Short communication

Impact of Elastane Addition on UV Protective Properties of Viscose and Polyacrylonitrile Knits

Alenka Pavko Čuden* and Raša Urbas

Department of Textiles, University of Ljubljana, Snežniška 5, 1000 Ljubljana, Slovenia

** Corresponding author: E-mail: alenka.cuden@a.ntf.uni-lj.si*

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Abstract

Textiles can provide effective protection against UV radiation because they reflect, absorb and scatter solar wavelengths. Properly designed, they significantly increase the area of covered skin. The optimal combination of thickness, fabric density, mass per unit area, knitted structure, yarn type and yarn linear density, facilitate the production of textiles with high UV protection properties. The objective of this research was to evaluate the impact of elastane on UV protection properties of viscose and polyacrylonitrile knitted structures. The investigation illustrated that wet relaxed elasticized knits show good UV radiation protection with UPF 20-40. In contrast, non-elasticized viscose and polyacrylonitrile knits are inappropriate for UV radiation protection. Comparing viscose samples, UPF is higher for dry relaxed elasticized structures, whilst for polyacrylonitrile samples, UPF is higher for wet relaxed elasticized structures. For non-elasticized structures, the UPF of polyacrylonitrile samples is greater than that of viscose samples. Generally, polyacrylonitrile knits investigated ensure better UV protection than viscose knits.

Keywords: Knit, elastane, porosity, UPF

1. Introduction

1. 1. UV Radiation

Daylight reaches us from the Sun, passing through the Earth's atmosphere and the spectrum of these solar rays extends from 290 nm to 3000 nm. Rays between 290 and 400 nm are referred to as ultraviolet radiation (UVR).[1] The UVR band consists of three regions: UVA – 315 to 400 nm; UVB – 290 to 315 nm and UVC – 100 to 290 nm. UVC is totally absorbed by the atmosphere and does not reach Earth's surface. UVA causes little visible effect on human skin, but has shown to decrease the immunological response of skin cells. UVB is responsible for the development of most skin cancers.[2, 3] UV radiation exposure encompasses the Sun's natural UV emissions, in addition to artificial UV sources. Natural UV radiation levels are influenced by a number of factors: Sun's elevation; latitude; cloud cover; altitude; ozone layer thickness and ground reflection.[4]

Limited exposure to UV radiation is beneficial to health and plays a key role in the production of vitamin D. However, excessive exposure to UV radiation is linked with various skin cancers; sunburn; accelerated skin ageing; cataract and other deleterious eye conditions. There is also evidence that UV radiation can reduce the effectiveness of the human body's immune system.[4]

1. 2. Ultraviolet Protection Factor (UPF)

UPF illustrates the level of protection from UV radiation provided to human skin. It is the ratio of UV radiation measured on the skin – without protection, compared to UV radiation measured on the skin – with added protection. Consequently, it forms a measure of UV radiation blocked by the fabric. General approaches to assessing textiles for their UV radiation protective ability, are laboratory testing *in vivo* and instrumental evaluation *in vitro*. *In vivo* testing is performed on human subjects and based on the determination of the minimal erythema dose for the test person´s skin, protected and not protected, by the fabric under test. Cost and ethical dilemmas impede and often exclude this form of testing. *It vitro* testing is based on instrumental determinations of UPF, defined as the ratio of the average effective UV radiation – calculated for unprotected skin, against the average effective UV radiation – calculated for skin covered by the test fabric.[5]

1. 3. UV Protective Textiles

Textiles can provide simple and effective protection against damaging UV radiation because they are able to reflect, absorb and scatter solar wavelengths. When UV radiation strikes a textile surface, some of the radiation is reflected at the boundaries of the textile surface. Another radiation element is absorbed when it penetrates the sample: more accurately, converted to a different energy form. The remaining part of the radiation passes through the fabric and reaches the skin: this part is referred to as transmission.[6]

Well designed protective clothing can substantially reduce UV radiation reaching the skin's surface. The advantage of textile products, in comparison with protective physical-chemical substances – creams, lotions, ointments, tonics etc. – is that textiles enable the protected area of the body to be segregated from the unprotected. For this reason, there are no side effects, such as irritation, or the development of skin allergies. Considering loose clothing, made from light material, there is also the added benefit of air movement and convection. This makes the skin cooler than if it was directly exposed to the Sun's rays, without protective clothin.[7] According to ASTM D 6603 standard, textiles in the UPF range 40–50 and 50+ exhibit excellent UV protection characteristics; UPF range 25–30 offers very good UV protection; UPF range 15–24 offers good UV protection. European standard EN 13578-2:2003 rates the protection category of textiles in the UPF range above 40 as excellent; UPF range 30–40 is considered as very good while UPF range 20–29 is defined as good UV protection. According to EN standard 13758-2, only textiles with a UPF greater than 30 are labelled as UV protecting material. When the fabric UPF is greater than 40, only UPF 40+ should be reported.[5]

Contrary to popular belief, not all textile materials offer adequate UV protection, the UPF value of a third of typical summer clothing sold, is less than 15.[8] The level of protection of clothing from the negative effects of UV radiation is mainly determined by the structural characteristics. These characteristics embrace porosity, cover factor, weight, areal density, fibre type – these are chemical and morphological qualities of fibres. Other factors include colour, both of the fabrics as well as material colour; effects of water and moisture – water binding to fabrics; regular use and care, finishing treatments and the presence of known UV absorbers and reflective materials.

The main purpose of the textiles designed to protect from UV radiation, is significantly to reduce the open-area portion, consequently implying an increase in the portion of covered skin. Since the transmitted UV radiation of textiles is made up of diffuse and direct components, modified by fabric yarns, reduction of UV transmission may be achieved by altering the construction parameters of textile materials. The optimal combination of thickness, fabric area density, mass per unit area, knitted structure, in addition to yarn type and yarn linear density, allow production of textile products with high UV protection properties.[9]

2. Experimental

2. 1. Sample Preparation

For the research, viscose and polyacrylonitrile (acrylic) fibres were selected as the base material, owing to their discrete origins (natural polymer vs. synthesized polymer) and diverse properties. The samples of basic – and the most often used knitted structure – single jersey (cf. Table 1) were made from two different kinds of structured yarns, produced with the same linear density (100 tex) and made of the same viscose and polyacrylonitrile fibres, respectively. One type of yarns included elastane (core-spun), while the other comparative yarns lacked added elastane (conventional, ring-spun). From these yarns, knitted fabric samples were produced under the same processing and environmental conditions in two density (porosity) levels, defined as compact and open. After the knitting process, the prepared samples were statically dry relaxed. At this stage, half portions of samples were also dynamically wet relaxed, to achieve full consolidation and the reference state. The consolidation process comprised laundering at 30 °C, spinning, 40-minute drying, four cycles of alternating rinsing and 40-minute tumble drying, and placing wet relaxed samples flat to the standard environment for at least 24 hours after the last drying cycle

Table 1. Sample characteristics and labelling

yarn	material composition	yarn structure	relaxation	knitted structure density compact	knitted structure density open
CV-EL	97.8% CV 2.2% EL	core-spun	dry	CV-EL DR C	CV-EL DR O
			wet	CV-EL WR C	CV-EL WR O
PAN-EL	97.8% PAN 2.2% EL		dry	PAN-EL DR C	PAN-EL DR O
			wet	PAN-EL WR C	PAN-EL WR O
CV	100% CV	conventional ring-spun	dry	CV DR C	CV DR O
			wet	CV WR C	CV WR O
PAN	100% PAN		dry	PAN DR C	PAN DR O
			wet	PAN WR C	PAN W O

was finished. All the yarns were made from raw fibres and not dyed. The knitted samples were not subjected to any dyeing, or finishing process, their colour remaining white.

Combining two yarn structures; two fibre types; two density (porosity) levels and two relaxation states, gave a total of sixteen different knitted samples to be prepared, comprised of loops of different shapes and sizes. Owing to differing porosity of the investigated knitted structures and preliminary tests for air permeability and moisture transfer[10], significant differences in UPF were anticipated.

2. 2. Structural Parameters Describing the Porosity of the Knits

In order to evaluate porosity and dimensional properties of structures, with and without elastane addition, the following structural parameters were determined by laboratory tests and calculation: fabric bulk density ρ_B $[gm^{-3}]$; voluminosity V $[\%]$; cover factor K $[tex^{1/2}mm^{-1}]$ and loop modules – δ (linear); δpl (planar) and δv (volume). The bulk density ρ_B represents the ratio between the fabric mass per unit area M $[gm^{-2}]$ and the fabric thickness t $[mm]$. The voluminosity is the ratio between the material density and fabric bulk density. Material density was calculated from yarn material composition (cf. Table 1) and fibre density of viscose fibres $\gamma_{CV} = 1.510$ gcm^{-3}, polyacrylonitrile fibres $\gamma_{PAN} = 1.180$ gcm^{-3} and elastane fibres $\gamma_{EL} = 1.210$ gcm^{-3}. The cover factor K represents the ratio between the square root of the yarn linear density and the loop length (portion of the yarn length forming one single loop). A higher cover factor indicates a tighter structure. The linear loop module δ indicates the ratio between the loop length and the yarn diameter. The planar loop module δpl indicates the ratio between the area of a rectangle outlining one loop and the area filled with yarn within that loop. The volume loop module δv indicates the ratio between the volume of a rectangular solid outlining one loop and the space filled with yarn within this loop. The parameters indicating the porosity of the examined knits are shown in Table 2. The optimal values of the above mentioned parameters are: $K = 1.4$; $\delta = 16.6$; $\delta pl = 1.0$; $\delta v = 1.0$.

2. 3. Testing Methods

UV transmission of the chosen samples was measured with a Lambda 800, UV/VIS Spectrophotometer, PELA-1000 (Perkin Elmer Inc.), which enabled measurement of transmission (T) and reflection (R). Measurements were made in accordance with EN 13758-1 standard, in 2 nm steps, over the range 700–200 nm. To calculate UPF, only data from the range 400–290 nm were used.

The average values of UV radiation transmission were calculated as follows:

$$UV_i = \frac{1}{n}\sum_{290}^{\geq 400} T_i\ (\lambda)\ [\%] \tag{1}$$

where T(λ) represents the spectral transmission of a chosen sample, at wavelength λ – in the range 400–290 nm. The observed transmission values were inserted into the equation for the UPF calculation:

$$UPF = \frac{\sum_{290}^{400} E\ (\lambda).\ \varepsilon\ (\lambda)\ .\ \Delta\ (\lambda)}{\sum_{290}^{400} E\ (\lambda)\ .\ \varepsilon\ (\lambda)\ .\ \mathrm{T}\ (\lambda)\ .\ \Delta\ (\lambda)} \tag{2}$$

... where E(λ) is the solar spectral irradiance (Wm^{-2} nm^{-1}); ε(λ) the spectral relative biological efficiency; Δλ wavelength interval of the measurements and T(λ) the spectral

Table 2. Parameters describing porosity of investigated knits: bulk density-ρ_B, voluminosity-V, loop modules- δ, δ_{pl}, δ_v, cover factor-K, fabric thickness-t and fabric mass per unit area-M

sample	ρ_B (gm^{-3})	V (%)	δ	δ_{pl}	δ_v	K (tex $^{1/2}$mm^{-1})	t (mm)	M (gm^{-2})
CV-EL DR C	0.25	591	11.00	0.29	0.90	1.29	1.92	488
CV-EL WR C	0.39	385	6.49	0.10	0.22	1.89	2.13	832
CV-EL DR O	0.20	766	14.77	0.28	1.09	0.96	2.40	471
CV-EL WR O	0.33	461	8.92	0.11	0.26	1.37	2.39	780
PAN-EL DR C	0.20	597	11.62	0.38	1.18	1.20	1.84	364
PAN-EL WR C	0.25	469	7.10	0.14	0.36	1.72	2.47	622
PAN-EL DR O	0.14	819	15.43	0.41	1.59	0.91	2.31	333
PAN-EL WR O	0.20	582	9.52	0.15	0.43	1.32	2.79	566
CV DR C	0.24	636	13.51	0.67	1.46	1.14	1.10	261
CV WR C	0.20	752	11.93	0.65	1.52	1.22	1.31	263
CV DR O	0.17	892	17.81	0.98	1.96	0.87	1.01	171
CV WR O	0.15	1029	15.90	0.89	1.97	0.92	1.24	182
PAN DR C	0.20	603	14.60	0.68	1.83	1.12	1.26	253
PAN WR C	0.19	646	13.67	0.61	1,76	1.13	1.43	268
PAN DR O	0.15	784	19.29	1.09	2.94	0.85	1.25	193
PAN WR O	0.14	859	17.91	0.82	2.34	0.86	1.42	200

transmittance at wavelength λ.[11] Average values of UVA and UVB transmission were also calculated. Reflection values were calculated similarly, using the equation (1) as well; in place of transmission values, corresponding reflection values – in the range 400–290 nm – were inserted into equation.

The obtained values of transmission (T) enabled the calculation of the UPF values and together with the measured values of reflection (R), the absorption (A) was calculated (Equation 3):

$$A = 100 - T - R \ [\%] \tag{3}$$

3. Results and Discussion

3. 1. Structural Parameters Determining Porosity

From Table 2 it can be seen that wet relaxed structures comprising an elastane core (samples CV-EL WR C, CV-EL WR O, PAN-EL WR C and PAN-EL WR O) are the most compact eg. the least porous. They also exhibit the highest thickness (t > 2 mm) and mass per unit area (M > 500 gm^{-2}). Loop modules and cover factor of all structures made from core-spun yarns, with elastane core, reflect higher compactness of the elasticized structure, compared to non-elasticized structures. Consequently, higher protection from UV radiation could be expected for the elasticized structures compared to the non-elasticized structures due to their cover, compactness and thickness.

3. 2. UV Protective Properties

Transmission, reflection and absorption data of UV radiation applied to elasticized viscose samples (labelled CV-EL) and non-elasticized viscose samples (labelled CV) are presented in Table 3 and Figures 1 and 2. UPF values of these viscose samples are shown in Table 3.

Transmission is significantly greater for non-elasticized structures and the absorption data for these samples is correspondingly lower.

The results of the measurements show that UPF of elasticized structures is substantially greater than for non-elasticized viscose structures. For dry relaxed elasticized viscose structures, it is >40, whilst for wet relaxed elasticized viscose structures, it is significantly lower – 24 and 32 respectively. For non elasticized viscose structures, it is extremely low at 2–5.

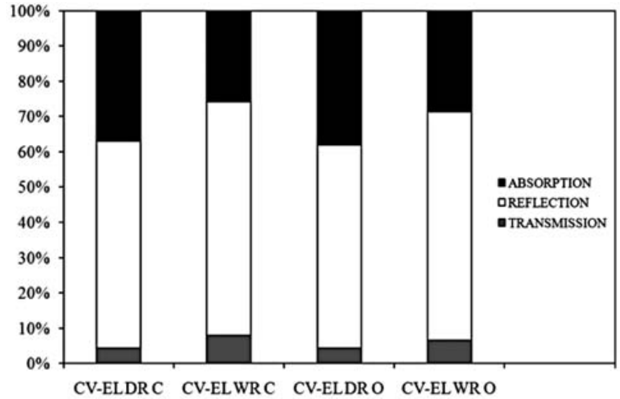

Figure 1. UV transmission (T), reflection (R) and absorption (A) of elasticized viscose knits

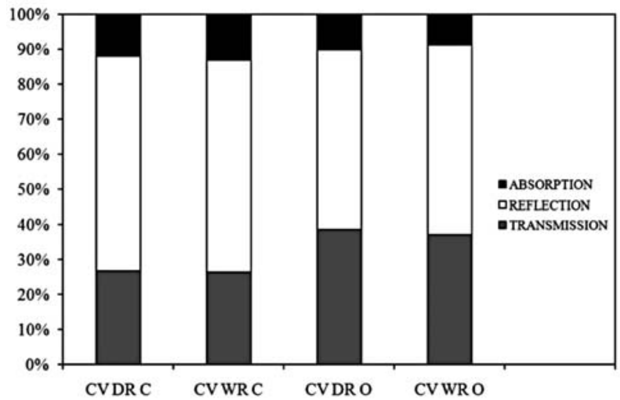

Figure 2. UV transmission (T), reflection (R) and absorption (A) of non-elasticized viscose knits

Table 3. Values of ultraviolet protection factor (UPF), transmission (T), reflection (R) and absorption (A) of UV radiation of the elasticized viscose knits and viscose knits without elastane

sample	CV-EL DR C	CV-EL WR C	CV-EL DR O	CV-EL WR O	CV DR C	CV WR C	CV DR O	CV WR O
UPF	40+	24.20	40+	32.02	4.39	4.54	2.78	2.95
T (290-400) UV	4.35	7.99	4.33	6.61	26.69	26.33	38.53	37.02
T (290-315) UVB	1.07	3.38	1.10	2.41	20.97	20.22	34.63	32.44
T (315-400) UVA	5.34	9.38	5.31	7.89	28.42	28.17	39.71	38.40
R (290-400) UV	58.65	66.15	57.60	64.69	61.19	60.44	51.17	54.20
R (290-315) UVB	48.87	55.35	47.63	53.50	54.62	53.75	46.82	48.23
R (315-400) UVA	61.60	69.42	60.61	68.07	63.18	62.46	52.49	56.01
A (290-400) UV	37.00	25.86	38.07	28.70	12.12	13.23	10.30	8.78
A (290-315) UVB	50.05	41.28	51.27	44.09	24.42	26.02	18.55	19.34
A (315-400) UVA	33.06	21.20	34.08	24.04	8.40	9.37	7.80	5.59

Absorption, transmission and reflection values of UV radiation applied to elasticized polyacrylonitrile samples (labelled PAN-EL) and non-elasticized polyacrylonitrile samples (labelled PAN) are presented in Table 4, in addition to Figures 3 and 4.

Transmission is substantially higher for non-elasticized polyacrylonitrile structures, but these values are lower than for non-elasticized viscose structures. Absorption for non-elasticized polyacrylonitrile structures is lower than for elasticized polyacrylonitrile structures. Generally, UV absorption of polyacrylonitrile samples is higher, in comparison to viscose samples. This difference is greater for non-elasticized samples.

The results of these measurements show that the UPF of elasticized polyacrylonitrile structures is substantially greater than that of non-elasticized polyacrylonitrile structures. For wet relaxed elasticized polyacrylonitrile structures, it is ~ 40, whilst for dry relaxed elasticized polyacrylonitrile structures, significantly lower, at ~20. For non-elasticized polyacrylonitrile structures, it is 6–13.

The UPF of all elasticized and non-elasticized structures is presented in Figure 5. All elasticized structures exhibit a significantly higher UPF than non-elasticized structures. For viscose samples, UPF is higher for those dry relaxed, than for wet relaxed, open and close structures. In contrast, for polyacrylonitrile samples, UPF values are higher for wet relaxed samples, than for dry relaxed open and close structures. Considering the dry relaxed elasticized structures, the UPF of viscose samples is greater, while in the case of the wet relaxed elasticized structures, the UPF of the tested polyacrylonitrile samples is greater. For non-elasticized structures, the UPF of polyacrylonitrile samples is greater than for the viscose samples, in all cases. As practical textile care normally includes washing – wet relaxation of garments cannot be avoided – polyacrylonitrile knits ensure higher levels of UV protection than viscose knits.

To evaluate linear correlation between the UV protection characteristics and porosity indicators of the investigated structures, the Pearson correlation coefficient (r) was calculated for all knitted samples. These analyses show that there is a weak inverse correlation between the UPF of the investigated samples on the one hand and the planar loop module δpl (r = –0.763) and the volume loop module δv (r = –0.653) on the other hand. Furthermore, UPF poorly correlates with fabric thickness t (r = 0.787) and mass per unit area M (r = 0.648). In contrast to the research results of woven fabrics cover factor effect on

Table 4. Values of ultraviolet protection factor (UPF), transmission (T), reflection (R) and absorption (A) of UV radiation of elasticized polyacrylonitrile knits and polyacrylonitrile knits without elastane

sample	PAN-EL DR C	PAN-EL WR C	PAN-EL DR O	PAN-EL WR O	PAN DR C	PAN WR C	PAN DR O	PAN WR O
UPF	20.79	39.42	20.68	39.71	9.98	12.64	6.68	7.14
T (290-400) UV	7.26	3.88	7.83	3.90	13.44	11.28	18.82	17.51
T (290-315) UVB	3.84	2.01	3.70	1.99	8.49	6.46	13.02	12.21
T (315-400) UVA	8.29	4.45	9.08	4.48	14.93	12.74	20.56	19.11
R (290-400) UV	52.80	50.34	50.41	51.52	52.19	53.06	51.46	49.73
R (290-315) UVB	42.91	39.60	39.99	40.84	42.56	42.55	41.74	40.51
R (315-400) UVA	55.79	53.59	53.56	54.74	55.10	56.24	54.40	52.52
A (290-400) UV	39.94	45.77	41.75	44.58	34.37	35.65	29.72	32.76
A (290-315) UVB	53.25	58.39	56.30	57.17	48.94	50.99	45.24	47.28
A (315-400) UVA	35.92	41.96	37.35	40.77	29.96	31.02	25.02	28.37

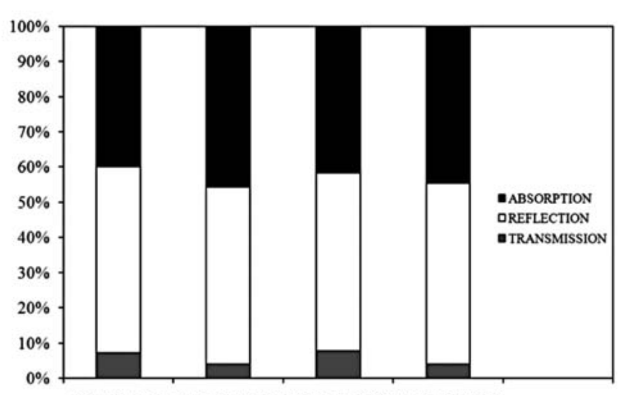

Figure 3. UV transmission (T), reflection (R) and absorption (A) of elasticized polyacrylonitrile knits

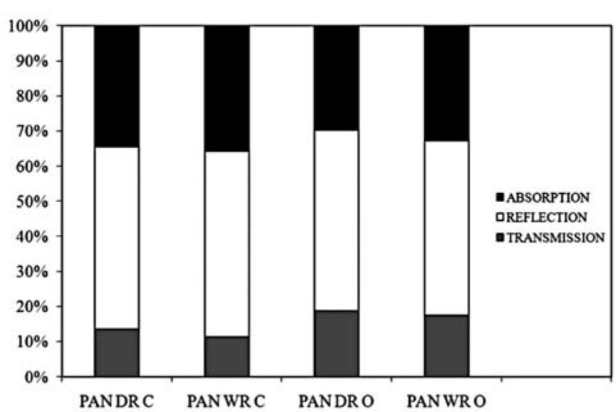

Figure 4. UV transmission (T), reflection (R) and absorption (A) of UV of the non-elasticized polyacrylonitrile knits

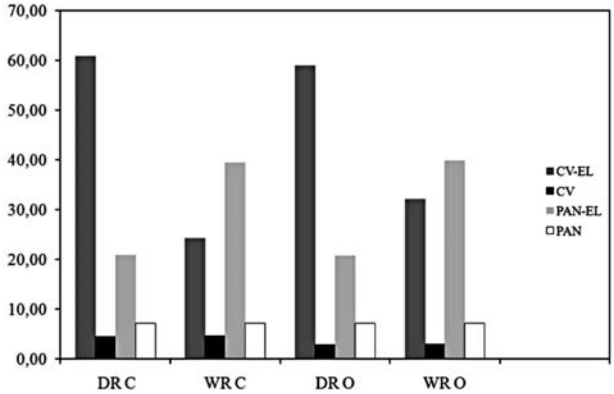

Figure 5. UPF of elasticized and non-elasticized viscose and polyacrylonitrile knits

UPF[12], no distinctive correlation was found between UPF and cover factor *K,* of the investigated knits.

Transmission of UV radiation correlates poorly with the voluminosity *V* (r = 0.692) and volume loop module δv (r = 0.618) of the investigated structures. It moderately correlates with the planar loop module δpl (r = 0.805). Furthermore, it also moderately inversely correlates with fabric thickness *t* (r = –0.817) and poorly with mass per unit area *M* (r = –0.680). Absorption of UV radiation correlates poorly with the fabric thickness *t* (r = 0.717).

4. Conclusions

UV protection of dry relaxed elasticized viscose knits is excellent (UFP >40), whilst it is good (UPF=24-32) for wet relaxed elasticized viscose knits. For non-elasticized viscose knits, UPF is extremely low, at UPF=2-5. UV protection of the wet relaxed elasticized polyacrylonitrile knits is very good (UPF ~ 40) but lower, e.i. good for the dry relaxed elasticized polyacrylonitrile knits (at UPF ~ 20). For non-elasticized polyacrylonitrile knits, UPF is low, at 6–13.

The investigation shows that wet relaxed elasticized knits show good to very good UV radiation protection. In contrast, non-elasticized viscose and polyacrylonitrile knits are inappropriate for UV radiation protection. As already stated, textile care usually includes washing and therefore wet relaxation of garments will always occur, consequently none of the investigated elasticized knits actually exhibits excellent UV protection (UPF >40). Generally, polyacrylonitrile knits investigated, ensure better UV protection than viscose knits.

Planar loop module is a moderate UV transmission indicator. Furthermore, UV transmission moderately inversely correlates with fabric thickness. There is no observed distinctive correlation between the UPF and the parameters describing porosity/compactness of the investigated knits.

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Povzetek

Tekstilije so lahko učinkovita zaščita pred UV sevanjem, ker odbijajo, absorbirajo in razpršijo sončno svetlobo. Če so ustrezno projektirane, povečajo delež pokrite kože. Optimalna kombinacija debeline, gostote, ploščinske mase in vezave tekstilije ter vrste in dolžinske mase preje omogoča izdelavo tekstilij z dobrimi UV zaščitnimi lastnostmi. Namen raziskave je bil oceniti vpliv dodatka elastana na UV zaščitne lastnosti viskoznih in poliakrilonitrilnih pletiv z vgrajenim elastanom in brez njega. Raziskava je pokazala, da mokro relaksirana pletiva z elastanom omogočajo dobro UV zaščito z UZF 20-40. Viskozna in poliakrilonitrilna pletiva brez elastana so, nasprotno, neprimerna za UV zaščito. Pri viskoznih pletivih z elastanom je višji UZF suho relaksiranih vzorcev, medtem ko je pri poliakrilonitrilnih pletivih z elastanom višji UZF mokro relaksiranih vzorcev. Pri pletivih brez elastana je višji UZF poliakrilonitrilnih vzorcev kot viskoznih vzorcev. Na splošno preiskovana poliakrilonitrilna pletiva zagotavljajo boljšo UV zaščito kot viskozna pletiva.