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A Review on Ultraviolet Protection of Textiles

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Abstract:*Protection of the skin against the action of solar radiation is a relatively new objective of textile finishing, since the textile does not always guarantee adequate protection. Specific protective functions of textiles against the most diverse influences are attracting more and more attention. Skin cells receive sunlight absorb harmful UV radiation, and slough off to excrete harmful UV from the body. The UV radiation is greatly influenced by the properties of fabric structure like weight basis, density and type of weaves. Generally a tight weave will provide greater resistance to UV penetration and higher GSM (g/m^2) weave provides a greater limit. Fabrics should block or reflect as much light as possible. Tightly woven fabrics generally protect better than loosely woven fabrics. Less UVR passes through tightly woven or knitted fabrics. Open weave fabrics have holes that do not block the UV light from skin. For achieving better UV protection, Titanium Dioxide (TiO_2) has good ultraviolet protection power and is very attractive in practical applications because there are few advantages as chemical stability at high temperature, nontoxic, and permanent stability under UV exposure.UPF has been widely used by the textile and clothing industry worldwide to encode the protective ability of a textile based on instrumental measurements.*

Keywords: Finishing, Protection, Ultra-violet radiation, Skin

INTRODUCTION

Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays. UV radiation is the one form of radiant energy coming out from the sun. The sun emits a range of energy known as the electromagnetic spectrum. The various forms of energy, or radiation, are classified according to wavelength. The shorter the wave-length, the more energetic the radiation. Sunlight that reaches the earth is composed of 66% of infrared light, 32% visible light, and 2% ultraviolet light (UVL). Ultraviolet, which is invisible, is so named because it occurs next to violet in the visible light spectrum [1].

Type of UV rays

UV radiation can be classified as UVA(320-400 nanometers), It causes premature skin aging, wrinkling and potentially skin cancer. It Penetrates skin more deeply than UVB rays and can impact skin during any hour of daylight. UVB (290-320 nm), which causes sunburn and also contributes to premature skin aging and potentially to skin cancer. It also causes most impact between 10 am and 4 pm and Penetrate clouds, but not glass. UVC (200-290 nm), which deadly to humans and It is absorbed by atmospheric gases before it reaches the earth's surface [2,3].

Impact of UV radiation on human skin

The sensitivity to light and tendency to pigmentation, there are six basic types of skin that demand different levels of UV protection (shown in Table 1). Lot of research has been carried out to assess the impact of the UV rays on various living organisms, specially humans and the relationship between skin cancer and UV dosage is well related. Different types of factors that affect solar UV radiation include cloud cover, the sun’s altitude, geographical position, ozone layer, scattering in the atmosphere, altitude, environmental and related conditions [4]. Skin cells receive sunlight absorb harmful UV radiation, and slough off to excrete harmful UV from the body. But absorption of too much harmful UV radiation leads to scars that can induce diseases like skin cancer. Prolonged UV radiation leads to cell damage and causes inflammation of human skin, the most obvious consequences which are erythema or sunburn. Thereciprocal value of these cuticle radiation doses is called erythema effectiveness whose maximumoccurs at 308 nm and the total UV radiation dose reaching the skin is an important factor in both erythema and skin cancer, moreover there is no proved link between erythema and skin cancer [5].

Table 1: Effect of UV rays on different types of skin

Skin type	Appearance unexposed	Critical dose mJ/cm^2	Self protection Time (min)	Risk level
I	White	15 – 30	5 – 10	Easily burns and has the maximum risk of premature skin ageing and greatest risk of developing skin cancer.
II	White	25 – 35	8 – 12	Burn and rarely tan
III	Brownish	30 – 50	10 – 15	Tan and occasionally burn
IV	Brown	45 – 60	15 – 20	Tan and occasionally burn
V	Brown	60 – 100	20 – 35	Sufficient levels of melanin and rarely burns, easily tan
VI	Dark brown-black	100 – 200	35 – 70	Sufficient levels of melanin pigment provide protection. Very rarely burns, easily tan.

Ultraviolet (UV) photons harm the DNA molecules of living organisms in different ways. In one common damage event, adjacent bases bond with each other, instead of across the “ladder.” This makes a bulge, and the distorted DNA molecule does not function properly [6].

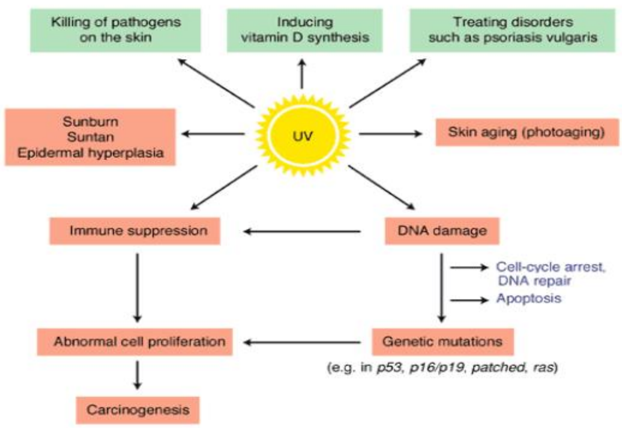

Figure 1: Effect of UV on living organism

What isUPF

UPF is the abbreviation for Ultraviolet Protection Factor and an accompanying numbered system defines a fractional value of how much UV radiation can penetrate the product [7]. UPF has been widely used by the textile and clothing industry worldwide to encode the protective ability of a textile based on instrumental measurements and is defined in Australian/New Zealand standard AS/NZS 4399:1996. UPF is the ratio of the average effective ultraviolet radiation (UVR) irradiance calculated for unprotected skin to the average effective UVR irradiance calculated for skin protected by the test fabric. Effective UVR irradiance is the product of relative erythemal spectral effectiveness and the relative energy value of solar irradiance reaching skin [8]. UPF measures both UVA and UVB radiation blocked. UPF rating does not refer to the design of the garment, just its material. For example a material of UPF 30 will allow a 1/30th of radiation to pass through it; the higher the UPF rating, the higher the protection level. Percent block is another scientific unit to express amount of UV protection. Actually, it is a unit that expresses a fabric property, the ability of the fabric to block UV from passing through it. The higher the percent of block, the better the fabric is at keeping UV radiation from reaching the skin. In many cases, UV block is expressed as UVA block and as UVB block [9].

Measuring systems of UPF

There are two systems are followed for the measure of the UPF values of textile materials are as follows:

1. InVitroand
2. InVivoorHumantesting

InVitro

Direct and diffuse UV transmittance through a fabric is the crucial factor determining the UV protection of textiles [10] .To measure the in vitro UPF an effective UVR dose (ED) for unprotected skin is calculated by convolving the incident solar spectral power distribution with the relative spectral effectiveness function and summing over the wavelength range 290±400 nm. The calculation is repeated with the spectral transmission of the fabric as an additional weighting to get the effective dose (ED_m) for the skin when it is protected. Thus UPF defined as the ratio of ED to EDm can be expressed by the following equation:

Ultraviolet Protection Factor,

$$UPF = \frac{ED}{ED_m} = \frac{\sum_{290\text{ nm}}^{400\text{ nm}} E_\lambda S_\lambda \Delta\lambda}{\sum_{290\text{ nm}}^{400\text{ nm}} E_\lambda S_\lambda T_\lambda \Delta\lambda}$$

Where, Eλ = erythemal spectral effectiveness, Sλ = solar spectral irradiance in W/m2/nm,Tλ = spectral transmittance of fabric,Δ λ = the bandwidth in nm and λ = the wavelength in nm [11].

In Vivo

In this technique, rectangular pieces of fabric are typically fastened to the skin and the MED of the protected and unprotected skin is assessed to give an SPF (Sun Protection Factor). With human volunteers, use of the sun as the UV source is impracticable to test the UPF of fabrics. Generally, xenon arc solar simulators are used, with filters to absorb wavelengths below 290 nm and to reduce visible and infrared radiation. Based on the skin photoype, MED is determined using incremental UV-B doses on the upper back of a subject and is read after 24 hours. The higher theSPF value, the better the fabric's ability to protect against sunburn.To measure the MED of protected skin, a textile is placed over the skin on the other side of the back [12]. The incremental UV-B doses for determining the MED of unprotected skin are multiplied by the UPF determined in vitro, with the product being the incremental UV-B doses for MED testing of the protected skin. The in vivo and in vitro methods are in agreement if the ratio of the MED of protected skin to the MED of unprotected skin results in the original in vitro UPF. Several studies however have shown that UPFs determined using the in vivo “on skin” method is significantly lower than the UPFs obtained in vitro. Again, as with the in vitro test method, the actual UPF of a garment would probably be much higher than the UPF determined using the in vivo test method [13].

$$\text{SPF} = \frac{\text{MED(protected skin)}}{\text{MED(unprotected skin)}}$$

The main advantage of the in vivo method is that it gives the direct response of the human body UVR and thus is a reliable check for results measured by optical techniques.

Classification of UV protecting clothing

Developed in 1998 by Committee RA106, the testing standard for sun protective fabrics in the United States is the American Association of Textile Chemists and Colorists (AATCC) Test Method 183. This method is based on the original guidelines established in Australia in 1994. Below is the ASTM Standard for Sun Protective Clothing and Swimwear which is considered the industry standard in rating such sun protective clothing. UPF Ratings and Protection Categories:

Table 2: UPF Classification system according to ASTM standard [14]

UPF Rating (hangtag)	UPF Range	UV Rays Blocked (%)	Protection Category
15+	15 – 24	93.3 – 95.8	Good protection
25+	25 – 40	95.9 – 97.4	Very good protection
40+	40 – 50+	>97.5	Excellent protection

Different standard for measuring UPF

Standard AS/NZS 4399 also establishes three categories of protection—excellent, very good, and good. The category in which a specific fabric belongs depends on the label UPF value. A fabric must have a UPF of 15 to be classed as UV protective. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) issues a certification label to those manufacturers who test and label their fabrics according to AS/NZS 4399.Standard Australia Committee, TX/21 "Sun Protective Clothing" have been working towards setting a standard for fabric protection. Table 3 shows the proposed UVR rating system.

Table3: Proposed UVR rating system for the textiles

UV protection	Mean % UVR	UVR Protection
UPF 10 – 19	10 – 5.1	Moderate
UPF 20 – 29	5.0 – 3.4	High
UPF 30 – 49	3.3 – 2.0	Very high
UPF > 50	< 2.0	Maximum

From the publication of the Australian/New Zealand standard in 1996 until today, American, British, Canadian, European, South African, and multinational groups have engaged in writing UV protective textile standard documents. Specific standard setting organizations at work include ASTM and the American Association of Textile Chemists and Colorists (AATCC) (United States), the European Commission for Standardization (CEN) (European), the British Standards Institution (BSI) (Britain), the Canadian General Standards Board (CGSB) and Commission on Illumination (CIE) (multinational). Each standard document being written by these agencies is not as comprehensive as AS/NZS 4399. For example, BS 7914, AATCC TM 183, and CEN/TC248WG 14 are standard documents presenting a method for taking fabric UV transmittance measurements and formulas for converting that data into UPF and/or percent block information. ASTM D 6544 is a standard document presenting a procedure for exposing fabric to simulated sunlight and to repeat laundering before transmittance measurements are done [15].

UV Index

The intensity of the sun, as well as the individual skin type, is crucial when selecting suitable UV protection. The international UV index (UVI) provides information on the intensity of UV radiation in a specific location. Sunlight intensity varies considerably according to location, time of day, season and atmospheric conditions. In Germany, for example, UV indices between 5 and 8 are common at midday from May to August. In the UK

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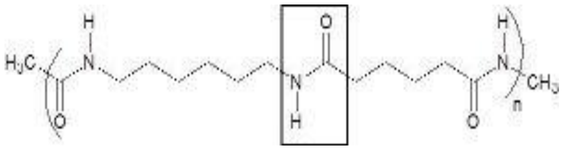
the light flux reaching sea level is greatest in July at noon. However, the overall flux is far less than that in, for example, a desert at the Ecuador, or elsewhere at high altitude. Thus, the testing of a material's resistance to UV degradation must be carefully considered according to location of use. Common testing sites are Arizona, Florida and Japan. These areas have high ambient temperatures and levels of ultraviolet radiation.The UV index is dependent on the time of day, the longitude and latitude, the time of year, ozone levels and cloud cover. Reflections from the sand and snow also affect the UVI level [16].

The Effects of ultraviolet light on polymeric materials

UV light contributes to the aging of plastics, and the discolouration of dyes and artwork. Typical property changes in a material include reduced ductility (increased brittleness), chalking, colour changes, a reduction in toughness, and cracking. Recently, polymers have been developed that are designed to degrade under light, and are used in products like biodegradable plastic bags.The effect of UV light on a polymeric material depends on the flux (power) of the light, its wavelength, and the chemical structure of the material. Ultraviolet light interacts primarily with a structure's pi electrons, meaning that double bonds and aromatic groups in a structure interact most strongly with it. For example, nylon 6 absorbs UV light in its amide bonds:



Structure of nylon 6Polymers containing no pi electron clouds, e.g. polyethylene, are relatively unaffected by UV light.The effect of UV light on a material can be determined using a number of analytical methods; typically:-

• Chemical structure analyses by employing UV and infrared spectroscopy and/or NMR (nuclear magnetic resonance);
• Surface analyses by scanning electron microscopy (SEM),
• Detection of free radicals by EPR (Electron Paramagnetic Resonance);
• measurement of molecular weight by viscosity measurements or end group analysis; or by
• changes in mechanical properties.

The UV resistance of materials may be determined by outdoor or laboratory testing methods. Outdoor testing is more expensive and time consuming than laboratory testing, but it remains the most appropriate by which other methods are compared. Laboratory test methods are not easily correlated with outdoor exposures because the wavelengths of the light sources do not always match those of sunlight.

Textiles and UV radiation

Textile materials are degraded by UV radiation due to excitations in some parts of the polymer molecule. Mostly depends on the fiber type and its chemical structure. Textile fabrics have a large surface area so that they are more susceptible to attacks by UV radiation. Natural fibers like cotton, silk, and wool have lower degree UPF absorption than synthetic fibers. Cotton fabrics shows higher degree of UPF because of they contain natural impurities as well as added impurities like pectin, waxes etc. Dyed cotton fabrics exhibit higher UPF and undyed bleached cotton yields very poor UPF. UVR attacks polyamides the most, by photo oxidation. The fabric looses its strength and its crystalline structure. Polyester too get affected by UV radiation, to the tune of 45-50% after 30 days of exposure. Polyester fibers absorb more in the UVA and UVB regions than aliphatic polyamide fibers. UPF also depends on the swelling capacity of the fibers. All wave lengths of light including visible light affect fabrics to some extent. The construction of woven and knitted fabrics and the fiber types have a great influence on protection from ultraviolet transmittance. The ultraviolet protection factor (UPF) of textiles depends on their construction, the spaces between the yarns, their fiber types, the color, the textile impregnation, and the presence of optical brighteners and ultraviolet absorbers. UV radiation, can be transmitted, absorbed, and reflected by the textiles as shown in Figure 2. Different textile fibres have the tendency to absorb a part of UV radiation and convert it into a different energy form. Another part of radiation is reflected or scattered by the fibre itself and this may be a part of transmitted radiation, because another part of UV radiation transmits directly through the fabric via interstices between fibres and yarns in the fabrics. It is evident that the clothing provides UV protection up to some extent. Clothing is associated with several factors which governs the effectiveness of UV radiation protection. In addition to the fibrous material, the fabric properties like fabric sett, fibre blend composition, tightness of weave, thickness, and areal density also affects the UPF of resultant fabrics. Wet processing of textiles (bleaching, usage of UV absorber, and coloration) also influences the UV radiation protection function of textiles and some refurbishment activities like wetness, stretch, heat, or chemical treatments. The combined effect of these parameters (fibre, yarn, fabric, and wet processing treatment) complicates the subject of UV radiation protection by clothing. The physicochemical type of fibrous material and fabric openness are other driving parameters to decide the UV radiation protection of clothing. It has been found that fibres containing conjugated aromatic system like PET are more effective for UV radiation absorption. The cellulosic fibres having no double bond in their molecular backbone have low UV radiation absorption capacity, exhibiting comparatively low UPF of textiles made thereof [17]. Different group of scientists conducted that UV radiation transmission occur through textile through interstices between fibre and yarns and this has been supported by a reduced free space between yarns in the fabric after subsequent washing and consequent increase in ultraviolet protection factor (UPF). In spite of the established fact that yarn structure can influence the UPF of fabric by altering the openness of fabric. Most of the research work was concerned about the influence of yarn linear density but there is no systematic research associated with the UV transmission behavior of fabric composed of multifilament yarns of different filament configurations [18].

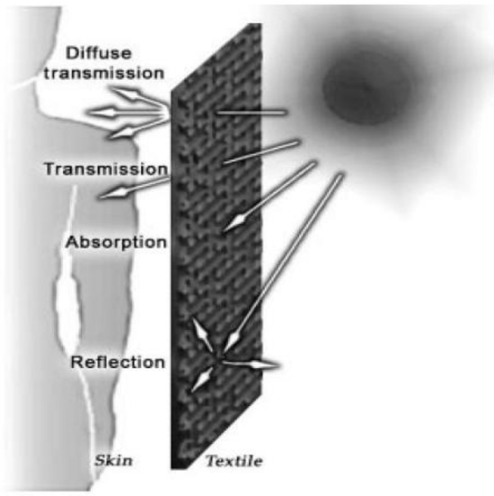


Figure 2: Textile materials attack by UV radiation

Different factors of fabric for UPF rating

Factors that contribute to the UPF rating of a fabric are (i) Composition of the yarns (cotton, polyester, etc), so different fabrics have different UVR absorbing properties; (ii) Tightness of the weave or knit (tighter improves the rating), Less UVR passes through; (iii) tightly woven or knitted fabrics than loosely woven or knitted fabrics; (iv) Colour (darker colours are generally better), darker colour usually protect more UVR than lighter colour; (v) Stretch (more stretch lowers the rating), Garments that are overstretched, wet or worn out may have reduced UVR protection; (vi) Moisture (many fabrics have lower ratings when wet); (vii) Condition (worn and faded garments may have reduced ratings); and (vii) Finishing (some fabrics are treated with UV absorbing chemicals)[19,20]

Figure 3: UV rays on white and coloured fabric

Fabric parameters for UV transmission

The fiber composition of a fabric affects UV transmission. The polyester fabric have an average transmission of 12% over the 280–380 nm range and more effective UV blocker than all but the unbleached cotton muslins. Polyester contains phenyl ester groups that are known to exhibit a very strong UV absorption below 310 nm. Synthetic fibers spun from aliphatic polymers such as nylon, acrylic, and polypropylene block little UV radiation unless they are delustered or dyed. The presence of titanium dioxide delustering pigment in the acrylic, polyester, nylon, polypropylene samples contributed to the blocking of UV radiation by these fabrics. Titanium dioxide absorbs about 90% of the incident radiation uniformly across the UV region 280–380 nm and has an absorption maximum at approximately 350 nm. Fabric mass and cover also affect UV transmission. The highest mass transmitted the least UV radiation; for example, black fabrics their low transmission was also a function of their color, thickness, and high cover (98-99%). Other researchers have also noted that high mass and cover resulted in low UV transmission values and found that the relationship between UV transmission and cover is not as strong as mass. A fabric with high cover does not necessarily block UV rays effectively because some transmission occurs through the fibers or yarns as well as the spaces between them [21].Process of light transmission through fabric. Radiation incident upon a fabric (Io) is either scattered (Is), absorbed (IA), transmitted through openings (ITO) or transmitted through the fibers (ITF). The total transmission (IT) is equal to the sum of ITF and ITO. Transmitted rays through the fibers and openings may damage the object beneath [22]. The following figure shows the fabric – light interactions.

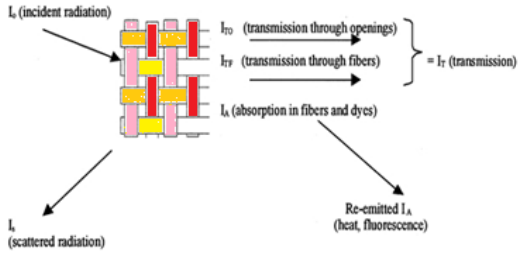


Figure 4: Model of fabric – light interactions.

Different chemicals used in textiles for UV protection

A number research has been carried out for the protection of textiles from UV radiation. UV radiation blocking properties of textiles depend on fibre type, fabric construction and type of finishing chemicals. Cotton, linen, silk and manufactured fibres like viscose rayon, nylon and acrylic offer little protection against UV radiation. It is necessary for these fibers to be treated with additives in order to improve their UV protection abilities. Polyester and cotton/polyester blended fabrics can be treated with a number of UV protecting chemicals. There are both organic and inorganic UV blockers. The organic blockers are also called UV absorbers because they mainly absorb UV rays. Inorganic UV blockers are usually certain semiconductor oxides such as TiO_2, ZnO, SiO_2, and Al_2O_3 etc. Using these types of chemicals on textile substrate, different types of functionalities can be carried out i.e. improved thermal stability and flame retardancy, water repellent properties, easy to clean properties, protective properties, e.g. UV and EMR shielding, antimicrobial activity, etc. Compared with the existing organic UV absorbers, inorganic UV blockers are more preferable to organic UV blockers as they are non toxic and chemically stable under exposure to both high temperatures and UV. Natural occurring aluminum potassium sulfate (Alum), Zinc Oxide (ZnO), titanium dioxide (TiO_2) to induce the UV-blocking properties. Textile materials can be treated with naturally occurring inorganic compound like Alum. Moreover, stepping up of Alum explored characterization was addressed by using ZnO,which is an already known good UV-absorber and is fromthe safest products in sunscreen blockers. An issue of considerationis the human safety, consequently ZnO is preferredover TiO_2, even $TiO_2$is stronger in UV scattering/absorbing with higher refractive index, but ZnO cover wider range of UV rays (UVA-1,UVA-2 and UVB) from 290–380 nm and it is not reactive as titanium dioxide which act to form radicals, that was found to be harmful if only it was absorbed and this was only proved through cell-culture [23]. UV protective properties can also be made on cotton and flax fabrics with multifunctional plant extracts. Natural dyes can provide vegetable fibres with strong colours if mordants are used. A very good protection level can be reached by flax mordanted with alum and dyed with Helychrysum. Chestnut tannins provided a slight support in phenols uptake for Lavandula and Helichrysum plant dyes with respect to potassium alum, but without an improvement of the fabrics UV protection properties; flax samples dyed with Helichrysum extract can be an improvement in UV protection properties when mordanted with potassium alum instead of tannins [24].Polyester fabric gives better UV protection than cotton fabric after surface modification and treatment with nanoparticles of zeolite due to polyester chemical structure. Polyester fibre has double bonds in polymer chain which can absorb small amounts of UV radiation and small amounts of UV radiation are reflected from polyester multifilament.Nano particles of zeolite on fabric surface are dispersed by scattering UV radiation resulting in better UV protection. UPF values for polyester fabric have a behavior similar to that of cotton fabric. Modification of polyester fabric results in a little better UV protection, while treatment with nanoparticles of zeolite results in good UV protection. Nano particles of a natural zeolite applied on textile material scatter the light wavelength of electromagnetic spectrum, resulting in enhanced UV protection [25].

CONCLUSION

People have known that fabric prevented one’s skin from tanning and/or burning from the Centuries. The main motivation for preventing such tanning was the desire not to be identified as a member of the working class who often labored out-of-doors.As having out-of-doors leisure time became a symbol of success, having tanned skin became socially desirable. Clothing styles changed and new social mores made it acceptable to cover less skin with fabric. Therefore, there was greater exposure of the skin to the sun’s radiation.As sun exposure increased day by day, and increased the rates of skin cancer, interest has soared in measuring the ability of fabric to block sunlight (especially its ultraviolet rays, which are responsible for tanning and burning), in quantifying the amount of ultraviolet protection (UV) provided by various fabrics, and in using that information to label clothing/fabric as UV protective.Sun protection fabrics are designed to absorb or reflect the sun’s UV radiation as a means of protecting the skin from damage. Factors that affect the level of sun protection provided by a fabric which include different factors that affect, in approximate order of importance, include weave, color, weight, stretch, and wetness. In addition, UV absorbers may be added at various points in the manufacturing process to enhance UV protection levels.

REFERENCES

1. "Environmental Health Criteria 160: Ultraviolet radiation" (1994), The joint sponsorship of the United Nations International programme, The International Labour Organization and the World Health Organization.
2. Saravanan D. (2007), “UV protection textile materials”*AUTEX Research Journal*, Vol 7 (1), 53-62.
3. Zimniewska M. (2008),“Innovations in UV protections in textiles” *Institute of natural fibres and medicinal plants*, power point presentations.

4. Allen M. W., and Bain G. (2008), "Measuring the UV protection factor of fabrics" *Thermo Fisher Scientific,* Madison, WI, USA. Application note 51664**.**
5. Hatch K. L. (2001), "UV-Protective textiles standards"*ASTM standardization News.*
6. Wood T.D. (2007), "Sun protective basics" http://www.rei.com/learn/expert-advice/sun-protection.html
7. Reinert G., Fuso F., Hilfiker R. and Schmidt E. (1997) "UV-Protecting Properties of Textile Fabrics and Their Improvement" *Textile Chemist and Colorist*, Vol 29 (12):36-43
8. Achwal W. B. (2000) "UV Protection by Textiles" *Colourage*, Vol 47 (4): 50-51.
9. Swiss Textile Testing Institute, (2006), "Enjoy the Sun Safely - Textile UV Protection" *TEXTEX*, http://www.testex.com/bilder/pdf/UV_standard_801_broschuere_e.pdf
10. Mukesh K., and Annika S. (2013), "Ultraviolet protection by fabric engineering" *Journal of Textiles*, 579129, 6.
11. Wim J., Ooij V., Shijian L., and Saswati D. (1999), "Surface modification of textile fibres and cords by plasma polymerization" *Plasma and polymers,* Vol 4, (1).
12. AATCC. (1996), Fiber analysis: Qualitative: Test Method 20–1990. In *Technical manual of the AATCC,* Research Triangle Park, N.C., American Association of the Textile Chemists and Colorists, Vol 69, 47–62.
13. Raslan W.M., Rashed U.S., El-Sayad H., and El-Halwagy A.A. (2011), "Ultraviolet protection, flame retardancy and antibacterial properties of treated polyester fabric using plasma-nano technology" *Materials science and applications*, 2, 1432-1442.
14. Bilimis Z. (2011), "Measuring the UV protection factor (UPF) of fabrics and clothing" *Aglient Technologies, Inc*, Australia, SI-A-1148.
15. "UVR rating systems for textiles" (2008), Australian govt. and Australian radiation protection and nuclear safety agency.
16. Dubrovski P.D. (2010). "Woven fabric and ultraviolet protection" *Woven Fabric Engineering*, PolonaDobnikDubrovski (Ed.), ISBN: 978-953-307-194-7.
17. Akgun M., Becerir B., and Alpay H. R. (2010)**.** "Ultraviolet (UV) protection of textiles: A review" *International scientific conference,*Unitech 10, Gabrovo.
18. Hongying Y. Sukang Z. and Ning P. (2004), "Studying the mechanism of titanium dioxide as ultraviolet-blocking additive for films and fabrics by an improved scheme"*Journal of Applied Polymer Science*, Vol 92, 3201–3210.
19. Zohdy M., Hossamy M., Wahab A., Naggar E., Fathalla A., and Ali N. (2009), "Novel UV-protective formulations for cotton, PET fabrics and their blend utilizing irradiation technique"*European Polymer Journal*, Vol 45(10):2926-2934, DOI:10.1016/j.eurpolymj.
20. Grifoni D., Bacci L., Lonardo S., Pinelli P., Scardigli A., Camilli F., Sabatini F., Zipoli G., and Romani A. (2014), "UV protective properties of cotton and flex fabrics dyed with multifunctional plant extracts" *Dyes and pigments*, 105, 89-96.
21. Shishoo R. (1996), "Plasma Treatment – Industrial Applications and its Impact on the C&L Industry" *Journal. of Coated Fabrics*, 26: 26–35
22. Chunying W., and Chaoxia W. (2010), " Surface pretreatment of polyester fabric for ink jet printing with radio frequency O_2 plasma" *Fibers and polymers*, Vol 11 (2), 223-228, DOI: 10.1007/s12221-010-0223-5
23. Grancaric A.M., Prlic I., Tarbuk A. and Marovic G. (2012), "Activated natural zeolites on textiles: protection from radioactive contamination" *Intelligent textiles and clothing for ballistic and NBC protection,* DOI: 10.1007/978-94-007-0576_8.
24. Kerr N., Capjack L., and Fedosejevs R. (2000), "Ability of textile covers to protect artifacts from ultraviolet radiation" *Journal of the American Institute for conservation*, Vol 39 (3), Art 3.
25. Ojstrsek A., Kleinschek K.S., and Fakin D. (2013), "Characterization of nano-sized TiO_2 suspensions for functional modification of polyester fabric" *Surface & coating technology*, 226, 68-74.