Testing Methods for Protection against Ultraviolet Radiation- A Review

By: Dr. Rajni Yadav &
Dr. Anjali Karolia

Testing Methods for Protection against Ultraviolet Radiation- A Review

By: Dr. Rajni Yadav & Dr. Anjali Karolia

Source: Textile Review

Textiles are intrinsically suited for use as UV protection, as they are able to offer particularly good protection against intense radiation from sun if suitable materials and constructions are used. UV protection factor far above those of the strongest sunscreens can be achieved. Unfortunately, one cannot hold up a textile material to sunlight and determine how susceptible a textile is to UV rays.

Light is an essential prerequisite for life on our planet. Sunlight is important for human health. The body needs it to form vitamin D. In medical practice, UV lamps are used for treating psoriasis (a condition causing itchy, scaly red patches on the skin) and for treating jaundice in new born babies. The ultraviolet component of the terrestrial solar spectrum comprises approximately 5% of the radiant energy; however this component is largely responsible for the deleterious effects of solar exposure. The ultraviolet radiation band consists of three regions: UV-A (320-400nm), UV-B (280-320nm), and UV-C (200-280nm). 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.

Incidence of skin cancer in Australia and USA are increasing. The rate of skin cancer in New Zealand and Norway also seem to be very high. Even in Great Britain, the number of persons affected with skin cancer appears to be rising. In Scotland, there was a rise of 82% of melanoma cases over the previous decades. In Switzerland, about 1000 persons a year develop malignant skin tumours. Recognizing these facts, it is important to protect the skin from excessive exposure of UV radiation.

Textiles are intrinsically suited for use as UV protection, as they are able to offer particularly good protection against intense radiation from sun if suitable materials and constructions are used. UV protection factor far above those of the strongest sunscreens can be achieved. Unfortunately, one cannot hold up a textile material to sunlight and determine how susceptible a textile is to UV rays.

The degree of protection that an fabric provides against ultraviolet radiation is calculated in terms of UPF (Ultraviolet Protection Factor). To determine UPF, standardised measuring methods are required.

Techniques for Quantitative Measurement of UVR Transmission and Calculation of Protection Factor

There are two major methods to assess the amount/degree of sunburn protection provided by various fabrics: the in vivo method and the in vitro method.

i) In Vitro

Direct and diffuse UV transmittance through a fabric is the crucial factor determining the UV protection of textiles. Radiometric UV transmission tests use a broadband UV light

source filtered for UV-B or combined UV-A and UV-B spectral regions to illuminate a fabric sample.

The total UV transmission through the textile is measured by a radiometer. For correct measurement, this test method requires a UV source that closely matches the solar spectrum, with detectors that respond similarly to human skin. Nevertheless, this technique is simple and suitable when a relative variation in UPF needs to be measured. Spectroradiometers or spectrophotometers collect transmitted and scattered radiation with the aid of an integrating sphere positioned behind a textile sample. Although spectrophotometers fitted with a double monochromator have a large dynamic range and high accuracy, regular scans of the UV source (deuterium or xenon arc lamp) are required to provide reference data.

As suggested by the AS/NZS and European standard, the spectrophotometer should be fitted with a UV radiation transmitting filter for wavelengths of less than 400 nm (UG11 fiter; Schott, Mainz, Germany) to minimize errors caused by fluorescence from whitening agents. The spectrophotometric measurements are performed in the wavelength range of 290 to 400 nm, in 5-nm steps or less. For UPF determination, at least 4 textile samples must be taken from a garment, 2 in the machine direction and 2 in the cross-machine direction. To determine the in vitro UPF, the spectral irradiance (of the source and transmitted spectrum) is weighted against the erythemal action spectrum, as follows:

$$UPF = \int E_\lambda S_\lambda d_\lambda / \int E_\lambda S_\lambda T_\lambda A_\lambda$$

Where,

λ= the wavelength in nm;
E_λ= relative erythemal spectral effectiveness;
S_λ= solar spectral irradiance of the source in watts per square meter;
d_λ= bandwidth in nanometer; and
T_λ= spectral transmission of the sample.

The integrals ($\int$) are calculated over the wavelength range of 290 to 400 nm. The definition of UPF is that it is the ratio of the average effective UV irradiance calculated for unprotected skin to the average effective UV irradiance calculated for skin protected by the test fabric. The three main factors that influence the determination of the UPF of fabric are[4]

Special transmittance: This represents the amount of energy that is transmitted through the fabric through the fabric through out the entire UV wavelength range.

Solar spectral irradiance: This is the function of the amount of the solar energy that reaches the surface of earth for each wavelength.

Erythema action spectra: this is a spectrum of the action of UV radiation on the skin for each wavelength.

Intercomparison measurements of different testing laboratories have shown that spectrophotometry is an accurate and reproducible test method for determining UPF.

ii) In Vivo

The in vivo method is one that closely parallels the method used to assess the effectiveness of sunscreen lotions that is to determine the sun protection factor (SPF) of the lotion. The major difference is hat fabric is placed on the skin surface rather than spreading sunscreen lotion over the skin surface. 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. Stanford and Gies and their co-workers described in vivo test methods based on minimum erythemal dose (MED) testing. However, the most frequently performed in vivo test method is in vivo confirmation of the UPFs measured in vitro. Based on skin phototype, MED is determined using incremental UV-B doses on the upper back of a subject and is read after 24 hours. To measure the MED of protected skin, a textile is placed over the skin on the other side of the back. 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 rotected 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 are 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. Cost and impracticability are limitations of the in vivo test methods. Some in vivo tests have used polysulfone dosimeters as small portable badges monitoring UV doses on mobile subjects Ravishankar and Diffey concluded that the actual protection provided by textiles worn in sunlight is, on average, 50% higher than that measured by conventional in vitro testing using collimated radiation beams. Similar results were found in studies of a biological UV-detector film using Bacillus subtilis.

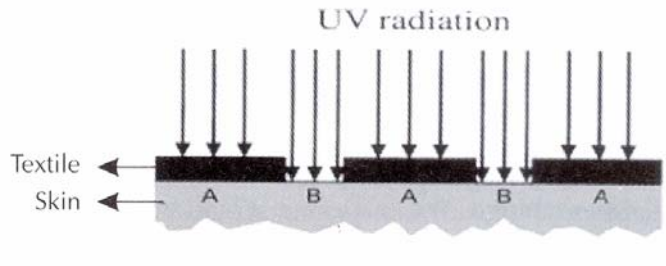

Figure 1: In vivo 'on skin' test with collimated ultraviolet (UV) radiation (A, non-irradiated skin; B, irradiated skin). After passing the spaces between the yarns of the textile the UV radiation directly hits the skin. Source: Gambichler 1. , Avermaete A. et al (2)

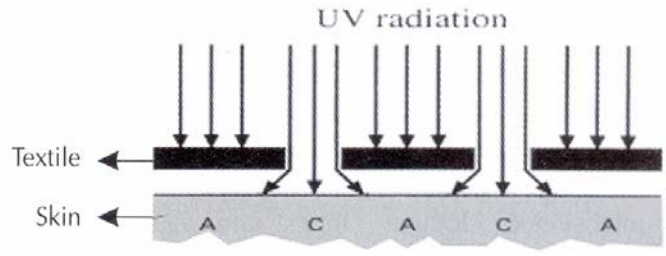

Figure 2: In vivo 'off skin' test with collimated ultraviolet (UV) radiation (A, non-irradiated skin; C, irradiated skin). After passing the spaces between the yarns of the

textile the UV radiation becomes more diffuse due to scattering; the irradiated sites (C) are greater than in 'on skin' testing. Source: Gambichler T., Avermaete A. et al (2)

iii) Percent transmittance

The calculation of total UV percent transmittance for a fabric is the ratio of the amount of radiation transmitted to the amount of radiation directed perpendicular to the fabric swatch surface. The calculation of the percentage of UVB transmitted through the fabric is the same, except only the data from the UV rays in the UVB region are used. Likewise, the calculation of the percentage of UVA transmitted involves only the data when UVA was directed at the fabric surface. Percent transmittance data do not take into account that certain wavelengths in the UV range are more responsible for skin damage than others.

iv) Penetrations/weighted transmittance

Another expression of sunburn protection is penetration or erythema weighted transmitted. It is calculated as the inverse of UPF (l/UPF). The significance of l/UPF is that the resulting value lies between 1 and 0 (or 100% and 0%). The interpretation is that the lower the percent or the closer to zero the value is, the greater the sunburn protection provided by the fabric. In contrast, the UPF value has virtually no upper limit to indicate the protection provided.

Standards for Assessment of of UV Protection

Specific details on how to conduct transmittance testing, and use the transmittance data to calculate a UPF value for the fabric tested can be found in the following standard documents developed by committees within national, regional or international standard setting organizations:

AS/NZS 4399:1996 Sun Protective Clothing: Evaluation and Classification. The standard describes the measurement of UPF ratings on dry, untensioned fabrics using a spectrophotometer to determine UV transmission levels in the 290-400nm wavelength range. Using at least four samples, two in the warp and two in the weft directions, each colour is tested separately. It is suggested that, when a textured fabric is used, the area with the lowest cover factor forms the sample.

The UPF rating applies to the fabric rather than the garment design: The consumer should be made aware that UPF ratings may be lowered during manufacture, for example by stretching and that stretch during wear, wetting, and general wear and tear may result in a decrease in the stated UPF rating. The standard also describes the labelling of UPF-rated clothing: fabrics are assigned a UPF rating number and also a protection category depending on how much made from fabrics with ratings higher than 50 are labelled as UPF50+.

BS 7914:1998 Method of Test for Penetration of Erythemally Weighted Solar UV Radiation Through Clothing Fabrics: The standard describes a test for assessing the penetration of solar UV radiation on dry, untensioned clothing fabrics and again does not consider garment design, only fabric protection. Testing is carried out using a spectrophotometer; each colour and structure used in the design in tested separately and any holes intentionally featured in the design are included for test. Four specimens are tested, with at least two of each color and structure. The standard does not contain requirements for clothing product labelling.

BS 7949:1999 Children's Clothing: Requirements for Protection against Erythemally Weighted Solar Ultraviolet Radiation: This standard refers specifically to the protection provided by clothing for children aged between 6 months and those which are 'subject to VAT' and refer to garment design as well as fabric. Three garment designs, illustrating the minimum coverage acceptable, are defined. A maximum penetration of 2.5% is allowed for fabric, exclusive of trimmings, which should be backed by a fabric of the same specifications. Garments are permanently labelled with reference to the standard and the wording 'helps to prevent sunburn'. A non-permanent label educates consumers to apply sun cream to exposed areas of skin. The exact UPF rating is not specified, only that UPF 40 or UPF 40+ is offered.

UV Standard 80:1999 General and Special Conditions is issued by the International Testing Association for Applied UV Protection and is said to employ a more rigorous procedure than the above tests. Measurement of UV protection is determined using the erythermal effectiveness and irradiance spectrum as shown is AS/NZS 4399:1996. The standard concerns any textile that could be used as a UV shield and tests it in the context of consumer demands made on the item, for example when wet or after wear. Measurements are made on new fabric and again after abrasion and after washing and dry cleaning is stretched and stretched and moistened states. Stretch is obtained by pulling the fabric in two directions and the UPF rating is measured while the stretched fabric is fixed in a holder. For measurements in the wet state, samples are immersed in a wetting solution and the UPF rating is measure once excess moisture has drained and again after two minutes. Subsequent readings are made at two-minute intervals if the second reading is lower and continue until there is an increase or no further decrease. Certified manufacturers must guarantee that all products conform to the standard. It is claimed that the European acceptance of the standard would make product comparisons easier.

BS EN 13758-1:2002: Textiles, Solar UV Protective Properties, Part 1. Methods of Test for Apparel Fabrics: The standard describes a method for the determination of the erythermally weighted UV radiation transmittance of apparel fabrics to assess their solar UV protective properties. At least four specimens are tested; at least two specimens of each colour and of each texture area are tested. The standard recognises the effect of wear and usage of clothing on its UV protection, particularly the effects of stretching and wetting. If a textile is to be tested when stretched, the standard recommends that the way it is stretched should be defined, for instance by applying a specified force or stretching to a specified elongation. The importance and possible effects of the anisotropy, necking and relaxation properties of textiles in this respect are referred to.

Table : Fabric Labelling Requirements of ASTM D 6603: Standard Guide for Labelling

UPF Rating	Category	Allowable UPF Rating for Label	UV Blocked* (approx. %)
15 – 24	Good protection	15 and 20	93.3 – 95.8
25 – 39	Very good protection	25, 30 and 35	96.0 – 97.4
40 or higher	Excellent protection	40, 45, 50 and 50+	97.5 – 98.0

*For labelling purposes, the actual percentage for the product should be used.

BS EN 13758-2:2001: Textiles, Solar UV Protective Properties. Part 2: Classification and Marking of Apparel. The guidelines introduce a yellow sun logo for items like T-shirts, swimwear and ski-wear and propose minimum requirements for the UV-permeability and skin coverage of clothes, to give reasonable protection for an average person exposed to the Sun in Europe. To comply with the standard, UV protective clothing will need to have

the sun-safety logo incorporating the number of the standard, EN 13758, and the UV protection factor 30+. This part of the standard also recognises the effect of wear on the UV protection of clothing and clothing will need to display the following wording: 'sun exposure causes skin damage'; 'noncovered areas should be protected with a suitable sun-screen'; and 'the protection offered by this item may be reduced with use if stretched or wet'.

AATCC Test Method 183-2000: Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation Through Fabrics. The standard describes a test to determine the UV radiation blocked or transmitted by textile fabrics which are intended to be used for UV protection. The UPF rating of the tested fabrics are determined. Fabrics should be repared before testing by being given 40 domestic washings and dryings, be exposed to stimulated light for a specified time and (for swimwear) be exposed to chlorine water for a specified time. Textiles tested according to AATCC 183 and intended for use for UV protection, should be labelled according to ASTM D 6603 Standard Guide for Labelling of UV-Protective Textiles which requires that the UPF rating, the protection category (Table 2) and a statement that the product has been labelled according to ASTM D 6603, must be included on the label. The UPF rating and classification category are similar to those stated in AS/NZS 4399.

The UPF is estimated from the wavelength-dependent transmission of the fabric, the solar UV spectrum and the erythemal action spectrum over the wavelength region 280400nm. Depending on the fabric UPF values range from 2 to several thousand. Several organizations around the world have developed or have proposed performance standards for UV protections.

Conclusion

The sun is essential for life. Yet sunlight can also be a source of such deleterious effects as sunburn and suntanning as well as premalignant lesions. These may all occur in individuals with normal response to sunlight. In the last 20 years or so, considerable attention has been paid to the use of fabric as photoprotective materials. Visual inspection of a fabric does not provide a standardised indication of the protection provided and therefore ultraviolet protection factor of the fabric has been determined. There are two major methods to assess the amount/degree of sunburn protection provided by various fabrics: the in vivo method and the in vitro method. In addition to in vivo measurement of fabric SPF, in vitro evaluation of fabric UPF has been carried out. The UPF is estimated from the wavelength-dependent transmission of the fabric, the solar UV spectrum and the erythemal action spectrum over the wavelength region 280-400nm. Depending on the fabric UPF values range from 2 to several thousand. Several organizations around the world have developed or have proposed performance standards for UV protections.

Clothing that has a standard UPF rating, could prove to be highly beneficial to those individuals who exhibit extreme sensitivity to sunlight or who live in the most sunlight intensive regions of the world. In additions, the availability of children's clothing with UPF ratings would be of benefit in reducing the cumulative effect of UVR exposure. Finally, and perhaps the most important goal of research in this area, is to develop consumer education programs on the intelligent use of clothing as protection from UVR exposure. Toward this goal, research is needed on consumer attitudes in various countries on covering up when in the sun and designing clothing to enhance protection from the sun.

Bibliography

1. Capajack L, Kerr N. et al (1994), "Protection of humans from Ultraviolet radition through the use of textiles: A Review", Family and consumer sciences research journal, 23, 198-218.
2. Gambichler T., Avermaete A. et al (2001) "Ultraviolet protection by summer textile, Ultraviolet transmission measurements verified by determination of the minimal erythema dose with solar-simulated radiation", British Journal of Dermatology, 484-489.
3. Goyal R. (2005), "UV radiation and protection", Colourage, 10, 81-87.
4. Hoffmann K., Laper j. et al (2001), "Defined UV protection by Apparel textile", Arch Dermatology, 137, 1089-1094.
5. Kathirvelu S., D'Souza and Dhurai B., (2009) "A review of testing of functional textiles", Journal of the Textiles Association, 3-4, 276-283.
6. Pearson j. and Mullen E.(2003), "Sunlight, skin cancer and children's clothing", Textile Magazine, 30, 4, 23-27.
7. Sharma D.K. and Singh M. (2001) "Effect of dyeing and finishing treatments on sun protection of woven fabrics- A study", Colourage Annual, 69-74.

Originally Published in Textile Review, May-2011

The authors are associated with Dept. of Clothing and Textile, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara.