		white	78.17	11.51	4.91	39.91	27.74	4.92
		r_{xy} all	-0.86	-0.22	0.32	-0.30	0.39	0.17
		r_{xy} without white	-0.76	-0.68	0.80	0.03	0.62	0.28
2	5.47	black	16.29	7.16	4.85	36.55	29.45	4.93
		blue	23.51	36.69	4.98	25.22	35.94	4.96
		green	37.78	19.71	2.95	28.24	26.84	4.77
		yellow	67.75	51.55	1.72	34.29	16.79	4.76
		red	35.45	40.70	0.20	27.05	31.45	5.16
		white	72.28	12.74	4.91	36.55	29.45	4.93
		r_{xy} all	-0.84	0.01	-0.06	-0.37	0.07	-0.05
		r_{xy} without white	-0.78	-0.95	0.76	0.26	0.36	-0.08
3	8.78	black	16.74	10.58	4.87	33.86	30.93	4.93
		blue	23.31	36.25	4.98	24.97	35.79	4.96
		green	36.31	17.53	3.09	27.48	27.95	4.80
		yellow	63.21	43.87	1.74	32.92	18.80	4.79
		red	34.09	36.83	0.10	26.27	31.91	5.12
		white	67.24	13.75	4.91	33.86	30.93	4.93
		r_{xy} all	-0.81	0.24	-0.20	-0.41	0.08	0.13
		r_{xy} without white	-0.92	-0.76	0.72	0.13	0.66	0.50

the UPF values of the samples by colour is the following: black, blue, red, yellow and green on the face side, and blue, black, red, yellow and green on the reverse side. On the face side the differences between the UPF values of samples of different weft thread colour are very high (for the sample with blue and green wefts, the difference in the UPF value is higher than 1500 when the open surface is minimal), and substantially lower on the reverse side, which was expected and is in accordance with the previously obtained results of reflectance. What is interesting is the high difference between UPF values of the face and reverse sides of the samples, which can be noticed in samples with blue weft threads and blue warp threads. Obviously, in this case the composition of weaves and the interlacing of threads play an important role in UV protection. As regards the influence of colour on UPF values, we can see that the changes in the UPF values of the reverse side of the blue/black thread combination are almost the same as the changes in these values for the reverse side of the blue/blue combination of threads, although the transmittance curves of these samples are relatively different. Thus, as regards the transmission presented in ***Figure 7.b*** (see page 51), the lines that present the face and reverse sides of the blue black combination of threads are almost parallel and separated from the others, whereas all the other lines lie at narrow limited intervals, slightly running apart. For samples with all weft colours except green, the transmittance is lower on the face side than on the back .

A more detailed analysis of the influence of individual colour values on the UPF was carried out on the basis of ***Table 4***, in which colour values L*, C*$_{ab}$ and h_{ab} of the face and reverse sides of samples 1, 2 and 3 with 0.0%, 5.47% and 8.78% of the open surface and with different colours of weft threads are presented. The table presents the correlation coefficients r_{xy} between individual colour values L*, C*$_{ab}$, h_{ab} and UPF values of samples with all colours of weft threads (including samples with white weft threads) and samples without white threads.

Comparison of the results was made only between the colour values of face and reverse sides with the same percentages of open surface. ***Table 4*** shows correlation coefficients between all three colour values, L*, C*$_{ab}$, h_{ab}, and open surface U_p: however, only some of these results are relevant for the research. As expected, on face side the correlation between the parameters analysed was more pronounced as in the case of the reverse side. This explains that changes in colour values L*, a*, b* and, consequently, C^*_{ab} and h_{ab} on the face sides of the samples due to changes in weft colour, in fact, correlate with the UPF value, while this is not the case for the reverse side of samples where constant blue warp threads have a more predominant and constant colour effect. Moreover, the lightness L* of samples of different weft colour shows, in general, a higher mathematical connection in relation to the open surface than to chroma C^*_{ab} and hue h_{ab}. It must be stated that the results of the t-test for 99% statistical reliability of correlation coefficients, in general, show the necessity of more measurements, which should be included in the analysis., while the results of the t-test for 95% statistical reliability of correlation coefficients were satisfactory. As a consequence, where the value of correlation coefficients was high enough (over ± 0.60), the presence of a mathematical correlation between the values analysed was highlighted.

The results show a highly negative correlation between the colour lightness L* and the UPF on the face side of the samples, either in the case of all colours being considered or in the case of the colour white being omitted from the correlation. Thus, the darker the colour, the higher the UPF value is, which can somehow correspond to expectations that for darker colours the amount of dyestuff used is higher and, consequently, the UPF value increases. With an increase in the surface openness, the degree of correlation between the colour lightness L* of all samples on the face side, as well as the UPF value, decreases. When samples with white threads are excluded from the analysis, the correlation increases with an increase in the open surface from 0.00% to 8.78%. The correlation between the colour lightness and UPF value on the reverse side is negative and increasing, but still less than half of that on the face side if all colours (also white) are considered, and minimal or even positive if the colour white is omitted from the correlation. This can be explained by the construction of fabric in sateen weave. To simplify, sateen is a double-layer fabric in which in the cases of 0% and 5.47% of the open surface, denser weft threads of different colours predominate on the face side, whereas warp threads of blue colour predominate on the reverse side (g_o – 40, 40 threads/cm; g_w – 59, 42 threads/cm), whereas in the case of 8.78% of the open surface, the situation is opposite (g_o – 40 threads/cm, g_w – 35 threads/cm).Differences in reflectance and absorbance (consequently, also differences in UPF values) occur primarily when wefts of different colours appear on the face side and constant blue warp is on the reverse side, while differences in reflectance and absorbance are lower in the case of the reverse side because of the constant blue colour of warp threads. The difference in the absorbance of the face and reverse sides is important and achieves a value of 1.04% in samples woven in the blue warp/blue weft combination when the open surface is minimal, a value of 0.06% in the case of 5.47% of the open surface, and a value 0.6% in the case of 8.78% of the open surface. In the sample made of the black weft/blue warp combination, these differences are higher still, i.e. 4.12%, 3.94% and 3.95%. These data can be calculated from the transmittance and reflectance values, which are presented in ***Table 4***.

Furthermore, ***Table 4*** shows that there is also acorrelation between colour chroma C^*_{ab}, hue h_{ab} and the UPF value on the face side of the samples, but is obviously smaller than with respect to the lightness, and relevant only if samples with a white weft colour are omitted. However, the correlation between colour chroma C^*_{ab} and colour hue h_{ab} and the UPF value has a negative tendency in the case presented and should, for more accurate analysis, include the systematic changes in the chroma values of a colour with a constant colour hue, or systematic changes in a hue colour of unchangeable chroma. For the same reasons as with colour lightness, the correlation between the chroma, hue and UPF values on the reverse side is not sufficient, which is presented with low values of correlation coefficients.

Conclusion

The open surface which is taken into account in the paper has been theoretically calculated. In fact, the real open surface of individual samples was probably smaller than the calculated one, primarily due to the deformation of the theoretically calculated diameter of the threads. The differences would be the highest in samples with the highest thread density. In spite of all this,, a theoretically calculated open surface has been applied in the research, because preliminary research on the reliability of this theoretical model gave an excellent correlation between the theoretically predicted cover factor of weaves and experimental results determined with image analysis. Consequently, it is not expected that the accuracy of a real open surface would negatively affect the results presented and conclusions of the discussion. However, it is most probable that the correlations and relations can be further supported.

On the basis of the researches carried out (designed samples, measurements performed, their statistical processing and analysis), the following conclusions can be made:

- The influence of the surface openness/closeness is a deciding factor in a fabric's UV ray protection.
- A theoretical surface openness higher than approximately 8% does not provide sufficient protection against UV radiation. In such cases, the UV protection is lower than the optimal protection (a UPF above 50).
- The higher the surface openness, the lower or more negligible the influences of other factors on UPF values are.
- The colour of a fabric plays an important role in UV ray protection in the samples with a sufficiently closed surface.
- Especially black and blue colours exhibit high absorbance in the UV wavelength range and provide excellent protection when the samples are highly closed (compact). Other chromatic colours, such as red, yellow and green also offer adequate (very good) protection against UV radiation.
- Comparison of the influence of such colour values as the lightness L*, chroma C^*_{ab} and hue h_{ab} on UPF values highlighted that only lightness can be directly mathematically connected with the UV protective factor. In our research, chroma and hue did not show sufficient correlation with UPF values.
- The construction of a fabric in sateen weave provides different types of protection against UV radiation with dependence on the openness/closeness of the face side and colour combination on the face and reverse sides. This fact should be considered when samples with interchanging colours on the face and reverse sides, following the pattern, are designed.
- The colour white does not provide good protection against UV radiation regardless of the constructional parameters of the samples. Even in the

most tightly woven and maximally covered samples, the UPF is insufficient due to the bleaching agent and, consequently, low UV absorbance.

By considering the above findings, we can also conclude that with proper fabric construction it is possible to produce lightweight, summer, fancy and fashionable clothing from a fabric with a sufficiently closed surface, which would provide adequate UV protection (would have a high enough UPF value) even without adding any UV blocking or absorbing agents. This UPF would maintain a permanent value which would not change considerably through wear and care (washing, dry cleaning). Such clothing could be labelled UV safe clothing without any prejudice or hesitation.

References

1. Urbas, R. Analiza zaščitnega učinka tekstilij pred negativnimi vplivi ultravijoličnih žarkov na kožo. Analyze of textiles protective properties from negative influence of ultraviolet rays on skin. Dissertation. Ljubljana, 2005.
2. Urbas, R., Sluga, F., Bartenjev, I. Zaščitni učinek tekstilij pred ultravijoličnimi žarki= Protection effect of textiles against ultraviolet radiation. V 33. Symposium on Novelties in Textiles : Book of Proceedings and Posters. Editor: D. Gregor-Svetec. Ljubljana : Faculty of Natural Science and Engineering, Department of Textiles, 2000, str. 108 -116.
3. Pailthorpe, M. Apparel textiles and sun protection : a marketing opportunity or a quality control nightmare? Mutation Research, 1998, vol. 422, p. 175-183.
4. Pailthorpe, M. Sun protective clothing. Textile Horizons, 1996, vol. 16, no. 5, p. 11-14.
5. Cox Crews, P., Kachman, S., Beyer, A.G. Influence on UVR Transmission of Undyed Woven fabric. Textile Chemist and Colorist, 1999, vol. 31, no. 6, P. 17-26.
6. Curiskisa, J., Pailthorpe, M. Apparel Textile and Sun Protection. Textilemagazine, 1996, vol. 25, no. 4, p. 13-18.
7. Davies, S., Capjack, L., Kerr, N., Fedosejevs, R. Clothing as protection from ultraviolet radiation : which fabric is most effective? International Journal of Dermatology, 1997, vol. 36, p. 15-22.
8. Algaba, I., Riva, A., Crews, P.C. Influence of Fiber Type and Fabric Porosity on the UPF of Summer Fabrics. AATCC Rewiew, 2004, p. 26-31.
9. Neves, J., Neves, M. The influence of interlacement degree of woven fabrics on the ultraviolet protection factor, 3rd Autex Conference, 2003, p. 229-236.
10. Wilson C. A., Bevin N. K., Laing R. M., Niven, B. E. Solar protection - Effect of selected fabric and use Characteristics on Ultraviolet Transmission, Text. Res. J., Vol. 78, No. 2, 2008, p. 95-104
11. Wilson C.A., Gies P.H., Niven B.E., MacLennan, A., Bevin N. K. The relationship between UV transmittance and color - Visual description and instrumental measurement. Text. Res. J., Vol. 78, No. 2, 2008, p. 128-137.
12. Urbas, R., Sluga, F., Bartenjev, I., UVR – protective properties of textiles, the controversity of black color, JEADV, Journal of European, Academy of Dermatology and Venereology, 2001, vol. 15, suppl. 2 p. 137.
13. International Progranmme on Chemical Safety, Environmental health criteria 160. Accessible: http://www.inchem.org/documents/ehc/ehc/ehc160.htm.
14. Gabrijelčič, H., Dimitrovski, K. Influence of yarn count and warp and weft thread density on colour values of woven surface. Fibres Text. East. Eur., 2004, vol. 12, no. 1(45), str. 32-39.
15. Gabrijelčič, H. Barva in optični pojavi na tkanini = Colour and optical phenomena on fabric. Tekstilec, 2007, letn. 50, št. 4/6, str. 93-132.
16. Gabrijelčič, H., Dimitrovski, K. Numerički i grafički prikaz i usporedba dvobojnih tkanina s različitim modelima boja = Numerical and graphical presentation and analysis of two-color woven fabrics with different color models = Numerische und graphische Darstellung and Gegenüberstellung von zweifarbigen Geweben in unterschiedlichen Farbmodelle. Tekstil, 2007, Vol. 56, No. 4, p. 209-220.
17. Christie, R. M., Mather, R.R., Wardman, R.H. The chemistry of colour application. Oxford: Blackwell Science, 2000.
18. Textiles. Solar UV protective properties. Method of test for apparel fabrics. BS EN 13758-1:2002.
19. Sun protective clothing – Evaluation and classification. Australian/New Zealand Standard®, AS/NZS 4339:1996.
20. Gambichler, T., Laperre, J., Hoffmann, K. The European Standard for Sun Protective Clothing: EN 13758. JEADV, vol. 20, 2006, p.125-130.
21. Gabrijelčič, H., Dimitrovski, K. Evaluation of theoretical geometrical model for determining surface of colour components in fabrics. V: Majcen Le Marechal, A. (ed.), Stjepanović, Z. (ed.), Kokol, V. (ed.), Žunič-Lojen, D. (ed.), Fakin, D. (ed.), Fužir Bauer, G. (ed.), Zimšek, D. (ed.), Križanec, B. (ed.), Volmajer, J. (ed.), Vončina, B. (ed.). 5th World Textile Conference AUTEX 2005, 27-29 June 2005, Portorož, Slovenia. Proceedings. Maribor: Faculty of Mechanical Engineering, Department of Textiles, 2005, p. 790-795.
22. AATCC Technical manual, Vol. 74, 1999, pp 351.
23. General principles for measurement of surface colour, EN ISO 105-J01:1997.

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