Polona Dobnik Dubrovski, Miran Brezocnik

University of Maribor, Faculty of Mechanical Engineering,
Smetanova ulica 17, 2000 Maribor, Slovenia,
E-mail: polona.dubrovski@uni-mb.si

Prediction of the Ultraviolet Protection of Cotton Woven Fabrics Dyed with Reactive Dystuffs

Abstract
Textile materials provide a simple and convenient protection against UV radiation. To assign the degree of UV radiation protection of textile materials, the Ultraviolet Protection Factor (UPF) is commonly used. This paper reports the effect of woven fabric construction (yarn fineness, type of weave, relative fabric density), the colour of bi-functional reactive dyestuffs, and Cibacron dyed fabrics on the ultraviolet protection of light summer woven fabrics. A predictive model, determined by genetic programming, was derived to describe the influence of fabric construction. Warp and weft densities, weave factor and CIELab colour components were taken into account by developing the prediction model for UPF. The results show very good agreement between the experimental and predicted values.

Key words: *ultraviolet protection factor, woven fabric construction, colour, prediction model, genetic programming.*

Introduction

Recently, dermatologists, meteorologists, biologist and others have been warning us about ultraviolet radiation and its harmful effects. Although textile scientists play an important role in ultraviolet protection, textile material can be a very simple and convenient barrier against ultraviolet rays and can offer suitable or even excellent ultraviolet protection. Ultraviolet radiation is electromagnetic, emitted by the sun, which we can not see or feel it. It is high energy radiation which dependent on its wavelength causes sunburn, skin ageing, skin cancer, eye disorders etc. The ultraviolet spectrum is divided into near UV (320 - 380 nm), middle UV (200 - 320 nm) and vacuum UV regions (10 - 200 nm) by physicists, or into UVA (315 - 400 nm), UVB (280 - 315 nm), UVC (100 - 280 nm) and UVD regions (10 - 100 nm) by biologists [1]. The natural source of UV radiation is the Sun, but there are also artificial sources like different types of lamps for phototherapy, solariums, work place lightening, industrial arc welding, hardening plastics, resins and inks, sterilisations, authentication of banknotes and documents, advertising, medical care, etc. UVC radiation is extremely dangerous but almost all the dangerous ultraviolet radiation is absorbed in the atmosphere's ozone layer before it reaches the ground, which is also valid for UVB radiation. UVB radiation is implicated as the major cause of skin cancers, sun burn and cataracts. Big doses of UVB radiation also cause changes at a molecular level - they destroy the fundamental building element - DNA. UVA radiation has a lower mean energy than UVB radiation but higher intensity. It is necessary for vitamin D formation and is also thought to contribute to premature ageing and wrinkling of the skin and has been recently implicated as a cause of skin cancer if we are too much exposed to it.

When there is no ozone depletion, only UVA and UVB radiation reach the Earth' surface. 99% of the UV radiation that reaches the Earth's surface is UVA radiation. Global depletion of stratospheric ozone is one of the most serious environmental and life problems. A reduction in ozone will lead to an increase in solar UVB at the Earth's surface. Decreases of 1% in ozone lead to increases in solar UV radiation at the earth's surface and may eventually lead to 2.3% increase in skin cancer [2]. We should also be aware that prolonged and repeated exposure to ultraviolet radiation in early childhood increases the risk of malignant tumours in adulthood.

Good UV protection, which includes behaviour, environment, legislation and personal protection, is obviously needed to avoid the harmful effects of repeated exposure to ultraviolet radiation. Textile materials have UV-blocking properties, enhanced by dye, pigment, delustrant, UV absorbers as well as by their construction [3 - 6]. Fabric construction presents the simplest and cheapest solution to achieve good UV protection without additional finishing processes. It is worth mentioning that not all fabrics offer sufficient UV protection. Most protective fabrics are not developed for long term wear [7]. To assign the degree of UV radiation protection to textile materials, the **U**ltraviolet **P**rotection **F**actor (UPF) is commonly used. UPF is the ratio of the average effective ultraviolet radiation irradiance calculated for unprotected skin to the average effective ultraviolet radiation irradiance for skin protected by the test fabric (Equation 1) [8, 9].

$$UPF = \frac{ED}{ED_m} = \frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda)\varepsilon(\lambda)\Delta\lambda}{\sum_{\lambda=290}^{\lambda=400} E(\lambda)T(\lambda)\varepsilon(\lambda)\Delta\lambda} \quad (1)$$

$E(\lambda)$ - the solar irradiance expressed in $Wm^{-2}\ nm^{-1}$, $\varepsilon(\lambda)$ - the erythema action spectrum, $\Delta\lambda$ - the wavelength interval and $T(\lambda)$ - the spectral transmittance at wavelength λ, ED – effective UV radiation dose for unprotected skin, ED_m – effective UV radiation dose for protected skin.

Solar irradiance is a quantity of energy emitted by the sun received at the surface of the earth per unit wavelength and per unit area. The solar UVR spectrum measured is between 290 nm and 400 nm.

Table 1. *UPF Ratings and Protection categories according to EN 13758-2.*

Protection category	UPF range	Rating	% UVR blocked
Excellent	above 40	40+	97.5 or more
Very good	30 - 40	30	96.7 - 97.4
Good	20 - 29	no value	95 - 96.6

Table 2. *Variation of constructional parameters of the woven fabrics.*

Level	Yarn linear density, tex	Weave factor	Fabric relative density, %
1	14	0.904 (plain)	55 - 65
2	25	1.188 (twill)	65 - 75
3	36	1.379 (satin)	75 - 85

Suitable UV sources, providing UV radiation throughout the wavelength range (290 nm to 400 nm), include Xenon arc lamps, Deuterium lamps and Solar simulators. The total spectral transmittance is measured by irradiating the sample with monochromatic or polychromatic UV radiation and collecting the total (diffuse and direct) transmitted radiation. The values for the erythema action spectrum, which represents the relative erythemal effectiveness of radiation with wavelength λ, are defined in reference [9].

UPF is the measure of UV radiation (UVA and UVB) blocked by the textile material. The testing laboratory procedure using *in vitro* measurements and UPF ratings were first described in 1996 with AS/NZS standard 4399 and later also with ASTM D 6603 (2000), as well as EN standard 13758-2 (2003). According to EN standard 13758-2 [10], only textiles with a UPF greater than 30 are labelled as UV protecting material (***Table 1***).

This paper reports the results of research focused on three main goals:

- to investigate and define the influence of woven fabric construction on UPF in order to provide guidelines for engineering cotton woven fabrics with ultraviolet protection. For this research only woven fabrics in a grey state were used;
- to investigate and define the influence of woven fabric construction and colour on UPF to provide guidelines for engineering lightweight cotton woven fabrics with ultraviolet protection. For this research bleached and dyed woven fabrics were used without any further finishing treatments:
- to define a prediction model of UPF on the basis of the constructional parameters of woven fabric and the colour values of dyed woven fabrics to provide tools for woven fabric constructors by developing a new fabric construction with the desired UPF.

Experimental

Materials and methods

To analyse the influence of woven fabric construction on the ultraviolet protection factor, twenty-seven woven fabrics made from 100% cotton yarns were used. They were woven according to the constructional plan, which was made on the basis of Kienbaum's setting theory, under the same technological conditions. The woven samples were varied according to the yarn fineness, type of weave and relative fabric density or fabric tightness. Plain - P (10-01 01-01-00), twill - T (20-02 02-01-01) and satin - S (31-01 04-01-03) weaves were chosen for this research, which are marked according to ISO 9354 (***Table 2***). The constructional parameters of the test fabrics are presented in ***Table 3***. The relative fabric density of fabrics with the same type of warp and weft threads [11], open area [12] and cover factor [13] were determined according to equations 2 to 4. The UPF values of the grey fabrics were measured with a UV-VIS Spectrophotometer- Camspec M 350, according to AS/NZ standard 4399.

$$t=\sqrt{\left(\frac{G_1}{5{,}117\cdot\sqrt{\rho_{fib}\cdot i}\cdot\dfrac{1.732\cdot R}{R+\dfrac{a\cdot(2.6-0.6\cdot z)}{f}\cdot 0.732}\cdot\sqrt{\dfrac{1000}{T}}}\cdot 100\right)\cdot\left(\frac{G_2}{5{,}117\cdot\sqrt{\rho_{fib}\cdot i}\cdot\dfrac{1.732\cdot R}{R+\dfrac{a\cdot(2.6-0.6\cdot z)}{f}\cdot 0.732}\cdot\sqrt{\dfrac{1000}{T}}}\cdot 100\right)} \quad (2)$$

Equation 2.

We used two apparatus for the UPF measurements. For the research described in the paper as step 1 Camspec, and for the research step 2 Varian Cary. The only reason was the financial cost of the measurements.

By trying to define an exact model for particular fabric properties using different modelling tools (deterministic or non-deterministic), a more precise model can be developed with more digits after point. This is especially valid for genetic programming, where more generations of models are developed. Equations 2, 3 and 4 have a practical meaning - with them the constructional parameters of the test fabrics, which represent the fabric structure, were defined.

$$P_o = N_p \cdot A_p \cdot 100 \quad (3)$$

$$K = \left(\frac{d_1\cdot G_1}{10}+\frac{d_2\cdot G_2}{10}+ -\frac{d_1\cdot d_2 G_1 G_2}{100}\right)\cdot 100 \quad (4)$$

t - relative fabric density in %, *G* - actual density in threads per cm, *T* - yarn fineness in tex, ρ_{fib} - bulk density of fibres in gcm^{-3}, *i* - yarn packing factor, *R* - number of threads in weave repeat, *a* - number of doubled passages of yarn in weave repeat, *z* - the smallest weave shift, *f* - yarn flexibility, P_o - open area in %, N_p - pore density in pores / mm^2, A_p - area of pore cross section in mm^2, *K* - fabric cover factor, *d* - yarn thickness in mm. Subscripts 1 and 2 denote warp and weft yarn, respectively.

Table 3. *Constructional parameters of woven samples – step 1.*

Nr. sample	Yarn fineness, tex	Type of weave	Fabric relative density, %	Open area, %	Cover factor, %
1	14	P	62	31.3	59
2	14	P	70	24.4	63
3	14	P	84	10.2	69
4	14	T	62	14.9	73
5	14	T	70	11.6	76
6	14	T	80	3.3	81
7	14	S	59	11.6	79
8	14	S	69	6.2	83
9	14	S	79	1.1	87
10	25	P	62	25.6	60
11	25	P	73	18.2	64
12	25	P	83	11.8	78
13	25	T	63	15.2	74
14	25	T	73	9.3	78
15	25	T	84	5.1	82
16	25	S	60	6.4	80
17	25	S	70	3.1	83
18	25	S	81	0.6	88
19	36	P	62	28.1	59
20	36	P	71	26.7	64
21	36	P	83	22.3	69
22	36	T	63	17.7	74
23	36	T	72	12.7	78
24	36	T	83	10.5	82
25	36	S	58	17.3	80
26	36	S	65	12.2	82
27	36	S	79	2.6	87

Table 4. *Variation of constructional parameters of the woven fabrics.*

Yarn linear density, tex	Colour of sample	Weave factor	Fabric relative density, %
14	white	0.904 (plain)	55 - 65
	dirty white		
	red	1.188 (twill)	65 - 75
	blue		
	black	1.379 (satin)	75 - 85

To analyse the influence of woven fabric construction and colour on the ultraviolet protection factor and to define a prediction model for UPF, forty-five woven fabrics samples were prepared, similar as in the previous step, by variation of the constructional parameters and colour (***Table 4***). Only the woven samples, made from yarns with a fineness of 14 tex, which are used for light summer clothes, were analysed further. They went through enzymatic treatment (boiling, desizing, and bleaching) with Baylase EVO enzyme and a dyeing process with bi-functional reactive dyestuffs - Cibacron LS to get a white (W), red (R), blue marine (BM) and black colour (B). One group of woven samples was in a grey state and has a dirty white or light yellow colour (DW). The constructional parameters of the prepared samples are given in ***Table 5***. The colour of the woven samples was determined by a DATACOLOR Spectra Flash SF 600 spectrophotometer with Lab colour components, while the UPF values of undyed and dyed fabric samples were measured again using a Varian Cary 50 UV-VIS spectrophotometer according to AS/NZ standard 4399. We then created a predictive model of UPF using genetic programming. Our research included the following independent input variables eg. the set of terminals, the weave factor (X_1), warp density (X_2), weft density (X_3), and CIELAB colour components: L^* (X_4), a^* (X_5), b^* (X_6). Instead of using descriptive terms for the colour of woven samples (red, white etc.) dyed with bi-functional reactive dyestuffs - Cibacron, the colouristic parameters (CIELab) of the colour samples were used. The dependent output variable was the ultraviolet protection factor. For modelling, the initial set of functions includes the basic calculating operations of addition, subtraction, multiplication and division.

Results and discussion

Effect of woven fabric construction on UPF

Measurement results of the UPF of the test fabrics are listed in the ***Figure 1***.

By analysing the results of UPF measurements of woven fabrics of different construction, the following conclusions can be drawn:

- woven samples in a grey state with the same relative density and yarn fineness offer different UV protection;
- observing the type of weave, the following ranking of UV protection in decreasing order can be made: satin – twill – plain. This was expected as fabrics of satin weave are usually woven with higher warp/weft densities regarding twill and plain weave with the same fabric relative density. Consequently, they have smaller and not so stable macropores as the lack of thread passages and UV radiation has less free space to pass through;
- higher fabric relative density in all cases means higher UV protection, but there is a limit to which woven fabrics offer at least good UV protection. Results show that none of the plain fabrics offer at least good UV protection even though they are tightly woven. In twill and satin fabrics, good UV protection depends on the yarn fineness and value of fabric relative density. The following generally lower limits of fabric relative density can be established to achieve at least good UV protection in woven fabrics: 70% in satin weave and 80% in twill weave.

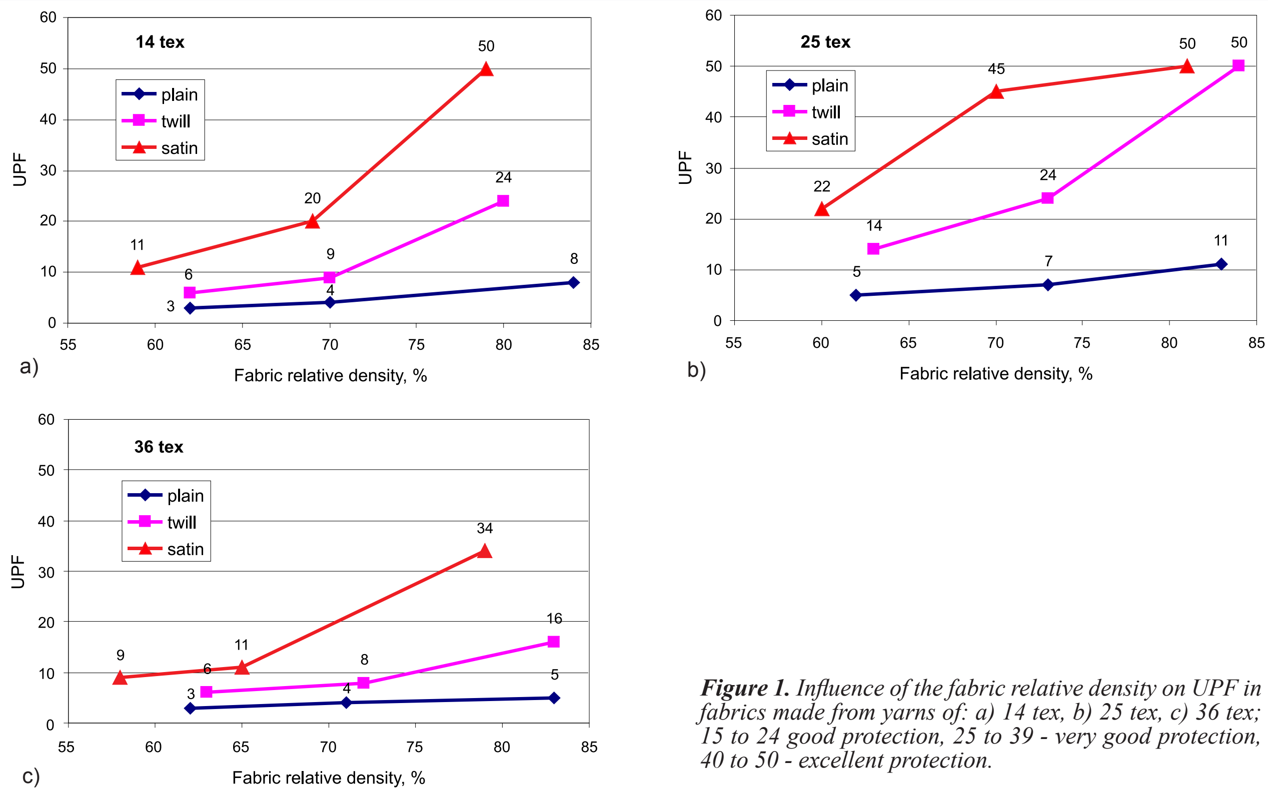

Figure 1. *Influence of the fabric relative density on UPF in fabrics made from yarns of: a) 14 tex, b) 25 tex, c) 36 tex; 15 to 24 good protection, 25 to 39 - very good protection, 40 to 50 - excellent protection.*

Table 5. Constructional parameters of woven sam,ples – step 2.

Nr. samples	Color	Type of weave	Fabric relative density, %	Warp - weft density, threads/cm	L*	a*	b*
1	DW	P	62	387 - 182	84.58	1.95	13.49
2	DW	P	70	394 - 230	86.09	1.99	13.82
3	DW	P	84	395 - 325	85.22	2.27	14.13
4	DW	T	62	511 - 240	85.90	2.11	14.21
5	DW	T	70	502 - 308	85.93	1.97	13.89
6	DW	T	80	516 - 396	86.80	2.11	13.77
7	DW	S	59	569 - 265	86.97	1.71	14.16
8	DW	S	69	569 - 357	87.77	1.62	13.41
9	DW	S	79	571 - 466	87.57	1.58	13.12
10	W	P	72	413 - 232	93.19	-0.48	4.39
11	W	P	80	400 - 294	93.34	-0.60	5.02
12	W	P	91	410 - 367	93.55	-0.62	5.40
13	W	T	67	510 - 283	94.22	-0.65	3.98
14	W	T	78	527 - 368	94.36	-0.64	4.60
15	W	T	83	532 - 414	93.70	-0.62	5.62
16	W	S	64	585 - 301	92.97	-0.49	4.55
17	W	S	76	588 - 424	93.99	-0.59	4.87
18	W	S	89	621 - 543	94.26	-0.61	4.73
19	R	P	71	396 - 230	44.34	55.68	-6.18
20	R	P	81	404 - 295	44.33	54.93	-6.52
21	R	P	88	410 - 346	44.41	54.60	-6.71
22	R	T	68	412 - 355	44.03	55.49	-6.03
23	R	T	79	485 - 409	44.47	54.94	-6.74
24	R	T	85	493 - 467	45.72	55.02	-7.21
25	R	S	61	493 - 323	44.02	55.70	-5.94
26	R	S	80	599 - 452	44.66	55.44	-6.97
27	R	S	88	624 - 526	45.61	55.63	-7.19
28	BM	P	71	400 - 234	30.78	-8.51	-17.9
29	BM	P	79	411 - 281	31.07	-8.46	-17.88
30	BM	P	91	426 - 360	31.39	-8.50	-18.01
31	BM	T	67	423 - 341	30.34	-8.31	-17.74
32	BM	T	70	445 - 352	30.96	-8.42	-17.94
33	BM	T	81	491 - 425	31.65	-8.71	-18.48
34	BM	S	62	527 - 309	30.61	-8.45	-17.95
35	BM	S	76	575 - 429	31.13	-8.46	-18.13
36	BM	S	84	583 - 510	31.88	-8.62	-18.35
37	B	P	71	417 - 220	17.85	-1.55	-3.12
38	B	P	83	423 - 297	18.10	-1.43	-2.95
39	B	P	91	427 - 358	17.65	-1.34	-2.81
40	B	T	61	438 - 272	17.11	-1.23	-2.83
41	B	T	76	459 - 394	17.88	-1.44	-3.02
42	B	T	81	496 - 420	17.94	-1.49	-3.11
43	B	S	65	573 - 312	17.88	-1.51	-3.07
44	B	S	77	578 - 437	17.79	-1.40	-3.01
45	B	S	85	585 - 521	19.04	-1.84	3.58

It is also possible to use lower relative fabric densities, which depends on the fineness of yarns used;

- if we compare the UPF values of woven samples regarding yarn fineness, we can observe that UPF values first increase with yarn fineness (from 14 to 25 tex) and then decrease again, which means that UV protection not only depends on the open area but also on fabric thickness or volume porosity. It is known that UV rays also go through the fibres themselves and not only through macropores.

Effect of woven fabric construction and colour on UPF

The results of UPF measurements of woven fabrics of different construction and colour components are listed in ***Figure 2***. The colour of the columns represents the colour of the fabrics (white, dirty white, red, blue and black coloured fabrics). In plain fabrics the UPF values of 15 and 40 are bold to show the limit in which the fabrics offer good and excellent UV protection, respectively, according to the AS/NZ standard.

It is obvious that colour has a great effect on UV protection. Fabrics with the same construction but of different colour have a very different UV protection. Dark coloured fabrics (black and blue) and also red coloured ones offer (“super”) excellent UV protection; satin and twill fabrics have even lower values of fabric relative density, while for plain fabrics this is valid only for black fabrics with a relative density of the third level. White coloured fabrics do not posses any UV protection and are not suitable to protect us against UV radiation. But, on the other hand, for summer shirts fabrics in light pastel colours are suitable to prevent the body against IR radiation. Dark coloured fabrics collect too much heat and feels unpleasant when wearing them. For the woven fabric constructor, it is very important to meet both demands or to develop a fabric with good UV protection as well as with good protection against heat accumulation. It is also worth mentioning that the higher UPF values of woven fabrics after dyeing compared with the UPF values before dyeing are also the consequence of warp and weft density changes during the dyeing process. For woven fabrics made from yarns of 14 tex, the results show that the average change in fabric tightness (which is a consequence of higher values of warp/weft density) of fabrics

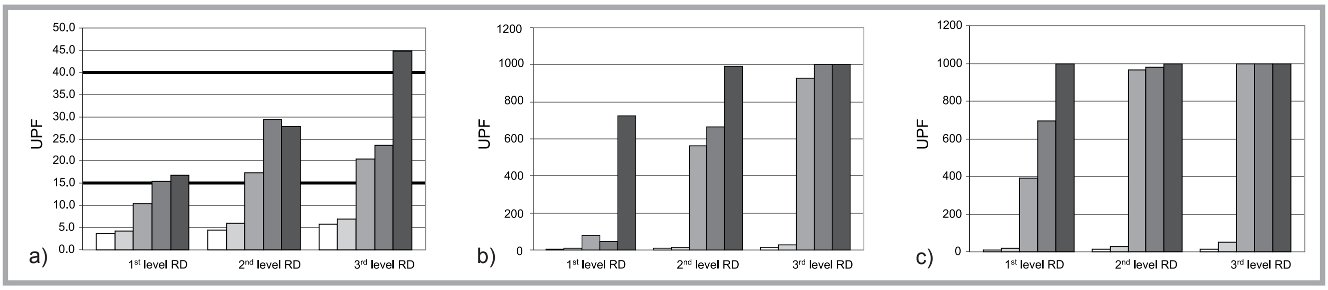

Figure 2. Influence of fabric relative density and colour on UPF in fabrics made of: a) plain weave, b) twill weave, c) satin weave.

$$UPF = e^{A}$$

$$\begin{aligned}
A = {} & 0.0139054 \cdot X_1 \cdot (X_3 - 0.00259294 \cdot (12.5187 - X_1 + X_4 + 5.29825 \cdot 10^{-14} \cdot X_1^6 \cdot \\
& (X_1 + X_2) \cdot (X_3 - 2X_4)^3 \cdot (X_3 - X_4) \cdot (X_3 - X_1 X_4) \cdot (X_3 - X_4 - X_5) \cdot (X_3 - X_4 + X_5)^2 + \\
& 0.00259294 \cdot X_1^3 \cdot (8.19051 - 2.3628 \cdot X_1^3)^2 \cdot (3.3628 \cdot X_1 - 65.0787 \cdot X_1^3 - X_1^2 \\
& (10.6012 + X_3 - X_4) + 5.94967 \cdot X_4 + 2X_5) + X_6 + 0.00259297 \cdot X_3 \cdot (X_1 + X_1 \cdot (X_4 + X_6))) \cdot \\
& (10.6012 + X_3 - 0.00259294 \cdot X_1 \cdot (-X_2 - X_3 + X_1 \cdot (6.68844 - 0.997407 \cdot X_1 \cdot X_3) - X_4 + X_1^3 \cdot \\
& (3.283321 + X_3) \cdot X_6 + 3.03917 \cdot 10^{-16} \cdot X_3^6 \cdot (3.28321 + X_3) \cdot X_6 - X_1 \cdot (X_4 - X_4 X_5 - X_6) \cdot \\
& (15.8484 + X_6) - 6.72334 \cdot 10^{-6} \cdot (X_1 + X_2) \cdot (X_3 - X_5 + X_6))))
\end{aligned} \qquad (5)$$

Equation 5.

in a grey state and treated fabrics (first bleached and then dyed) was 9.3% (min value 0.4%, max value 18.3%), while the average change in UPF between the non-treated and treated fabrics was 1861.9%. Regarding the type of weave, the change in the average fabric tightness of fabrics in a grey state and treated fabrics was 12.6% for plain weave, 6.0% for twill weave and 9.2% for satin weave, while the average UPF change in fabrics in a grey state and treated fabrics was 223.4% for plain weave, 3009.1% for twill weave and 2353.3% for satin weave.

Prediction model for the Ultraviolet Protection Factor of Woven Fabrics

In order to help woven fabric constructors by developing woven fabrics with an optimum UPF, the prediction model for UPF was developed by means of genetic programming (Equation 5) on the basis of woven fabric constructional parameters and colour values of dyed woven fabrics. The method of modelling the UPF presented in this article does not clearly presents the kind of dependence between this parameter and the parameters selected, which characterise the construction of the textile product and its colour. The dependency presented in equation (5) has such a complex form compared to classical modelling that it is difficult to draw simple conclusions concerning the dependency of UPF on the six parameters selected. The mathematical model proposed is valid only for bi-functional reactive dyestuffs - Cibacron and the dyeing conditions used in our research. The use of other types of dyes was neither measured nor analysed. We believe that it is impossible to consider all types of dyes and dyeing conditions, therefore we focused our research on selected types of fabric, dyes and dyeing conditions. Besides this, the “objective” value of colour shades to obtain a defined colour pattern on woven fabric is essential for the fabric designer. Therefore the colour shade was determined with coloristic parameters, which characterise the colour of woven samples in the visible spectrum range, despite the fact that UPF is influenced by the chemical structure of dye molecules. We would like to show that genetic programming is a useful method for fabric designers to predict UPF.

UPF presented by Equation 5 where X_1 is the weave factor, X_2 is the warp density in threads per cm, X_3 is the weft density in threads per cm, X_4 is CIELab colour component L^*, X_5 is CIELab colour component a^* and X_6 is CIELab colour component b^*.

The experimental values of UPF deviate from the predicted ones on average by 8%, which means that our proposed model is a satisfactory “tool” for developing new woven fabric constructions with the desired UV protection.

Conclusion

Ultraviolet radiation has positive as well as some negative effects on humans. The UV-A and UV-B radiation which reaches the Earth surface can contribute to premature ageing and the wrinkling of skin, and they are the major cause of skin cancers, sun burn and cataracts. The need to protect us from UV radiation is obviously necessary, and textile materials can provide simple and very efficient protection. In this paper, the effect of woven fabric construction and the colour shades of bi-functional reactive dyestuffs - Cibacron dyed fabrics on the ultraviolet protection factor of light summer clothes is presented. We believe that it is impossible to include all woven fabric types, and kinds of dyes to predict the ultraviolet protection factor accurately enough, therefore we focused our research on light cotton woven fabrics dyed with bi-functional reactive dyestuffs - Cibacron only. We would like to show that genetic programming is a useful tool to establish the relationship between woven fabric constructional parameters and the ultraviolet protection factor. The model proposed provides guidelines for engineering woven cotton fabrics to provide the UV protection desired.

References

1. *R. Williams, G. Williams, ‘Reflected ultraviolet photography’, Medical and Scientific Photography, online resource, http://msp.rmit.edu.au*
2. *C.R. Roy, H.P. Gies, S. Toomey, ‘The Solar UV Radiation Environment: Measurement Techniques and Results’, Journal of Photochemistry and Photobiology B: Biology, 1995, Vol. 31, pp 21-27.*
3. *G. Hustvedt, P.C. Crews, ‘The Ultraviolet Protection Factor of Naturally-pigmented Cotton’, The Journal of Cotton Science, 2005, Vol. 9, No. 47, pp. 47-55.*
4. *T. Gambichler, S. Rotterdam, P. Altmeyer, K. Hoffmann, ‘Protection against ultraviolet radiation by commercial summer clothing: need for standardized testing and labeling’, BMC Dermatol, 2001, 1:6, published online 2001 October 25.*
5. *K.L. Hatch, U. Osterwalder, ‘Garments as solar ultraviolet radiation screening materials’, Dermatol Clin., 2006, Vol. 24, pp. 85-100.*
6. *K. Kaspar, K. Hoffmann, P. Altmeyer, ‘Determination of the ultraviolet protection factor of viscose fabrics in vitro and in vivo’, INABIS Internet World Congress, 1998, http://www.mcmaster.ca/inabis98/dermatology/.*
7. *M. Vikova, ‘Visual Assessment of UV Radiation by Colour Changeable Textile Sensors’, AIC 2004 Colour and Paints, Interim Meeting of the International Colour Association, Proceedings, pp.129-133.*
8. *A.R. Scott, ‘Textiles for protection’, Woodhead Publishing in Textiles, 2005, pp. 356-377.*
9. *EN 13758-1:2001, Textiles. Solar UV protective properties. Part 1: Method of test for apparel fabrics.*
10. *EN 13758-2:2003, Textiles. Solar UV protective properties. Part 2: Classification and marking of apparel.*
11. *Kienbaum, M., Gewebegeometrie und Produktenwicklung, Melliand Textilber. 71, 1990, pp. 737-742.*
12. *Dubrovski, P. D., Brezocnik, M., Using Genetic Programming to Predict the Macroporosity of Woven Cotton Fabrics. Textile Res. J., 72(3), 2002, pp. 187-194.*
13. *Lord, P. R., Mohamed, M.H., “Weaving: Conversion of Yarn to Fabric”, Merrow Publishing Co.Ltd, Shildon, England, 1992.*

Received 07.12.2006 Reviewed 27.11.2007