

ULTRAVIOLET (UV) PROTECTION OF TEXTILES: A REVIEW

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Abstract

Daylight from the sun reaches the surface of the earth through the earth's atmosphere and its spectrum extends from 290 nm to 3000 nm. The visible region lies between 400 and 700 nm. Radiation between 290 and 400 nm is referred to as ultraviolet radiation. Ultraviolet radiation has short wavelength and high energy and it is harmful for the human skin. Human beings must protect themselves against the harmful effects of the ultraviolet radiation. This paper summarises the interaction between ultraviolet radiation and textile surfaces and reviews the recent researches focused on the subject. A detailed review among the relation between ultraviolet light and the structural and physical properties of textile materials were presented.

Keywords: Ultraviolet Protection Factor, Fabric Structural Parameters, Porosity, UV Transmittance.

INTRODUCTION

The Nature of Electromagnetic Radiation

The nature of electromagnetic radiation can be described by two major theories; the wave and the quantum or corpuscular theory [1, 2]. The wavelength and frequency of radiation are related to its velocity, but the absorption and the emission of light cannot be fully explained by the wave theory. The basic elements of the quantum theory of light are energetic packets known as photons. According to this theory, higher frequency light has a higher energy and a shorter wavelength. Ultraviolet radiation is the energetically high, short wavelength light. Daylight reaches us from the sun through the earth's atmosphere; its spectrum extends from 290 nm to 3000 nm [1, 3-8]. Radiation between 290 and 400 nm is referred to as ultraviolet radiation [1]. The ultraviolet radiation (UVR) band consists of three regions: UV-A (320 to 400 nm), UV-B (290 to 320 nm), and UV-C (100 to 290 nm). UV-C is totally absorbed by the atmosphere and does not reach the earth. UV-A causes little visible reaction on the skin but has been shown to decrease the immunological response of skin cells. UV-B is most responsible for the development of skin cancers [9, 10].

Ultraviolet Protection Factor (UPF)

Ultraviolet protection factor (UPF) is the scientific term used to indicate the amount of ultraviolet (UV) protection provided to skin by fabric. UPF values are analogous to SPF (Sun Protection Factor) values the only distinction being that SPF values for sunscreens are determined through human testing whereas UPF values are based on instrumental measurements. UPF is defined as the ratio of the average effective UV irradiance calculated for unprotected skin to the average UV irradiance calculated for skin protected by the test fabric [10, 11]. The general approaches to testing fabrics for the ability to prevent sun burning are laboratory testing in vivo and instrumental evaluation in vitro. The quantitative measure of an in vivo determination is the sun protection factor (SPF), and that used to indicate the result obtained instrumentally is the ultraviolet protection factor (UPF) [12]. The quantification of protection that a fabric offers against ultraviolet radiation is obtained by the determination of the in vitro ultraviolet protection factor (UPF) [13]. Ultraviolet protection factor (UPF) defined in Australian/New Zealand Standard AS/NZS 4399:1996 has now been widely adopted by the textile and clothing industry worldwide

[14,15]. AATCC Test Method 183-1998 also uses the term UPF and the calculation defined by that test method and the UPF results are very similar to that of the AS/NZS 4399:1996 [14].

UV Protection of Textile Fabrics

Direct and diffuse UV transmittance through a fabric is the crucial factor determining the UV protection of textiles [10, 16]. The UV radiation transmitted through a textile fabric consists of the waves that pass unchanged through the pores of the fabric and scattered waves that have interacted with the fabric [17]. The UPF is actually the measure of UV radiation (UVA and UVB) blocked by the fabric. Higher UPF value means more blocked UV radiation [18]. 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 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 [19].

Several different effects occur when UV radiation hits a textile surface, causing the UV radiation to be broken down into several components. Part of the radiation is reflected at the boundaries of the textile surface; another part is absorbed when it penetrates the sample, that is, it is converted to a different energy form. Yet another part of the radiation travels through the fabric and reaches the skin; this part is referred to as the “transmission” [20]. Clothing has the ability to protect the skin from incident solar radiation because the fabric from which it is made can reflect, absorb and scatter solar wavelengths. Fabrics differ in their ability to attenuate light in this way because they differ in fiber composition and moisture content, as well as in type and concentration of dye, optical whiteners, or UV-absorbing finishes adsorbed to fibers. Each fabric must be tested to determine its ability to protect from solar radiation, as this cannot be known from visual observation nor calculated from descriptions of the fabric’s composition and structure [21]. The

dependence of the UV protection level on different clothes is determined by the shape and design of fabrics, and especially by their construction parameters. The main purpose of textiles designed to protect against ultraviolet radiation [22].

Table 1. Protection categories of fabrics according to ASTM D6603 [18]

Protection category	UPF range	Rating
Excellent	40-50, 50+	40,45,50, 50+
Very good	25-39	25, 30, 35
Good	15-24	15, 20

Since the transmitted UV radiation of textiles is composed of a diffuse component, which is modified by the fabric absorption properties, and an unchangeable component, which directly phases through the spaces between fabric yarns, the reduction of UV transmission can be achieved by changing the construction parameters of textile materials. The optimal combination of thickness, density, mass per unit area, and weave of woven or knitted fabric, as well as yarn type (mono or multifilament) and fineness, allow production of textile products with high UV protection properties [22]. 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, the porosity of fabrics or their cover factor which all together influence the most important parameter [3, 19, 23-25]. In engineering woven fabric with good UV radiation protection, the following factors must be considered [18, 27-31]:

1. Composition of the fibers (most natural fibers transmit UV radiation more than synthetic ones),
2. Tightness of the weave (the more closely woven fabric, the less of UV radiation is transmitted),
3. Color (dark colors of the same fabric type will absorb UV radiation more strongly than light pastel shades and will consequently have higher UPFs),
4. Stretch (the greater the stretch the lower the UPF rating),
5. Moisture (wet fabrics provide less UVR protection),
6. Finishing (UV absorbing chemicals improve UPF) [18]

Woven fabric construction is one of the basic factors that have a direct effect on UPF. Woven fabric construction is altered by three primary constructional parameters, namely; yarn fineness, weave type and warp/weft density. Primary parameters of fabric construction are dependent variables, where the choice of one parameter influences the effect of the others. Therefore, yarn fineness influences fabric densities over the weave type. Via the defined selection of primary parameters of fabric construction, all other fabric construction parameters (cover factor, fabric porosity, crimp, mass, thickness, etc.) may be seen as constant and dependent on primary parameters [18]. Many factors influence the UVR transmission properties of textiles. Among the most important factors are fiber type, dyes and finishes, and fabric porosity. Radiation absorbed by a dye, pigment, delustrant, or UV absorber cannot be passed through to the skin and in this way enhances sun protection provided by a textile. In general, dyed fabrics provide better sun protection than bleached fabrics [9, 11, 32-36]. Pailthorpe observed that unbleached cotton has a higher UPF than bleached cotton and speculated that this was due to the pigments remaining in unbleached cotton. The UVR transmission of bleached conventional cotton is nearly twice as high as unbleached conventional cotton [34].

EFFECTS OF STRUCTURAL PARAMETERS ON UV PROTECTION PROPERTIES OF TEXTILES

Effects of Fiber Chemistry

Fiber type is known to affect UV transmission with differences in absorption occurring among fibers e.g. cotton transmits less than other natural fibers, while polyester absorbs strongly in the UVB region [37]. Fabric composition is another important factor in determining UV protection degree because fibers can have different radiation-absorbing properties. Recent studies have demonstrated that synthetic fibers, such as polyester, offer good protection from UV radiation, but they are water-repellent and therefore uncomfortable to wear at high temperatures (generally associated with high UV levels).

Naturally fibers, like cotton and flax, are most commonly used for making summer clothes and their use, as well as that of other natural fibers like hemp, is increasing also due to their hypo-allergenic properties. Most researchers into UV protection properties of natural fibers have focused on cotton [26]. A fabric's ability to block UVR depends on fiber chemistry. In general, it was found that fibers with large conjugated aromatic polymer systems such as polyester were more effective in blocking UVR [35, 38-40]. Polyester, an aromatic polyethyleneterephthalate, which is also a highly hydrophobic fiber, is known to have a high protective factor against transmittance of UV light [1, 7, 41]. Polyester contains benzene rings in the polymer chains and this fact may account for the increased absorption of UV light [38]. Polyester fabrics offered increased protection over cotton. The presence of dyes increased protection considerably. The UVR-blocking ability of polyester is further significantly enhanced by the addition of a delusterant such as titanium dioxide. Among natural fibers only wool possessed good UV-protecting abilities [35, 39]. White cotton, linen, and viscose rayon offered little protection against UVR [39, 40]. Nylon, acrylic, and acetate also were found to be poor inhibitors of UVR [38]. In terms of fiber content, it is evident that the presence of polyester in a blended fabric increases the UPF of the fabric [39]. Blending of polyester and cotton in a fabric would provide significantly better protection than cotton alone. Such a blended of polyester and cotton would provide increased absorbency and thus increased comfort for clothing worn in warm weather [38]. As for cotton fabrics, it is equally clear that irrespective of fabric construction, greige (untreated) fabrics afford superior protection against UVR transmission [39]. The cotton samples consistently offered less protection than similar polyester fabrics. Fabrics with similar construction, tightness of weave, or knit, count, or mass, had SPF values 3-4 times lower than their polyester counterpart [38]. The transmission of UVR through fabric depends on the wavelength. The polyester samples exhibited a distinctive pattern of UVR transmission in which the transmission increased significantly at 313 nm, close to the

boundary between the UVB and the UVA spectral regions. This pattern is important to note because polyester fabrics offer less protection from UVA than from UVB radiation [38]. The diffuse ultraviolet transmittance spectra through the cotton and modal fabrics present an increasing curve with the wavelength; that is, the fabrics block a higher amount of UVB radiation than of UVA radiation. Although there is some blocking of ultraviolet radiation, the average transmittance values in the complete UVR spectra are excessively high and the fabrics do not provide sufficient protection [13]. Riva and Algaba reported that the modal sun fibre, specially designed for use in ultraviolet-radiation-protective clothing, has proved to be very efficient for its specific functionality. Although the structures of the modal sun fabrics are similar to those of the cotton and modal series, the UPF of the modal sun fabrics is remarkably higher. It is important to remark that the modal sun fibre mainly absorbs a great part of the radiation in the UVB wavelengths. This type of radiation is the most harmful for the human skin. For this reason, it is more weighted in the UPF formula. Thus, an effective blocking of the UVB radiation produces a remarkable increase in the UPF values of a fabric. The structure of the fabric is another factor that has an influence on the protection provided against ultraviolet radiation. Nevertheless, the higher or lower level of influence will depend on the type of fibre used to make the fabrics. Therefore, the UPF of the cotton or modal fabrics is less sensitive to variations in the structure, while the UPF of the modal sun fabrics is very sensitive [13].

Effects of Yarn Structure

Yarn twist proved to be the important determinant of the UV protection properties of fabric through the effectiveness of fiber packing in the yarn as well as through the influence on its surface properties [42]. Stankovic et al. reported that the yarn structure has a significant influence on UV protection properties of high UPF knitted fabrics through the influence on air volume distribution within the fabric, i.e. the fabric openness. The spacing of yarns was confirmed to be an important

determinant of fabrics' free open surface. The twist level affects to great extent yarn spacing. Since yarn twist determines both core and surface geometry of the yarn, the yarn surface characteristics need to be a known parameter in order to estimate fabric pore size distribution precisely. The yarn twist to a great extent influenced the UV protection properties of the knitted fabrics through the influence on yarn compactness and surface properties, which in turn influenced the open porosity of the fabric. It should be stated that UV protection properties of the knitted fabrics are also influenced by some differences in stitch density caused by yarn twist level introduced [42].

Effects of Weave Type

UPF depends on the type of weave. From the thermo physiological point of view, it is better to use light shaded clothes which reflect the IR radiation. It is known that with satin weave it is possible to achieve higher warp/weft density than with twill or plain weaves, so the macro pores are smaller and UV radiation has less free space to pass through than in twill or plain weaves. Besides that, the macro pores in plain fabrics have very stable and uniform form as a consequence of higher thread passages. On the other hand, the pores in satin fabrics are not as stable due to fewer thread passages or interlacings, and tend to group together which further reduces the free space area. According to Dubovski and Golob higher actual warp/weft density by each weave means higher fabric tightness and consequently higher UV protection. The macro pores as three-dimensional forms are bigger, more stable and uniform in plain fabrics compared with macro pores in twill or satin fabrics at the same volume porosity. Lower volume porosity means higher UPF [18]. Researchers have shown that fabrics woven in sateen weaves provide the best UV protection (in comparison with twills and weaves similar to plain weave). 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 [19].

Effects of Yarn Count and Density

According to Sarkar and Crews et al., a possible explanation for the negative correlation between thread count and UPF is the fact that fabrics that are thinner tend to contain finer yarns and therefore have the highest thread counts [11]. Thread count appears to negatively correlate with UPF [10].

Effects of Fabric Weight and Thickness

Sarkar reported that fabric construction parameters of weight and thickness showed a positive correlation with UPF values. Higher the weight and thicker the fabric, higher is the degree of protection afforded by the fabric. Fabric weight and thickness are important predictors of UPF values for undyed cotton fabrics. In general, it was found that increase in weight and thickness increased the UPF though the relationship was not linear [10]. Davis et al. reported that fabric SPF generally increased with increase in mass or weight, but the relationship was not linear [38]. Fabric thickness also seems to be important in the sense that thicker, denser fabrics tend to transmit less UVR [38, 39, 43, 44].

Effects of Fabric Porosity and Cover Factor

Fabric construction is the primary determinant of fabric porosity, followed by fabric weight. The closer the weave or knitting, the less UV radiation is transmitted. Spaces between the yarns are generally wider in a knitted fabric than in a woven textile, and plain woven textiles have a lower porosity than textiles in other weaves. An increase in weight per unit area also decreases fabric porosity. Thickness is also a useful variable for understanding differences in UV protection between fabrics [26]. Cloth cover is a measure of the fraction of area covered by both the warp and weft yarns in a given fabric and calculated by using thread density (number of warp and weft threads per inch in a woven fabric) and yarn count (relative measure of fineness of yarns; higher the number, the finer is the yarn) according to an equation by Booth [45]:

$$\text{Cloth Cover} = C_{f_{\text{warp}}} + C_{f_{\text{weft}}} - [(C_{f_{\text{warp}}} \times C_{f_{\text{weft}}}) / 28]$$

$$\text{Cover Factor (Cf)} = \frac{\text{Threads per inch}}{\sqrt{\text{Yarn number (cotton count system)}}}$$

In terms of cloth cover it seems that a higher cloth cover translates into higher UV protection. A cover factor of 28, means that all yarns touch each other and therefore in theory fabric should permit little or no UVR transmission [39]. The positive correlation between fabric weight and fabric thickness with UPF values can be explained with reference to porosity. Porosity is a measure of tightness of weave and is also called as cover factor [10, 34, 46]. The closer the weave, the more is the percentage area occupied by the yarns and more opaque is the fabric to UV radiation. Cover factor is increased by an increase in weight per unit area. Heavier fabric minimizes UV transmission by virtue of having smaller spaces between yarns thus blocking more radiation [9, 10, 34]. A related variable is thickness. Thicker, denser fabrics transmit less UV radiation and have a higher cover factor [10,11]. According to Capjack et al., with regard to fabric construction, porosity of fabrics was determined to be the best predictor of UVR transmission particularly for white and undyed fabrics. Plain woven textiles have the lowest porosity because the interlacement of yarns in a plain weave creates double layers of fibrous material. Fabric porosity is also the reason why knit fabrics by virtue of their open structure provide less UVR protection than their woven counterparts. In knit fabrics, loops are pulled through previously formed loops and double layers are rare [9,39]. The effect of fabric structure has been related to the cover of woven or gauge of knitted fabrics [6,37,47] with tighter or closer structures associated with fewer ‘holes’ in the fabric and thus less transmission [37,47,48]. Fabric effects have also been linked to the degree of cover/interstitial space present in a particular fabric, fiber type [11, 13, 37], structure[37, 49, 50], and/or thickness [11,37]. Dubrovski and Golob pointed that the fabric cover factor is one of the parameters representing the woven structure, but its disadvantage is the absence of weave influence. The relationship between cover factor and UPF followed the exponential function, with very high index of correlation (0.97). The higher the cover factor the greater the UV protection. Higher cover factor meant higher UPF, but this correlation was not linear

and depended on the color of the fabrics [18]. Gabrijelčič et al. reported that 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 (UPF above 20). At coverage higher than 95%, the fabrics analyzed could be generally divided into three groups with respect to the effectiveness of their UV protection: fabrics of darker colors (black, blue) with extremely high UPF values, fabrics of chromatic lighter colors (yellow, red, green) with UPF values half of those of darker colors in general, and white fabrics (bleached) in which the desired UPF values are not reached regardless of the degree of the cover factor [19].

Effects of Dyeing

Dyes are selective absorbers of visible light. Most dyes absorb light in the region between 400 and 700 nm, and some also absorb light in the near ultraviolet region [1, 51-53]. On textiles, those dyes often provide a great blocking effect of ultraviolet light transmittance [1, 54]. Undyed and untreated cotton fabrics (woven or knitted) have high UV transmission and, therefore, little protection. However, when dyed, the dyed fabrics could provide better protection than undyed fabrics. This protection depends on the type of dye, its concentration and the type of fabrics. The chemical cross-linking of undyed fabric with UV absorber appears to be the best way to increase its UPF and to provide an excellent UV protection [17]. Fabric color also has a fundamental importance in UV protection; dyed fabrics protect more than undyed ones and their protection levels rise with the increase in dye concentration. In general, light colors reflect solar radiation more efficiently than dark ones, allowing incident radiation to penetrate through the fabric with reflecting actions (scattering). With the same fabric construction and dyestuff, the darker the shade, the higher the fabric ultraviolet protection factor. Black, navy blues, dark greens, etc. significantly improve fabric UPF, whereas very light pastel shades only provide slight improvements. However, particular hue dyes can vary considerably in the level of UV protection because of specific

transmission and absorption characteristics [26]. Dyed fabrics provide better sun protection than bleached fabrics. The naturally-pigmented cottons exhibited significantly higher UPF values than conventional cotton (bleached or unbleached) [32]. Gorenssek and Sluga reported that the influence of disperse dyes on the UPF of fabrics is high. The structure of dye molecules plays an important role. Besides the transmittance and reflectance of UV radiation, the absorbance of UV radiation by molecules becomes important. Deep dyed polyester fabrics show excellent protection from UV radiation. Possibility of UV light absorbing in the short UV region is probably the consequence of the formation of bonds between dye molecules and between dye molecules and fibers [1]. Gies et al. indicated that dyeing fabrics in deeper shades and darker colors improves sun protection properties [49]. According to Sarkar, the K/S values of the dyed fabrics which are a measure of color depth seem to support the claim that higher color depths increases UPF values. However, the relationship of K/S with UPF is limited to the same fabric type and the results cannot be generalized across fabrics of different weave structures [10]. Sarkar reported that UPF of undyed fabrics was significantly enhanced by dyeing with natural colorants especially for fabrics such as the plain weave and the sateen weave fabrics that displayed no protective abilities in the undyed state. The degree of protection imparted after dyeing was a function of the concentration of the colorant in the fabric. Within the same fabric type, as the percentage depth of shade increased so did the UPF values. In addition, darker colors such as indigo provide better protection on account of higher UV absorption [10].

Effects of Bleaching

Bleaching is the removal of hydrophobic impurities from fabrics. Optical brightening agents also known as fluorescent whitening agents are weak chemical compounds that absorb light at one wavelength and reemit the energy at another wavelength. They have the effect of making whites appear 'whiter than white' [39, 55]. Preparatory treatments, that is, treatments before dyeing and finishing such as

sizing and particularly bleaching have a deleterious effect on the UV protective ability of fabrics. Thus in practical terms the data show that for summer wear a lightweight, thin bleached cotton garment is not a wise choice for protection against UVR. However, a simple choice of a wrinkle-free garment treated with an optical brightener would be sufficient protection against harmful UVR transmission [39]. Inclusion of bleaching processes (e.g. by removing naturally occurring pigments and lignins which act as UV absorbers) and introduction of optical brightening and fluorescent and whitening agents also affect transmission [3, 37, 47, 48, 56]. Crews et al. [11] and Curiskisa et al. [51] reported that bleaching considerably increases the transmittance of cotton textiles and aggravates their UV protection. The color 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 [19]. Zhou and Crews showed that optical brightening agents used in laundering detergents improved the UV radiation blocking ability of cotton fabrics and cotton/polyester blends [57, 58].

Effects of Enzymatic Treatments

Cellulase is one of the important enzymes used in knit fabric processing to improve fabric smoothness, a process referred to as bio-polishing. Bio-polishing is now an established procedure for cleaning the surface of knit fabrics that suffer from excess surface hairiness and neps due to excess mechanical action or prolonged dyeing in a jet dyeing machine. Cellulase like all other enzymes is a biological catalyst that temporarily binds to the fabric during treatment. It is not consumed in the reaction and is released at the conclusion of the reaction thus adding no moieties to the fabric. However, the enzymatic action of cellulase on cotton is a surface phenomenon that results in significant structural changes in the treated fabric [39, 59, 60]. Contrary to the effect of chemical processing on UPF values, bio-chemical processing seemed beneficial in that the UPF value of the fabric increased after

treatment. There was a 51–70% increase in the UPF value as a result of enzymatic treatment at various agitation speeds and treatment durations [39, 44]. Chemical processing methods such as desizing and bleaching have a deleterious effect on UV transmission through fabrics. Bio-chemical processing such as the use of enzymes is comparatively benign and does not adversely impact the UV protective ability of cotton fabric [39].

Effects of Wet Treatments

Conditions of use may also influence the actual UVR transmission and UPF capacity of the fabric. For example, during use the fabric may become wet, is often extended, and has a geometric arrangement different to the arrangement of flat fabrics assessed during laboratory testing. Additional use effects such as differences in the surface area of the body covered the angle of incidence with which UV transmission occurs and differences among garment designs may also affect the protection provided by garments [61]. Wilson and Parisi reported that a loose fit, which would increase the thickness of the underlying air layer, is associated with reduced transmission. However, in the white, “cotton/elastane, jersey” T-shirt, the fit relationship was modified to the extent that degree of fit did not affect UVB transmission. Physical variables such as fabric structure and physical properties possibly modified by finishing may have affected how the fabric fitted thus influencing UVB transmission. The low transmittance through the fitted white “cotton/elastane jersey” T-shirt also appears consistent with the presence of a UV reducing finish. If this is the case the finish was more effective at reducing transmission when worn as a fitted rather than a loose design. The effects of fit, color, and wetness also varied according to the fabric and specific combination of characteristics evaluated. Fabric type, fit, color, and wetness all affected UVB transmission. Thus, the effects of fabric type and fit on transmission were modified by the fabric color and the extent of wetness [61]. Pre-treating fabrics prior to measuring UV transmission is important if claims about transmission are to reflect the characteristics of the fabric during care and use. The effect of wetness and color

were less important influences on transmission of UVB during wear [61]. Stankovic et al. reported that the strong influence of yarn core and surface geometry on UPF of plain cotton knitted fabrics was confirmed by wet relaxation of the knits. Although the differences in knitted fabrics' construction became smaller after wet treatment, the differences in UVR transmittance of the released and shrunk knitted samples were still retained [42]. It is also known that worn and faded fabrics may have reduced UPF ratings, while washed cotton and polycotton fabrics, because of fabric shrinkage, slightly improve UPF [18]. Recent trials showed a significant increase of the UPF of different fabrics after one or more wash-and-wear cycles, which is due to shrinkage of the textile. On the other hand, when garments are wetted or stretched, the UPFs substantially decrease. Moreover, it is notable that cumulative UV exposure of garments induces photo-oxidative processes that impair the stability of the fabrics and perhaps result in decrease of the UPFs. In comparison to synthetic polymers (e.g., polyester, polyacrylic) viscose fabrics have poor stability to UV-induced photo-oxidation [20, 23, 62, 63].

Effects of Extension and Layering

Extension, color, and layering also affected transmission, with their effects commonly varying among fabric types. Transmission was also affected by interactions between other variables, for example, the effect of extension varied between colors. Extension and layering also modified protection, illustrating the importance of considering the effects of fit and design both when developing and selecting clothing. Selecting dark colors, limiting extension and layering fabric were shown to be effective ways of increasing UV protection and UPF by decreasing transmittance. However, the effect of color, extension and layering varied among fabric types and modified UVA and UVB transmittance differently [37]. Variables modified transmission in the UVA and UVB parts of the spectrum differently. For example, the main effect of color was on the UVA part of the spectrum while wetting, extension, and layering had the greatest effect on UVB

transmission. Such differences may have implications in term of claimed protection from UVR as expressed by calculated UPF value [37]. A double layer of uncolored fabrics results in approximately 3.5 times higher UPF than that of the monolayer fabric. A higher UPF is also shown by combinations of the uncolored fabric turned to the source of UV radiation with pale dyed fabrics. The highest UPF values appear with combinations of the uncolored fabric turned to UV radiation with deep dyed fabrics. The UPF of such combinations increases approximately 30 times [1]. The influence of a UV absorber on the UV blocking effect of uncolored polyester fabrics is very high. The UPF is six times higher compared to the UPF of double layered uncolored fabrics. A similarly high effect is true for the application of a UV absorber on pale dyed polyester fabrics. Aftertreatment of deep dyed fabrics with high UPF values seems unnecessary [1].

Effects of UV Absorbers

Crews et al. and Algba et al. conducted studies to investigate the factors affecting the UV radiation transmission of undyed fabrics [11, 57, 64]. It was concluded that the fabric porosity was the single best predictor of UV-blocking properties of an undyed woven fabrics. Other studies focused on the improvement of the UV protection of fabrics by applying available commercial UV absorbers (such as Cibatex UPFTM for cotton and cotton blend fibers, Cibafast WTM for wool, silk, and polyamide fibers and their blends, and Cibatex APSTM for polyester and its blends) [35, 57, 65]. Recent research has focused on modifying the cotton fabric surface using sol-gel method [57, 66]. Titania hydrosol prepared from tetrabutyl titanate $[Ti(OCH_2-CH_2CH_2CH_3)_4]$ and fluorescent whitening agents were applied using the sol-gel method to improve UPF of cotton fabric, and to improve the durability of the UVR protection provided by the fabric during the laundering process, a polyacrylate binder was used [80, 84]. In another study, titania nanosol was synthesized from titanium tetraisopropoxide as precursor $[Ti(OCH(CH_3)_2)_4]$ and applied to the cotton fabric [14,57]. Abidi et al. reported that

lightweight 100% cotton fabric was successfully modified by the sol-gel process to impart high ultraviolet radiation (UVR) scattering property to the fabric surface. Active ingredients were tetraethyl orthotitanate $[\text{Ti}(\text{OCH}_2\text{CH}_3)_4]$ and tetraethyl orthosilicate $[\text{Si}(\text{OCH}_2\text{CH}_3)_4]$. Scanning electron microscopy showed continuous and uniform film on the fiber surface. Excellent UVR scattering was obtained with all treated fabrics. Increasing titania content in the nanosol solution leads to increased UVR protection. This is attributed to the increase of the refractive index of the film formed on the fabric surface. Excellent durability of the treatment was obtained, which indicates a good adhesion between the coating and the fabric surface. This treatment imparted excellent UVR protection to the cotton fabric especially in the region of the UVB [290–315 nm]. The formation of covalent linkages between the OH groups of cellulose and the OH groups of titania and titania-silica network imparted excellent durability of the treatment to repeated home laundering [57]. UV absorbers are substances, such as substituted benzothiazoles, which selectively absorb UV radiation and convert it to heat [20, 23, 53, 67–70]. These substances should be attached to the fabric with covalent bonds to achieve a permanent improvement of UV protection. Dyes with an absorption spectrum within the UV range may also be used for this purpose. One problem associated with both UV absorbers and dyes is that they are potential allergens. The UV permeability of synthetic polymers can be reduced by deposits of pigments (e.g. TiO_2). Incorporated pigments bring about a permanent improvement of UV protection because the pigments are surrounded by the fibers and cannot be washed out. Moreover, since these pigments are located inside the fibers, they cannot penetrate the skin. The incorporated pigments exert two beneficial effects: first, they have a great impact on the increase in reflection, and second, they improve absorption [20]. Ibrahim et al. reported that post treatment with Cu-acetate or post dyeing with anionic or basic dyes results in a dramatic improvement in UPF values, irrespective of the used finishing additive. The extent of improvement in UPF

values follows the decreasing order: resin finishing followed by post-dyeing > resin finishing followed by subsequent treatment with cu-acetate > resin finishing > resign finishing without additives [71]. The improvement in other performance properties of the evaluated fabrics are determined by: the chemical nature of additive, its functionality, ability to interact with and modify the cross linked structure, additional active sites (anionic or basic groups), as well as location and extent of distribution [71].

CONCLUSION

The interaction between ultraviolet radiation and textile surfaces were summarised and the recent researches focused on the subject were reviewed in this paper. A detailed review among the relation between ultraviolet light and the structural and physical properties of textile materials were presented. The subject was reviewed according to the structural and wet processing properties of the textile fabrics. The ultraviolet protection of the textile surfaces change considerably according to the fibre type, fabric construction, fabric porosity and to the treatments associated with water. A supporting increase in a property can cause a decreasing affect because of its relation with the other properties.

REFERENCES

- [1] Gorensek, M., Sluga, F., Textile Res. J., 2004, 74(6):469-474.
- [2] McDonald, R., Ed., Society of Dyers and Colourists, U.K., 1987, pp.1-8.
- [3] Pailthorpe, M., Textile Horizons, 1996, 16(5):11-14.
- [4] Bohringer, B., Schindling, G., Schon, U., Hanke, D., Hoffmann, K., Altmeyer, P., Klotz, M.L., Melliand Int., 1997, (3):165-167.
- [5] Eckhardt, C., Rohwer, H., Textile Chem. Color. Am. Dyest. Rep., 2000, 32(4):21-23.
- [6] Palacin, F., Melliand Textilberichte, 1997, (7/8):519-522.
- [7] Reinert, G., Hilfiker, R., Schmidt, E., Fuso, F., Textilveredlung, 1996, 31(11/12):227-234.
- [8] Schuierer, M., Melliand Int., 1997, (3):168-169.
- [9] Capjack, L., Kerr, N., Davis, S., Fedosejevs, R., Hatch, K.L., Markee, N.L., Family Consumer Sci. Res. J., 1994, 23:198-218.
- [10] Sarkar, A.K., BMC Dermatology, 2004, 4(15)
- [11] Crews, P.C., Kachman, S., Beyer, A.G., Textile Chemist and Colorist, 1999, 31(6): 17-26.

- [12] Menter, J.M., Hatch, K.L., Elsner P, Hatch K, Wigger-Alberti W (eds): Textiles and the Skin, Curr. Probl. Dermatol., Basel, Karger, 2003, 31, pp. 50–63.
- [13] Riva, A., Algaba, I., Journal of The Textile Institute, 2006, 97(4):349–357.
- [14] Xin, J.H., Daoud, W.A., Kong, Y.Y., Textile Res. J., 2004, 74:97-100.
- [15] CIE Research Note, A Reference Action Spectrum for Ultraviolet Induced Erythema in Human Skin, CIE J., 1987, 6:17-22.
- [16] Hoffman, K., Laperre, J., Avermaete, A., Altmeyer, P., Gambichler, T., Archives of Dermatology, 2001, 137:1089-1094.
- [17] Abidi, N., Hequet, E. F., Abdalah G., Proceedings of the Beltwide Cotton Conference, 2001, 2:1301-1303.
- [18] Dubrovski, P.D., Golob, D., Textile Res. J., 2009, 79(4): 351-359.
- [19] Gabrijelčič H., Urbas R., Sluga F., Dimitrovski K., Fibres & Textiles In Eastern Europe, 2009, Vol. 17, No. 1 (72): 46-54.
- [20] Hoffmann, K., Kaspar, K., Gambichler, T., Altmeyer, P., The American Academy of Dermatology, 2000, 1009-1016.
- [21] Mentera, J.M., Kathryn L. Hatch, K.L., Textiles and The Skin, 2003, 31:50-63.
- [22] Dimitrovski, K., Sluga F., Urbas, R., Textile Res. J., 2010, 80(11):1027–1037.
- [23] Pailthorpe, M., Mutation Research, 1998, 422:175-183.
- [24] Davies, S., Capjack, L., Kerr, N., Fedosejevs, R., International Journal of Dermatology, 1997, vol. 36, p. 15-22.
- [25] Algaba, I., Riva, A., Crews, P.C., AATCC Review, 2004, p. 26-31.
- [26] Grifoni, D., Bacci, L., Zipoli, G., Carreras, G., Baronti, S., Sabatini, F., Photochemistry and Photobiology, 2009, 85 (1): 313-320.
- [27] <http://www.arpana.gov.au>
- [28] Zambetakakis, A., “Book of Proceedings International Textile, Clothing and Design Conference”, University of Zagreb, 2002, pp.152-157.
- [29] Roy, C.R., Gies, H.P., Toomey, S., J. Photochem. Photobiol. B., Biol., 1995, 31:21-27.
- [30] Edlich, R. F., Cox, M.J., Becker, D.B., Horowitz, J.H., Nicher, L.S., Britt, L.D., Edlich, T.J., Long, W.B., J. Long Term Eff. Med. Implants, 2004, 14(2):95-105.
- [31] Gies, P.H., Roy, C.R., Toomey, S., McLennan, A., Mutat. Res., 1998, 422(1):15-22.
- [32] Gwendolyn Hustvedt, G., Crews, P.C., The Journal of Cotton Science, 2005, 9:47–55.
- [33] Abidi, N., Hequet, E., Abdalah, G., In AATCC Book of Papers, SC. 21- 24 Oct. 2001: 105-109
- [34] Pailthorpe, M.T., In Proceedings of the Textile and Sun Protection Mini-Conference, 1993:32-50
- [35] Reinert, G, Fuso, F., Hilfiker, R. and Schmidt, E., Textile Chemist Colorist, 1997, 29 (12):36-43.
- [36] Zhou, Y. and Crews, P.C., Textile Chemist Colorist, 1998, 30 (11):19-24.
- [37] Wilson, C.A., Bevin, N.K., Laing, R.M., Niven, B.E., Textile Res. J., 2008, 78(2):95-104.
- [38] Davis, S., Capjack, L., Kerr, N., Fedosejevs, R., Int. Journal of Dermatology, 1997, 36: 374-379.
- [39] Sarkar, A.K., Photodermatol Photoimmunol Photomed, 2007, 23: 191–196.
- [40] Gambichler, T., Avermaete, A., Bader, A., Altmeyer, P., Hoffman, K., Br. J. Dermatol., 2001, 144: 484–489.
- [41] Schuierer, M., Melliand Int., 1997, 3:168-169.
- [42] Stankovic, S.B., Popovic, D., Poparic, G.B., Textile Res. J., 2009, 79(11): 1034-1042.
- [43] Wong, J.C.F, Cowling, I., Parisi, A.V., In: First Internet Conference on Photochemistry and Photobiology, 1997.
- [44] Sliney, D.H., Benton, R.E., Cole, H.M., Epstein, S.G., Morin C.J., Appl. Indus. Hyg., 1987, 12: 36–44.
- [45] Booth, J.E., Yarns and Fabrics, Boston: Newnes-Butterworths, 1968.
- [46] Rieker, J., Guschlbauer, T., Rusmich, S., Melliand Textilberichte, 2001, 7– 8:155-156.
- [47] Curiskis, J.I., Postle, R., Norton, A.H., The Textile Machinery Society of Japan, Osaka, Japan, 1983, pp.539-550.
- [48] Pailthorpe, M.T., Australas. Textiles, 1994, 14(6): 54, 56, 59, 61-62, 64, 66
- [49] Gies, H.P., Roy, C.R., Elliott, G., Zongli, W., Healty Phys., 1994, 67(2):131-139
- [50] Taylor, M.A., “Technology of Textile Properties”, Revised 3rd., Forbes Publications, England, 1995.
- [51] Curiskisa, J., Pailthorpe, M., Textile Magazine, 1996, 25(4):13-18.
- [52] Gorenssek, M., Sedeljsak, J., Tekstilec, 2000, 43(11-12):405-413.
- [53] Hilfiker, R., Kaufmann, W., Reinert, G., Schmidt, E., Textile Res. J., 1996, 66(2):61-70.
- [54] Burkinshaw, S.M., Blacky Academic & Professional, U.K., 1995, pp.2-7.
- [55] Kadolph, S., Textiles, New Jersey: Pearson Prentice- Hall, 2007, 420: 366-368.
- [56] Bajaj, P., Kothari, V.K., Gosh, S.B., Indian J. Fibre Textile Res., 2000, 25(4):315-329.
- [57] Abidi, N., Hequet, E., Tarimala, S., Dai, L.L., Journal of Applied Polymer Science, 2007, 104: 111–117.

- [58] Zhou, Y., Crews, P.C., AATCC Rev., 1998, 30(11):19-24.
- [59] Buschle-Diller, G., Zeronian, S.H., Pan, N., Yoon, M.Y., Tex. Res. J., 1994, 64:270–279.
- [60] Haga, T., Takagishi, T., J. Appl. Polym. Sci., 2001, 80:1675–1680.
- [61] Wilson, C.A., Parisi, A.V., Textile Res. J., 2006, 76 (3): 216-225.
- [62] Bobeth, W., Textile Faserstoffe: Beschaffenheit und Eigenschafften, Berlin: Springer-Verlag, 1993.
- [63] Sayre, R.M., Menter, J.M., Willis, I., Hughes, S., Photodermatol Photoimmunol Photomed 1999,15:154.
- [64] Algba, I., Riva, A., Crews, P.C., AATCC Rev., 2004, 4:26.
- [65] Hilfiker, R., Kaufmann, W., Reinert, G., Schmidt, E., Text. Res. J., 1996, 66: 61.
- [66] Xu, P., Wang, W., Chen, S.L., AATCC Rev., 2005, 5:28.
- [67] Palacin, F., Textilveredlung, 1996,31:11-2.
- [68] DIN Norm.Textiles: Standard Atmospheres for Conditioning and Testing; ISO 1973, 139–German version 1992, EN 20 139.
- [69] Reinert, G., Schmidt, E., Hilfiker R., Melliand Textilberichte, 1994, 75:606.
- [70] Stanford, D.G., Georgouras, K.E., Pailthorpe, M.T., Med. J. Aust., 1995, 162:422-5.
- [71] Ibrahim, N.A., Allam, E.A., El-Hossamy, M.B., El-Zairy, M., Polymer-Plastics Technology and Engineering, 2007, 46: 905–911.