PROTECTIVE FUNCTIONAL TEXTILES

E. Perrin Akçakoca Kumbasar¹

¹Ege University Textile Engineering Department, 35100 Bornova-İzmir/TURKEY
perrin.akcakoca@ege.edu.tr

Keywords: protective textiles, antibacterial textiles, protective clothes, functional textiles, electromagnetic protection

Abstract

Animal skins would constitute the first protective clothing. Until industrial revolution in the 19th century clothing was used for protection especially against weather conditions. With the industrial revolution a significant increase in the use of protective clothing against industrial hazards such as heat, fire, blast, impact, cuts, chemical splashes and dirt in the emerging metal, glass, ceramic and chemical industries and crafts has been observed. The increasing emphasis on human personal protection and the continued introduction of health and safety means the technical textile market continues to be buoyant market. Personal protection include protection against heat, cold, rain, snow, wind, UV radiation, micro-organism, nuclear, biological, chemical, mechanical and electrical hazards. In this training material protection against UV radiation, electrical, mechanical, chemical and bacterial hazards were summarized..

1 INTRODUCTION

Especially the beginning of the 21st century has witnessed an extraordinary period of innovation in textile science and new materials have transformed the familiar functions of textile to the advance: fabrics can collect solar energy and emit light or heat, fabrics can change color, textiles protect human beings against chemical, mechanical and electrical radiation etc.

While all clothing is protective to some degree, the concern of protective functional textiles is not with routine needs, such as clothing for warm or cold, rainwear, or routine work clothing. Protective functional textiles focus on more sophisticated needs, protection in situations where hazards or risks are present that have the potential to be life threatening or damage to the person working in and around the hazard.
Protective textiles is manufactured using traditional textile production technologies such as weaving, knitting and non-wovens and also by specialized techniques such as 3D weaving, spacer fabric knitting and braiding using natural and man-made fibers, and finishing technology. Today, a wide range of high-performance fibers is commercially available for technical and industrial applications. These types of fibers are used in protective wear developed for impact protection and in textile reinforcement products for different applications. Many of the "high-tech" fibers, such as Kevlar®, Nomex® (DuPont), and Twaron® (Acordis) aramids, Spectra® (Allied) HDPE fibers, PBI, Keremel® (Rhone-Poulenc), P84® (Inspec), carbon impregnated fibers, aramid spunlace materials, fiberglass, even steel, copper, and other metal fibers have applications in the protective clothing areas. Conventional materials such as nylon and polyester, cotton and wool, are also used and provide satisfactory protection in certain applications depending on the hazard or exposure. When new fibers with unique properties are being developed, they are often considered for protective clothing [1]. Using of high-tech fibers in protective textile production can be summarized following:

- **Aramid fibers:**
  - p-aramid fiber to impart high strength and ballistics
  - m-aramid fiber to impart flame and heat resistance

- **Ultra high tenacity polyethylene fibers (UHMWPE):** Gel spun, ultra high molecular weight polyethylene fibers with extremely high specific strength and modules, high chemical resistance and high abrasion resistance

- **Polyphylene sulphide fibers (PPS):** Crystalline thermoplastic fiber with mechanical properties similar to regular polyester fibers. Excellent heat and chemical resistance.

- **Polyetherketone fibers (PEEK):** Crystalline thermoplastic fiber with high resistance to heat and to a wide range of chemicals.

- **Novoloid (cured phenol-aldehyde) fibers:** High flame resistance, non-melting with high resistance to acid, solvents, steam, chemicals and fuels. Good moisture regain and soft hand.

- **PBO (p-phenylene-2,6-benzobisoxazole) fibers:** The strength and modules of this fiber exceed those of any known fibers [2].

The first critical step in developing a complete safety is to identify physical and health hazards in workplace or environment. Potential hazards may be physical or health related, or in both categories. For example, innovative functional textiles for protective clothing were introduced by W. Gore and Associates. Gore-Tex Airlick is a functional textile which was developed by Gore for the special needs of firefighters. The concept of this product is to eliminate the conventional, bulky, thermal insulation layer and substitute it by a protective air cushion. Dots consisting of foamed silicone are discontinuously applied to a fiber substrate and anchored within the microporous Gore-Tex membrane. They measure only a few millimeters in height, creating a defined air cushion between the adjacent flame-retardant face fabric and the inner lining. This laminated fabric is characterized by thermal insulation, breathability, perspiration transport, and absorption and quick-dry properties [2].
Classifying personal protective textiles is not easy because no single classification is possible for all kinds of protection. Depending on the end use functions, personal protective textiles can be classified as thermal protective textiles, flame protective textiles, radiation protective textiles, biological protective textiles, chemical protective textiles, electrical protective textiles, mechanical protective textiles [3].

In this chapter textiles for personal production against UV radiation, mechanical and electrical hazards and radiation, chemical and bacterial/viral environment were summarized from some references.

2 UV RADIATION AND PROTECTION

Medical textiles are one of the 12 main application areas of technical textiles defined by Techtextil which is the leading international trade exhibition for technical textiles [4]. In healthcare/hygiene products, protection against ultraviolet (UV) radiation is one of the most important properties especially for skin diseases. For years, a rising rate of skin cancer has been observed worldwide. Although there are many factors effecting the formation of skin cancer, it must be accepted that UV radiation is an important variable.

2.1 UV Radiation

UV radiation is a small part of the electromagnetic spectrum which is divided into shortwave UVC (200–280 nm), middle-wave UVB (280–320 nm) and long-wave UVA (320–400 nm) (Figure 1-a). The penetration of UV radiation in human skin is important for the development of various pathological changes. It was reported that, UVA can penetrate the deep dermis but does not cause sunburn, and UVA radiation can be carcinogenic resulting in chronic reactions and injury, accelerated ageing of the skin while UVB affects the epidermis, superficial dermis and causes sunburn, and increases the risk factor of melanoma and skin cancer [3]. On the other hand, UVC radiation hardly penetrates into the epidermis and damage DNA in human skin (Figure 1-b). However UVC radiation is absorbed by the ozone layer [5-9].

The amount of UV radiation received at the surface depends on cloud cover, geographical position, altitude, ozone layer, scattering in the atmosphere, environmental and related conditions. The risk of skin diseases increases with ozone depletion in the stratosphere which increases the amount of UV light that reaches the earth [10-12]. Skin diseases also depend on the sun exposure in childhood. In a person’s lifetime, most of the UV exposures occur during childhood [13-15]. Thus protection from sun is highly important especially in childhood.
In terms of sensitivity to light and tendency to pigmentation, there are 6 basic types of skin that demand different levels of protection [16].

Table 1 effect of UV rays on different types of skin

<table>
<thead>
<tr>
<th>Skin type (appearance unexposed)</th>
<th>Critical dose (mj/cm²)</th>
<th>Self protection time (min)</th>
<th>Risk level</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-White</td>
<td>15-30</td>
<td>5-10</td>
<td>Burn easily, has the highest risk of premature skin ageing and greatest risk of developing skin cancer</td>
</tr>
<tr>
<td>II-White</td>
<td>25-35</td>
<td>8-12</td>
<td>Burn and only rarely tan</td>
</tr>
<tr>
<td>III-Brownish</td>
<td>30-50</td>
<td>10-15</td>
<td>Tan and occasionally burn</td>
</tr>
<tr>
<td>IV- Brown</td>
<td>45-60</td>
<td>15-20</td>
<td>Tan and occasionally burn</td>
</tr>
<tr>
<td>V- Brown</td>
<td>60-100</td>
<td>20-35</td>
<td>Sufficient levels of melanin and rarely burns, easily tan</td>
</tr>
<tr>
<td>VI – Dark Brown - Black</td>
<td>100-200</td>
<td>35-70</td>
<td>Sufficient levels of melanin pigment provide protection. Very rarely burns, easily tan</td>
</tr>
</tbody>
</table>
The minimal erythematic dose (MED) is apparently consistent with a fair complexion, but shows variations among people of types III and IV. For practical purposes, the population could be classified into two main groups, sensitive and less sensitive individuals [16].

2.2 UV Protection Factor and Standards for UV Protective Textiles

Given the increasing interest in sun protection test methods and a rating scheme for clothing were needed to ensure sufficient UV protection. The Australian/New Zealand Standard was the first normative publication offering test methods to be used for determining UV protection factor (UPF) and a classification scheme [3,17].

Assessment of protection of a textile against UV radiation can be performed either through laboratory testing in vivo or instrumental measurement in vitro.

In vitro testing: The term, UV protection factor (UPF) has been widely adopted by textile and clothing industry worldwide to denote the protective ability of a textile and which is defined as ‘the ratio of the average effective UV irradiance calculated for unprotected skin (effective dose-ED) to the average effective UV irradiance calculated for skin protected by the test fabric (effective dose-EDf)’ [11, 17, 18]. 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. For correct measurement, this test method requires a UV source that closely matches the solar spectrum, which detectors that respond similarly to human skin [17]. To determine the in vitro UPF, the spectral irradiance (of the source and transmitted spectrum) is weighted against the erythemal action spectrum can be calculated by Eq. 1:

$$UPF = \frac{ED}{ED_f} = \frac{\sum_{\Delta \lambda = 290}^{\Delta \lambda = 400} E(\lambda) S(\lambda) \Delta \lambda}{\sum_{\Delta \lambda = 290}^{\Delta \lambda = 400} E(\lambda) T(\lambda) S(\lambda) \Delta \lambda}$$

where $E(\lambda)$ is the relative erythemal spectral effectiveness, $S(\lambda)$ is the solar spectral irradiance in Wm\(^{-2}\)nm\(^{-1}\), $\Delta \lambda$ is measured wavelength interval in nm, $T(\lambda)$ is average spectral transmittance of the fabric specimen, and $\lambda$ is the wavelength in nm. The higher the UPF values, the higher the UV protection of the skin [3,11, 17].

There are two in vitro quantitative measurement techniques to test UVR transmission through textiles or measure UPF. One is radiometry where the total transmission of UVR through a fabric is measured using a real or simulated solar spectrum. The other is spectrophotometry where the transmission of UV radiation through a fabric is measured as a function of wavelength from which UPF is then calculated. For both radiometry and spectrophotometry the primary requirement is an ultraviolet radiation source that includes both the UVA and UVB radiation. Total diffuse radiation transmitted through fabric is measured by both techniques because it simulates radiation hitting the skin beneath the textile in a real-life scenario [3].
**Radiometry:** Radiometric UV transmission techniques use a broadband UV light source filtered for UVB or combined UVA and UVB bands to illuminate a fabric sample. The total UV transmission through a textile is measured by a radiometer. The radiometer produces an output reading corresponding to the total radiant energy passing through the textile and falling on the detector surface. The radiometric technique was used by Bech-Thomsen et al. [3] in a study. In their study radiation from a solar stimulator lamp was filtered to a band in the region of 298 to 329 nm with a peak at 313 nm. A radiometer with a diffuser was used to measure the transmitted radiation in the presence and absence of a textile material. To ensure that the scattered light transmitted by the fabric was also measured by the detector the textile material was wrapped around the detector. The protection factor was determined by taking the ratio of the measured power in the absence of the textile material to the measured power in the presence of the textile material. It should be pointed out though that radiometric measurement does not yield a definitive value for the protection factor of a given textile. A probable reason could be that the absorption of the textile is not independent of the wavelength in the UVA and UVB bands of interest. Nevertheless, the technique is useful when for example only a relative variation in UPF needs to be measured such as the variation in UPF from site to site within a textile or the effect of stretching the textile on the UPF.

**Spectrophotometry:** It was reported in reference [3] that the spectrophotometric technique relies on the collection of transmitted and scattered radiation with the aid of an integrating sphere positioned behind the textile material. The AS/NZS and European standards for measuring and labeling UPF of textiles suggests equipping the spectrophotometer with a UV radiation transmitting filter for wavelengths of less than 400 nm to minimize errors caused by fluorescence from optical brightening agents. Spectrophotometric measurements are generally done in 5 nm or less steps in the wavelength range from 290 to 400 nm. Step size is important since it has been shown that using a step size of 1 nm results in the most accurate determination of UPF; using a 5 nm step size produces results within 0.5% while with 10 nm steps the UPF values are within 1.5 to 2.5%. A minimum of four samples must be measured from a textile material with two in the machine direction and two in the cross-machine direction. One of the first attempts to measure spectral transmission of ultraviolet radiation through textiles by a spectroradiometer was reported by Robson and Diffey. In their method the spectral irradiance from an unfiltered 75 watt xenon arc lamp was measured in the range from 290 to 400 nm in 5 nm steps using a spectroradiometer. Subsequently, a 3 x 3 cm fabric material was placed over the quartz input optics of the spectroradiometer and the spectral irradiance measurement was repeated. As in the radiometric technique, the wrapping of the fabric material directly around the detector ensured that the scattered radiation transmitted by the fabric was also measured by the detector. The monochromatic protection factor \(PF(\lambda)\) at wavelength \(\lambda\) nm was defined as the ratio of the spectral irradiance of the unfiltered radiation to that of the radiation transmitted through the fabric. The UPF values measured by this technique had a range from UPF 2 for a polyester blouse to more than 1,000 for cotton twill jeans.
Subsequently, many other researchers have used the spectrophotometric technique and laboratory testing has proven spectrophotometry to be an accurate and reproducible method of measuring UPF. It is noted, however, that spectrophotometric measurements are made with collimated radiation incident at right-angles to the fabric and thus represent a worst-case scenario. In practice, the actual protection afforded by a textile might well be higher than that predicted by an in vitro measurement since in the real world UVR would be incident on a textile at angles other than normal incidence and in addition there would be the presence of diffuse UV radiation from the sky.

In vivo testing: With human volunteers, use of the sun as UV source is impracticable to test the UPF of textiles. Generally, xenon arc solar simulators are used, with filters to absorb wavelengths below 290 nm and to reduce visible and infrared radiation [17]. The simplest way of in vivo testing is by attaching rectangular pieces of fabric to the back of a human subject and determining the minimum erythemal dose (MED) of the unprotected and protected skin. MED is defined as the minimum quantity of radiant energy required to produce first detectable reddening of the skin, 22 ± 2 hours after exposure. MED for unprotected skin is determined first using incremental UVB doses. Subsequently, MED for protected skin is determined by a series of incremental and decremental UVB doses centered at the estimated SPF [3] of the given fabric as estimated from UPF values determined in vitro [3]. The higher the SPF value, the better the fabric’s ability to protect against sunburn. 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. It was reported in the studies which showed UPFs determined using the in vivo “on skin” method is lower in significant level than the UPFs obtained in vitro.

\[
SPF = \frac{MED(\text{protected skin})}{MED(\text{unprotected skin})} \tag{2}
\]

Cost and impracticability are limitations of the in vivo test methods, so in vitro test methods are included in standards.

There are several standards for measuring and classification for UV protection of textile materials. All standards employ Eq. 1 for measuring UPF of fabrics although their scanning intervals, positioning of the fabrics in the instrument, the erythemal action spectrum designated, classification and marking are different from each other [11].

European standard EN 13758-1:2002 indicates a method to determine erythema-weighted UV radiation transmittance of standard prepared and conditioned apparel textiles. For UPF measurements, at least four specimens are necessary. The conditioning and testing is carried out in accordance with EN 20139: 1992. This standard determines the transmittance between 290 nm and 400 nm by wavelength interval of 5 nm [11, 19].

EN 13758-2:2003 determines general clothing design that offers UV protection to the upper and/or lower body ‘shall at least cover the upper and/or lower body completely’. There is only one category for UV protective textiles which should have a minimum UPF in excess of 40
and UVA transmission lower than 5%. UV protective textile is marked with pictogram (Fig. 2) in this standard [11, 19-21].

**Figure 2.** Pictogram for UV protective clothing according to the EN standard 13758-2 [19]

AATCC Test Method 183-2004 determines UPF of fabrics either in dry or wet states. Minimum two specimens of tested fabric which should be prepared according to the ASTM D 6544 requires for this test method [11].

Australian/New Zealand Standard AS/NZS 4399:1996 is the first standard about UV protective textile materials and indicates requirements for determining and labeling UPF of sun protective textile materials which are worn in close proximity to the skin. The effects of stretch, wetness, wear, and use are not included in this standard. According to this standard sun protective clothing is classified to its rated UPF as given in Table 1[11, 18, 22].

<table>
<thead>
<tr>
<th>UPF Range</th>
<th>Protection Category</th>
<th>Effective UV-R Transmission (%)</th>
<th>UV-R</th>
<th>UPF Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>15–24</td>
<td>Good</td>
<td>6.7–4.2</td>
<td></td>
<td>15, 20</td>
</tr>
<tr>
<td>25–39</td>
<td>Very good</td>
<td>4.1–2.6</td>
<td></td>
<td>25, 30, 35</td>
</tr>
<tr>
<td>40–50, 50+</td>
<td>Excellent</td>
<td>Less than 2.5</td>
<td></td>
<td>40, 45, 50, 50+</td>
</tr>
</tbody>
</table>

ASTM D 6603-07 determines the UPF value which is placed on a garment and this value should be the lowest protection value expected during consumer use over a two-year period. The protection classification is similar as described in AS/NZS standard [11, 23].

### 2.3 Textile Materials and UV Protection

Here firstly the effect of UV radiation on textile materials can be discussed. UV radiation is one of the major causes of degradation of textile materials, which is due to excitations in some parts of the polymer molecule and a gradual loss of integrity, and depends on the nature of the fibers. Because of the very large surface volume ratio, textile materials are susceptible to influences from light and other environmental factors. The penetration of UV radiation in
nylon causes photo oxidation and results in decrease in elasticity, tensile strength and slight increase in the degree of crystallinity. In the absence of UV filters, the loss in tensile strength appears to be higher in the case of nylon (100% loss), followed by wool, cotton and polyester, with approximately 23%, 34% and 44% respectively after 30 days of exposure. Elevated temperature and UVB radiation on cotton plants result in severe loss of bolls [16].

Apart from sun avoidance and use of sunscreens, hats and clothing provides protection from sun and skin diseases. Summer clothing is usually made of cotton, viscose, rayon, tencel, linen, polyester, or combinations of these fibers. Other fibers such as nylon and elastane, are also found in bathing suits and nylon stocking. People generally prefer lightweight natural fibers to be most comfortable for wearing in summer. UV protective clothes should have high UV absorption or reflection properties as much as possible [24]. There are a number of factors that affects UV radiation permeability of a textile product such as fiber type, fabric structure, particularly porosity, thickness and weight; moisture content, dye concentration, finishing chemicals, UV absorbers and etc. [3].

2.3.1 Fiber Type

Textile fibers have different UV absorption properties and UV protection of textile materials depends on chemical structure of the fibers [18, 25-28]. Wool absorbs strongly in the region of 280-400 nm and even beyond 400 nm [17]. In general, synthetic fibers such as polyester have higher UPF values than natural fibers such as cotton. Particularly, polyesters provide higher UVB radiation resistance since they include large conjugated system of its polymer chains [17, 25, 28]. On the other hand, polyester blended fabrics may be the most suitable fabric type for the use in UV protective clothes, since polyesters results in discomfort to wear in summer [18, 25]. However, its permeability of wavelengths in the UV-A range is frequently higher than that of other fiber types.

In reported studies [3, 17, 18, 25] the type of fiber used in fabric structure have a substantial effect on the UPF. Raw natural fibers like linen and hemp possess a UPF of 20 and 10 to 15 respectively, and are not perfect UV protectors even with lignin content. However, the strong absorption of jute is due to presence of lignin, which acts as a natural absorber [16].

Bleached cotton is transparent to UV radiation and thus gives relatively low UV protection. Hoffman [17] reported that Crews et al described that bleached cotton print cloth had a UV transmission of 23.7%, whereas the same unbleached fabric had a UV transmission of only 14.4%. The effect of bleaching was also evident among silk fabrics in their study. Compared with bleached textiles, unbleached fabrics such as cotton and silk have better UV protective properties due to UV-absorbing natural pigments and other impurities.

2.3.2 Fabric Construction Factors

Cloth cover %, weight, thickness and porosity are the important structural parameters that influence the UPF of fabrics. Fabric cover specifies the percentage of fabric area that is
covered by the yarns. Fabrics with a higher weight, thickness and cover density absorb higher amount of UV rays, thus these fabrics offer better protection against UV radiation [4, 26-30].

Tightly woven or knitted fabrics provide higher UV protection due to the lower porosity of the structure. In general woven fabrics have lower UV transmittance values compared with the knitted fabrics. Among the weave structures, plain woven textiles have the lowest porosity [11, 18, 29].

It was indicated that UVR transmission through a fabric to its `cover factor', the term used to describe a fabric's porosity. Percentage UVR transmission and UPF can then be calculated using the following equations: [3]

\[
\text{\%UVR transmission} = 100 - \text{cover factor} \quad (3)
\]

\[
\text{UPF} = \frac{100}{200 - \text{cover factor}} \quad (4)
\]

Eqns. 3 and 4 show that the cover factor of a fabric must be greater than 93% to achieve a minimum UPF rating of 15. Also, once the cover factor exceeds 95%, very small increases in cover factor lead to dramatic improvements in the protective ability of the fabric. It should be noted, however, that fabrics with the same cover factor can have widely different UPF ratings, particularly if their fiber chemistries are different. In general, knit fabrics have a lower cover factor than woven textiles because of their open structure. Among woven textiles, plain weaves have a higher cover factor than other weaves [3].

Porosity can be quantified by several methods. Perhaps the simplest method is by calculating cloth cover. Cloth cover is a measure of the fraction of area covered by both the wrap and weft threads in a given fabric and calculated simply by using thread count and yarn number according to an equation by Booth and Pollitt [3].

\[
\text{Cloth cover} = \text{Cover factor}_{\text{wrap}} + \text{Cover factor}_{\text{weft}} - [(\text{Cf}_{\text{wrap}} \times \text{Cf}_{\text{weft}})/28] \quad (5)
\]

Where Cover factor (Cf) = threads per inch/√ yarn number (cotton count system). The above equation was developed for a plain weave fabric and the basic premise is that the cover factor would be 28 if all yarns just touched each other. In practice, cover factors can range from 8 to 28 for commercially available fabrics.

Elemen at al. [31] studied prediction of the UPF of woven fabrics with different porosities using NN (neural network) models. In the study the porosity of the fabrics was calculated by using Equation 6.

\[
\varepsilon = 1 - \frac{\rho_a}{\rho_b} \quad (6)
\]
where $\rho_a$ is the fabric density (g/cm$^3$), $\rho_b$ is the fiber density (g/cm$^3$) and $\varepsilon$ is the porosity. Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness. The mean density of cotton fibers is accepted as 1.52 g/cm$^3$ [32]. In order to calculate the inter-yarn porosity geometrically which is defined as the ratio of the projected geometrical area of the opening across the material to the total area of the material, Equation 7 was used.

$$
\varepsilon = \frac{\text{open pore area}}{\text{total area}} = \frac{P_1P_2}{(P_1 + d_1)(P_2 + d_2)} 
$$

(7)

where, $P_1$ the distance between warp threads, $P_2$ the distance between weft threads, $d_1$ the diameter of the warp yarn, $d_2$ the diameter of the weft yarn. Figure 3 shows relation between the porosity parameters and UPF values of the samples.

![Figure 3](image)

**Figure 3.** Relation between the porosity parameters and UPF values of the samples

The increase in the porosity decreased the UV-protection values. The results indicated that the UV-protection values were affected by the pores between yarns and inter-yarn pore area. It was observed that there is a strong polynomial relationship between the inter-yarn porosity and UPF values. Additionally, geometrically calculated inter-yarn pore area which is directly related to the inter-yarn porosity, showed an analogy with the UPF values. However, the total porosity which includes also inter-fiber porosity was seemed to be not discriminative with a very low correlation coefficient. It can be claimed that the pores within the yarns are
insignificant in terms of UV-protection. In the study it was observed that inter-yarn porosity and inter-yarn pore area were found to be the determinative factors for the UV protection properties of the fabrics. UPF values of fabrics with different structures were successfully predicted by applying a three-layered artificial neural network with 5 neurons in the hidden layer and using a back propagation algorithm. An analysis of the relationship between the predicted results of the designed ANN model and the experimental data was also conducted. It was concluded that the performance of the proposed ANN model by using porosity parameters was found to be satisfactory in terms of the estimation of UV-protection properties.

2.3.3 Dyeing and Finishing

Naturally, colored cottons contain pigment ranges from light green to tan, brown and inherent long-term UV protection properties with a UPF of 64 and 47, whereas normal cotton shows a UPF of 8 [16]. Textile dyes affect the UV protection of textiles, depending on the position and intensity of the UV wavelength absorption bands of the dyes and the concentration of the dyes in the textile material. Dark shades offer better UV protection as a result of increased UV absorption [12, 17, 18, 29, 33]. However, particular hue dyes can vary considerably in the degree of UV protectiveness because of individual transmission and absorption characteristics [17].

Besides dyeing, there are other processes for textiles which have an effect on UV protection of textiles. Bleaching affects UV protective properties of fabrics. Unbleached textiles provide better UV protective properties than the bleached textiles due to UV-absorbing natural pigments and other impurities [28, 29].

Optical brightening agents might be used to improve UV protection of fabrics. Optical brightening agents can absorb UV radiation and re-emission in the visible blue range of the electromagnetic spectrum. However, durability of optical brightening agents decreases by washing process and they only absorb in UVA range, weakly [16, 34].

UV absorbers are one of the agents which improve UV protection properties of textiles. UV absorbers are colorless compounds with strong absorption in the wavelength range of 290 to 400 nm. The protection can be obtained by embedding of UV absorbers in polymers, or by coating with UV absorbers. UV absorbers incorporated into the fibers convert electronic excitation energy into thermal energy, function as radical scavengers and singlet oxygen quenchers. The high-energy, short-wave UVR excites the UV absorber to a higher energy state; the energy absorbed may then be dissipated as longer- wave radiation. Alternately, isomerisation can occur and the UV absorber may then fragment into non-absorbing isomers. Sunscreen lotions contain UV absorbers that physically block UVR. The most widely used UVB screens, 2-ethyl hexyl-4-methoxy cinnamate with high RI, make a substantial contribution to the RI matching of skin, i.e. ‘refractive index matching’. An effective UV absorber must be able to absorb throughout the spectrum, to remain stable against UV radiation, and to dissipate the absorbed energy to avoid degradation or loss in color.
There are organic and inorganic UV absorbers. Organic UV absorbers are mainly derivatives of o-hydroxy benzophenones, o-hydroxy phenyl triazines, o-hydroxy phenyl hydrazines. The orthohydroxyl group is considered essential for absorption and to make the compound soluble in alkaline solution. Some of the substituted benzophenones penetrate into synthetic fibers much like disperse dyes. Commonly used UV absorbers are 2-hydroxy benzophenones, 2-hydroxy phenyl benzotriazoles, 2-hydroxy phenyl-S-triazines and chemicals such as benzoic esters, and hindered amines [16]. The strong absorption in the near UV of 2, 4 dihydroxy benzophenone is attributed to conjugating chelation between the orthohydroxyl and carbonyl groups. Organic products like benzotriazole, hydro benzophenone and phenyl triazine are primarily used for coating and padding processes in order to achieve broad protection against UV rays. Suitable combinations of UV absorbers and antioxidants can yield synergistic effects. Benzophenone derivatives have low energy levels, easy diffusibility and a low sublimation fastness, and a self-dispersing formulation can be used in high temperature dyeing in pad-baths and also in print pastes [16].

Organic absorbers cannot provide sufficient protection to UV radiation since they absorb only UV light of appointed wavelengths due to the typical absorption bands of molecular systems (UVA or UVB). In addition the presence of UV absorbers in PET, nylon, silk and wool protects the fibers against sunlight-induced photo degradation. On wool, UV absorbers can retard the photo-yellowing that occurs upon exposure to sunlight.

Inorganic absorbers such as TiO\textsubscript{2} and ZnO absorb the light with energy higher than their band gap energy completely. The presence of these inorganic pigments in the fibers results in more diffuse reflection of light from substrate, and provides better protection. Titanium dioxide and ceramic materials have an absorption capacity in the UV region between 280 and 400 nm, and reflects visible and IR rays; these absorbers are also added as dope additives. For maximum effect, the particles have to be monomolecularly distributed, and are often applied in one bath. Nanoscale titanium gel particles strongly bound to the cotton fabrics can give a UPF \(\geq 50\) without impairing the tensile properties. Brighter viscose yarns provide the highest UV transmittance compared to dull pigmented viscose yarns, modal yarns. Zinc oxide nanoparticles, which have a very narrow size distribution (20-40 nm) and minimal aggregation, can result in higher levels of UV blocking. Use of TiO\textsubscript{2}, ZnO alone produces less absorption of UVR than a mixture of (67/33) titanium dioxide and zinc oxide on cotton and nylon fabrics. Microfine nylon fabrics with a porosity of 0.1\% are capable of giving UPF > 50 with 1.5\% TiO\textsubscript{2}. Incorporating UV absorber in dyeing decreases the dye uptake slightly, except ib post-treatment application [16].

The combination of organic and inorganic UV absorbers in one coating may improve protection of textiles to UV radiation [16, 35-36]. However, the absorption of titanium dioxide particles is frequently less protective in the UV-A wavelength range.
2.3.4 Moisture and Swelling

The moisture content affects the UPF of the fabrics as a result of scattering effect and consequently increases the UV transmittance. Wet garments have lower UPF values than the garments in dry state.

The influence of moisture depends on type and hygroscopicity of fibers as a result in swelling phenomena which reduce the interstices [16, 37-38]. A typical cotton fabric could have 15-20% UV transmission, however this value could rise to more than 50%, if the garment is wet [16,38]. For adequate protection, the UVR transmission should be lower than 6% and 2.5% for extremely good protection. Dependence of humidity is more pronounced in silk and viscose, of which viscose has a higher water absorption and swelling capacity, while silk has poor swelling properties. Even though silk has poor swelling properties, it’s very fine nature and a greater number of fibers in the cross-section of yarn results in higher swelling due to capillary absorption, and in turn less UV transmittance. Finishing treatments given to the fabrics to reduce swelling reduce the decrease the transmittance of UV radiation [16].

2.3.5 Stretching

Stretching increases fabric porosity during wear, with a consequent decrease in UPF values [7, 16, 17, 37]. The cover factor can be modified through many dry finishing processes through overfeed on the stenter, compressive shrinkage processes such as compacting and sanforising, which are normally used to obtain dimensional stability, incidentally increasing the cover factor and hence the UPF.

The upper back is the maximum stretch point on the body for tight fitting garments. Textiles can be stretched up to 15% in the upper back. On the other hand, the effect of stretch on UV protection of a textile may be significant only for garments with a UPF of less than 30 in non-stretched state, such as leggings, women’s stockings, and swimsuits [17].

2.3.6 Laundering

It was reported by Hoffman [17], Stanford at al examined effect of laundering on UV protection of T-shirts. They showed that UPFs increased after first washing and did not change significantly with subsequent washing. The original UPF of a new cotton T-shirt was found to be 15, increasing to UPF 35 after first laundering. These UPFs were obtained when participants were instructed to wear their T-shirt for 4 to 8 hours per week and to wash their T-shirt one per week for 10 wash and wear cycles. Most fabrics undergo a combination of relaxation and consolidation shrinkage when washed. Thus, the spaces between the yarns decrease and UV protection increases. The effect of laundering on UPF raises questions about qualities and factors of other fabrics that decrease UPF.
3 ELECTRICAL PROTECTION

Textile materials and clothing used in certain hazardous environments need to be chosen or treated to minimize the risk of fire or explosions caused by static electrical charges building up and being released via the wearer. For example, these concern protective clothing which protects especially against electrical risks, such as electric insulating protective clothing, shielding clothing for working on live equipment for nominal voltage up to AC 800 kV, protection against high-frequency electro-magnetic fields, complex flame-retardant and antistatic protective clothing. A range of protective clothing types require, apart from a guarantee of non-combustibility, suitable electrical conductivity of the materials, in order to avoid the danger of electrostatic ignition (e.g., explosives, chemicals industry, mining, oil industry, tanker transport, oil extraction, military) [3].

Electrical hazards can be divided into electrostatic charge, lightning strike and high-voltage electricity. Protective textiles for all these hazards incorporate electrical conductive materials. A proportion of conductive fibers, for example carbon, metal, synthetic fibers with a carbon core and conductive polymer fibers are commonly used. The other methods are to apply a conductive finish, coating or laminate the fabric to conductive polymer films.

The other important electrical protection is electromagnetic protection. The usage of electrical and electronic devices with high frequency is growing day by day. Due to this increase, electromagnetic pollution caused by many factors such as mobile phones, remote control devices, computer and TV screens, and radio channels have gained considerable importance [39]. These types of devices are capable of emitting radio-frequency energies. There is a growing need for setting limits on the electromagnetic emissions from these devices in order to minimize the possibilities of interfering with radio and wire communications as well as human health. Many countries are legislating new regulations so that the manufacturers of electrical and electronic equipment should comply with the electromagnetic compatibility (EMC) regulations [40,41].

3.1 Electromagnetic Protection

Electromagnetic radiation has harmful effects for human health. To prevent the negative effects of electromagnetic waves on human beings, shielding is needed. Electromagnetic shielding prevents electromagnetic radiation transmission by a material [42] and provides the protection of human beings from the hazardous effects of electromagnetic radiation. Regardless of its type and structure, a shielding material is characterized by its shielding effectiveness [43]. Effectiveness of electromagnetic shielding depend not only on the type of the shielding material, but also on the distance between the wave source and the material and the structural properties of the material [41,44].
3.1.1 Effects of Electromagnetic Waves on Health

When electromagnetic waves enter human body, they vibrate molecules producing heat and they cause the inhibition of DNA and RNA regeneration in the cell and also support the cancer cell formation by causing abnormal chemical reactions [41,45]. Human nervous system has huge electronic system with around 25 billion cells. The results of electromagnetic fields can be neurologic, neuroendocrinologic, hematologic and cardiovascular effects on biological systems, and in addition the immune system and cell growth are also effected [41, 46].

Possible hazards of electromagnetic fields on human health can be summarized as follows:

- Protein changes in skin
- Excited brain cells.
- DNA damage
- Brain cell damage.
- Aggressive growth in leukemia cells
- Increased blood pressure [47]

3.1.2 Electromagnetic Shielding With Textiles

Health effects of electromagnetic radiation depend on:

- Field intensity
- Cumulative exposure
- Exposure duration [41]

These factors could be critical for the health of human being exposed to electromagnetic radiation in their professional lives. Especially, long-term exposure can result in cumulative physiological effects that may ultimately cause serious disease [41].

Electromagnetic shielding refers to the reflection and/or adsorption of electromagnetic radiation by a material, which acts as a shield against the penetration of radiation through the shield. In recent years, conductive fabrics have been used for electromagnetic shielding and conductive fabrics can be designed basically with laminating conductive layers onto the surface of the fabric by using conductive coatings, addition of conductive fillers (carbon fibers, metal fibers (copper, steel, aluminum)), and incorporating of conductive fibers or yams into the fabric [40,48].

The limitations of textiles clothing manufactured can be seen in three issues:

- Protective factor: The attenuation of the intensity of the electromagnetic field at current solutions of protective clothing is limited.
• Material: Metals have some disadvantages. Stainless steel in the fibres can represent a stability risk of defined attenuation characteristics by using the clothing frequently. Vacuum deposition technology limits the versatility of textile materials. Printing method malfunctions because of material peeling, which results in damage to the protective layer and decrease in ESE values. Copper threads oxidise and transition resistance can decrease the efficiency of the textile material.

• Weight of protective clothing: Metal fibers used in the production of protective clothing increases the weight of the clothing and it also decreases wearing comfort [47].

Many synthetic fibers that are used in the textile fabrics are insulating materials with resistivity of the order of $10^{15} \, \Omega / \text{cm}^2$. This is much higher than the desired resistivity for electromagnetic shielding applications. The desired value for shielding material is lower than $10^2 \, \Omega / \text{cm}^2$ [48]. Typical shielding structures are made of metals for which the decrease is realized by reflection. The metals are used under different forms such as films, plates or meshes, or they are incorporated as particles in polymeric materials or as thin metallic coatings. The materials for which the attenuation is realized by absorption have a restricted application area compared to metals [41]. The design of electromagnetic shields take into account more variables such as production cost, material weight and therefore plastics with metallic coatings, structural materials, conducting polymers and textile materials with metallic insertion such as metallic and conducting fibers are more frequently utilized. Conductive textiles possess very good elastic behavior and they can be produced in various forms with low production cost [41,49].

For the last few decades fine and flexible conductive yarns were developed, which ensure very good electrostatic properties. Furthermore, since conductive yarns have high stiffness, weaving and knitting them is difficult so in recent studies combining of conductive yarns with cotton or polyester is preferred. Cheng [50] produced plain knitted, 1x1 rib knitted and 2x1 rib knitted fabrics from stainless steel/polyester yarn. As expected higher ratios of steel showed higher electromagnetic shielding effectiveness (EMSE). In addition knitted fabrics with higher stitch density had the highest EMSE.

Researchers used stainless steel as the conductive filler to produce stainless steel hybrid yams to make woven fabrics. The experimental results show that a denser structure has a higher EMSE. The fabric made from the core yarns has a higher EMSE than that made from the cover yams and the plied yams [51].

Vojtech [47] focused on human protection against high frequency electromagnetic fields and related protective clothing. The textile fabric developed in the research is based on synthetic yarn with the addition of silver nanoparticles. The results showed that it decreases the weight comparison with fabrics, which contain stainless steel fibers. The textile fabric achieves EMSE values of about 40 dB, which is about 10 dB better than the best existing solution known for a reference frequency of 500 MHz.

Duran et al [52] investigated the shielding behavior of woven fabrics, produced with copper filament containing (Cu/Co) core spun yarns. They found that the electromagnetic shielding
effectiveness of the woven fabric produced can be tailored by modifying the copper filament inclusion in the yarn structure. These fabrics can be used as shields against electromagnetic radiation in a wide variety of application areas including military and medical fields, and for the protection applications in daily life such as wall papers, curtains. Researchers tested electromagnetic shielding properties of the woven fabrics by using unechoic chamber test system according to EN50147-1 standard, in 200 MHz-5.8 GHz frequency range (Fig. 3).

The system was composed of;

- A signal generator which produces the signals
- An RF power amplifier which amplifies the signals before being sent to the sample
- Two antennas; one connected to signal generator and the other to the spectrum analyzer as receiver
- Two adjacent shielded rooms, each having one of the antennas inside
- A spectrum analyzer which analyses the signals obtained from receiver antenna

![Electromagnetic test system](image)

**Figure 3.** Electromagnetic test system [52]

During the measurements the sample is placed between the signal generator and the receiver. The signal generated is first amplified and then sent onto the sample by an antenna. The signals transmitted by the sample are detected by the receiver antenna, situated on the other side of the sample. According to the basic principle of EMSE test, the amount of transmitted signals is measured and electromagnetic field blocked by the sample is calculated. In order to eliminate the effects of reflections in the measurement system and losses caused by antennas and cables, blank measurement for each sample and thus the actual shielding effectiveness results are obtained [52].
3.2 Electrostatic Protection

Static electricity is generated when almost any pair of surfaces is separated. The amount of charge transferred from one surface to another depends on the relative affinities of the materials for a charge of given polarity [3]. The static charge which is involved in a spark phenomenon is often generated on the clothing or footwear of the individual and transferred onto the skin. Electrostatic charges accumulate easily on ordinary textile materials, especially in dry conditions. Charges once accumulated are difficult to dissipate. An electrostatic system can be represented by a simple circuit (Fig. 4). It contains four elements: a charge generator, $I$, to represent the charge generating mechanism, a capacitor, $C$, on which charge is stored, a resistance, $R$, which represents the charge relaxation mechanism in the electrically stressed insulator, and a spark gap which limits the maximum charge that can be held in the system. Charge storage occurs on the system capacitance while the resistance of the system allows the charge to dissipate. The capacitor may be an insulating material or a person not properly grounded. The magnitudes of the capacitance and resistance determine the decay time of the charge in the system:

$$\tau = RC$$ (8)

Figure 4. An electrostatic system [3]

3.2.1 Charge Generation

Most textiles and polymers are poor conductors of electricity and the causes of charging are very complex. The clinging of garments is a common problem caused due to the presence of electrostatic charges. Electrostatic attraction may impede the opening of parachutes and even lead to catastrophic failure under certain circumstances. The surface of textiles is usually contaminated with additives, finishes, dirt and moisture, in all of which resides an abundance of ions. In this case, charging may comprise electrons, ions and charged particles of the bulk materials, or any combination of these [3].
Charging that occurs when two solids come into contact has been referred to as contact charging, frictional charging, tribo-electric charging and tribo electrification. Contact charging is used to explain simple contacts between surfaces. Thus, static electricity is generated when almost any pair of surfaces is separated, unbalancing the molecular configuration in the case of relatively non-conductive materials [3].

### 3.2.1 Electrostatic Discharges

Static electricity has long been cited by researchers as a possible cause accidental ignition of flammable or explosive liquids, gases, dust, and solids. Static electricity manifests its destructive nature through electrostatic discharge. The electrostatic build-up on people or materials, especially non-conductive materials such as textiles, can be important in dry conditions. Antistatic performance is an essential requirement for clothing worn by workers in the military, oil and gas industries, electronics, etc. The antistatic performance requirement of a textile material may differ according to its end use and can be determined by the risk of explosion, shock, electronic damage, and dust protection [3].

The basic rule for fighting the unwanted effects of static electric charges is to ground all conductors that might become charged or exposed to induction from other charged objects. In the electronics and other industries, grounding through footwear and a floor covering is a widely accepted procedure in many areas of the electronics industry. For this aim the device employed is a wrist strap, which consists of a band or chain, similar to an expandable watchband and made of metal and conductive plastic or conductive fibers, and a strap that connects the band to ground.

It is often possible to provide highly insulated textile materials effectively surface-conductive, even at relatively low humidity, by treating the surface with antistatic agents. Antistatic finishes reduce the electrical resistivity in the fabric [2]. The antistatic agents are amphipatic compound, their molecules containing a hydrophobic group to which is attached a hydrophilic end group. According to the nature of the end group the agents can be anionic, cationic or non-ionic.

### 4 MECHANICAL PROTECTION

#### 4.1 Historical Background

Mechanical protection requires soft body-armor, various cut and/or slashes hazards, such as chain saws, sheet metal, glass, knives or other sharp edges, and stab and puncture resistant materials. For ballistic protection fibers must have high strength, high modules and low elasticity. Fibers with high strength and high modules absorb projectile impact, while low elasticity avoids indentation of the body and subsequent bursting. The most significant advance in the ballistic area has been the development and use of para aramids, DuPont's
Kevlar, to replace nylon as a ballistic barrier. This very high strength fiber, the same as used in tire cord, composites, and the like, is used in soft body armor by loosely stacking layers (16+) of (usually) filament aramid fabric, each providing coverage and progressive resistance to bullet or fragment penetration. Similar technology with rigid composites result in superior lightweight "hard" armor as well, for uses such as helmets and replacement of heavier steel armor plate areas such as vehicle and aircraft armor [1].

Agrawal [53] described historical background of ballistic production as follows:

“As far as textiles are concerned, the first ballistic armour, *Myunjebaegab* was invented in Korea in 1860s and was made of 30 folds of cotton. The vests were used in battles when the US Navy attacked Ganghwa Island in Korea in 1871. One of the early instances of ballistic armour being used was in Australia in 1879, when Ned Kelly's "Kelly Gang" made armour from scrap metals which covered their torsos, upper arms, and upper legs. Along with the helmet, the home-made suit weighed 44 kg. During World War I, the United States developed several types of body armor, including the chrome nickel steel Brewster Body Shield, which consisted of a breastplate and a headpiece and could withstand Lewis Gun bullets at 820 m/s, but was clumsy and heavy at 18 kg. In the early stages of World War II, the United States designed body armor for infantrymen, but most models were too heavy and mobility-restricting. These armor vests were often incompatible with existing equipment as well. In these systems comfort aspects were also entirely overlooked. Later on protection fabrics were tried with synthetic fibers like nylon but were not fully successful. In the mid-1970s, the DuPont Corporation introduced Kevlar synthetic fiber, which was woven into a fabric and layered. In 1976, Richard Davis, founder of *Second Chance Body Armor* designed this company's first all-Kevlar vest, named the Model Y. The lightweight, concealable vest industry was launched and a new form of daily protection for the late 1980s, an estimated 1/3 to 1/2 of police patrol officers wore concealable vests daily. By the year 2006, more than 2,000 documented police vest "saves" were recorded, validating the success and efficiency of lightweight concealable body armor as a standard piece of everyday police equipment. Since the 1970s, several new fibers and construction methods for bulletproof fabric have been developed besides woven Kevlar, such as DSM's *Dyneema*, Honeywell's *GoldFlex* and *Spectra*, Teijin Twaron's *Twaron*, Pinnacle Armor's *Dragon Skin*, and Toyobo's *Zylon*. These materials are advertised as being lighter, thinner and 2 more resistant than Kevlar, although they are much more expensive. However, they offer excellent protection from bullets.” Some of these materials, e.g., aramids are the most widely used ballistic protective materials.

The term “aramid” is short for “aromatic polyamide”. Aromatic polyamides were first applied commercially as meta-aramid fibers in early 1960s, with para-aramid fibers being developed in the 1960s and 1970s [53,54].

### 4.2 Ballistic Trade Fibers

Scott [3] was reported ballistic fibers as follows:
**Kevlar®**

Developed by Dupont, this is widely used in the modern generation of light weight concealable body armors with drastically improved ballistic protection over their predecessors. Kevlar fibers consist of long molecular chains produced from poly-paraphenylene terephthalamide. The chains are highly oriented with strong interchain bonding that results in a unique combination of properties, which include high tensile strength at low weight, low elongation to break, high modulus (structural rigidity), low electrical conductivity, high chemical resistance, low thermal shrinkage, high toughness (work-to-break), excellent dimensional stability, high cut resistance and flame resistance. Kevlar fiber does not melt or soften and is unaffected by immersion in water, although its ballistic properties are affected by moisture. It is five times stronger than steel on an equal weight basis and it is lightweight, flexible and comfortable. Kevlar fibers can be processed by textile manufacturers with little difficulty. Kevlar, introduced in the early 1970s, was the first generation of bullet resistant fibers to make the production of flexible, concealable body armor practical for the first time.

Kevlar® fiber and filament come in a variety of types, each with its own unique set of properties and performance characteristics for different protection needs [55].

**Kevlar® 29 (K29)**
The original family of product types of Kevlar®, having similar tensile properties with many deniers and finishes. These yarns are used in ballistic applications, ropes and cables, protective apparel such as cut-resistant gloves, in life protection uses such as helmets, vehicular armoring, and plates, and as rubber reinforcement in tires and automotive hoses.

**Kevlar® 49 (K49):** High-modulus type used primarily in fiber optic cable, textile processing, plastic reinforcement, ropes, cables, and composites for marine sporting goods and aerospace applications.

**Kevlar® 100:** Producer-colored Kevlar® yarns, used in ropes and cables, tapes and strappings, gloves and other protective apparel, and sporting goods.

**Kevlar® 119:** Higher-elongation, flexible-fatigue–resistant yarn types found in mechanical rubber goods, such as tires, automotive belts, and hoses.

**Kevlar® 129:** Lightweight, high-performance, and high-tenacity type of yarns used in motorcycle racing gear, life protection accessories, ropes and cables, and high-pressure hoses used in the oil and gas industry.

**Kevlar® KM2:** Woven into fabric meeting performance requirements for helmets and vests for military and high-performing UDgs for spall liners.
**Kevlar® KM2 Plus**: High tenacity, high toughness, and finer denier fiber used in vests and helmet for both military and law enforcement officers.

**Kevlar® AP**: Kevlar® AP for Advanced Performance helps dramatically improve cost-effectiveness and design flexibility to manufacturers helping them build leaner, more robust consumer and industrial products.

**Teijin Aramids** [54]

**Twaron®**: Twaron is high-performance man-made 100% paracrystalline fiber and Teijin Aramid’s flagship para-aramid product. It offers a unique combination of mechanical properties, chemical resistance, durability and thermal stability. It is highly valued across a wide range of industries for the benefits it brings to a great many high-performance applications.

**Technora®**: Technora is a para-aramid fiber made from co-polymers. Technora has a range of unmatched performance properties, including:

- High tensile strength – weight for weight, Technora is eight times stronger than steel
- Good fatigue resistance
- Long-term dimensional stability
- Excellent resistance to corrosion, heat, chemicals and saltwater

**Sulfron®**: Sulfron is a modified Twaron aramid. Used as a compounding ingredient, it improves the properties of sulfur-cured and peroxide-cured rubber compounds. It reduces hysteresis, heat build-up and abrasion, while improving flexibility, tear- and fatigue-resistance properties. It can be used to reduce the hysteresis of carbon-black-filled compounds and of compounds containing both carbon black and silica. As the Sulfron 3001 is mixed with the compound at elevated temperatures, intermediate reaction products are formed that interact with the carbon-black particles, thereby reducing the filler-filler interaction. The result is a compound with reduced frictional energy and thus improved hysteresis properties. With carbon black, this reaction takes place at elevated temperatures of between 140°C and 160°C. It is suitable for compounds containing both natural rubber (NR) and synthetic rubber (SR). According to the Tejin, tires that contain Sulfron are more durable and longer lasting, with better fuel efficiency, without compromising performance.

**Tejinconex®**: Tejinconex is a meta-linked aromatic polyamide fiber with flame-proofing and heat-resistance properties. It will not catch fire through exposure to direct flame or heat, and it neither burns nor melts, which means it cannot stick to skin. It is thermal insulator and has outstanding chemical resistance. According to Tejin, Tejinconex also meets the standard requirements of a clothing material – it is lightweight, easy to clean, and comfortable to wear.
**Spectra®**: This fiber, manufactured by Honeywell, is an ultra-high strength polyethylene fiber. Ultra high molecular weight polyethylene is dissolved in a solvent and fibers are produced through the gel-spinning process. In general, Spectra fibers are a bright white polyethylene fiber with high resistance to chemicals, water and ultraviolet light. Spectra is stronger than steel and 40 percent stronger than aramid fiber and capable of withstanding high-load strain-rate velocities [3, 56].

**DSM Dyneema®**: Another HPPE fibre like Spectra, this is made of ultra-high-strength gel-spun polyethylene used in body armour. Dyneema has an extremely high strength-to-weight ratio and is light enough to float on water [3,57].

**Dyneema®** is used in armored helmets, vests, shields and inserts to protect against a wide range of ballistics threats. Personal Armor, made with Dyneema®, help safeguard "everyday heroes"—such as soldiers, law enforcement officers, commercial pilots and high-profile civilians.

**Dyneema® Soft Ballistic (SB)** armors are used in vests and clothing to provide life-saving protection against handgun ammunition and knives.

**Dyneema® Hard Ballistic (HB)** armor solutions are incorporated into ballistic inserts and helmets to protect against heavier and more penetrating threats.

**Zylon® (PBO)**: Zylon fibers is high performance fiber developed by Toyobo [3,58]. Zylon consists of rigid-rod chain molecules of poly(p-phenylene-2,6-benzobisoxazole).

![Figure 5. Chemical structure of Zylon [58]](image)
Zylon fiber has strength and modulus almost double that of p-aramid fiber and shows 100°C higher decomposition temperature than p-aramid fibre. The limiting oxygen index is 68, which is the highest amongst organic super fibers. These properties are displayed in comparison with other high-performance fibers. There are two types of Zylon fibers, AS (as spun) and HM (high modulus). Zylon body armor is believed to be lighter, more comfortable and stronger than aramid body armor. However, the tensile strength of Zylon fiber might be susceptible to degradation under certain extreme temperature and humidity conditions [3].

4.3 Textiles for Ballistic Protection

Ballistic-resistant materials for military purposes presently fall into three general categories:

1. garments, such as vests
2. helmets
3. vehicle and structural reinforcement.

Ballistic-resistant vests, jackets, and similar garments are often mainly for protection against shrapnel and bomb fragments. Protection from military caliber small arms is quite challenging in most cases because of the high velocities, low aspect ratios and hard surfaces of the projectiles. Although such high-level protection is vital, it is cumbersome for long-term use in field situations [59].

The fabrics used for ballistic protection may be woven, knitted or non-woven. Each of the fabric design technique has its own merits and demerits.

**Woven textiles:** Woven textiles are most commonly used for ballistic protection. Their advantage is ease of development and suitability for the purpose. Majority of the woven fabrics for ballistic protection are woven from heavier denier yarns with minimum twist (spun twist). Fabric design is generally plain or basket.

**Nonwovens:** Nonwoven fabrics are used in ballistic protection against bullets (police vests, light weight Armour panels, etc.) as it gives a far better protection at the same weight than fabrics.

**Composites and laminates:** For non ballistic applications, High Performance Polyethylene (HPPE) fibers are mainly used to improve the impact resistance and the energy absorption of glass or carbon fiber reinforced products. In composites used for ballistic protection, such as helmets and light-weight Armour panels, only the ballistic fiber types are used [3, 51, 53, 60].

Ballistic protection textiles involve absorption of energy of the projectiles/fragments of various shapes, sizes, and impact velocities. Projectiles have huge kinetic energy and at the time of striking the target velocity of the projectile are equally important. High-performance ballistic functional clothes dissipate the energy of the projectile with the deformation of the
fabric layers under impact punching or cutting of the yarns, dissipation of impact energy from one layer to next layer [53].

The large materials’ deformation is a method of increasing energy absorbency given adequate strength. Thus, ballistic-resistant properties increase by placing high elongation fiber behind the main impact layer [60].

The energy absorption of the ballistic protective cloths depends on fabric design and design parameters, fabric density, impact conditions, projectile mass and geometry and striking. Different fabrics and different projectiles have different effects. When a projectile hits a woven fabric a shock wave or strain wave is introduced in the fabric, which spreads through its yarns. The strain wave can thus be pushed over a large number of yarns. The positive effect of this mechanism is that the energy will be absorbed over a large area [53, 61]. The bulletproof vest is a functional clothing item. The elements of energy absorption of a bulletproof vest can be summarized as;

1. Deformation of fabric
2. Generated heat energy from friction force and
3. Bullet deformation

Specialized materials must be used for bulletproof vests to improve their performance; therefore, the bulletproof vest is heavy and uncomfortable. Nonwoven textile materials can be used in ballistic protection applications because they offer the advantages of light and flexible fabrics. Lin et al, studied on improving ballistic-resistance products by using different composite nonwoven fabrics that were placed on the laminated Kevlar fabrics. It has been reported that the composite nonwoven fabric increase protection against handgun threats (the velocity being between 350 m/s and 430 m/s) compared to Spectra shield alone. The addition of the cushion layer of the composite nonwoven fabric was useful for the Kevlar laminated to dissipate the impact energy and transmit the impact stress [61].

5 CHEMICAL PROTECTION

The chemical hazard is the most complex and varied of all the hazards. It is reported [3] that more than 100,000 chemical products with very different toxicological properties are in use throughout the world. Each chemical phase is differently and so requires different strategies for protection.

There are four possible interactions between a chemical and a chemical protective textile [3]:

- Chemical degradation, which is a breakdown of the textile structure.
- Chemical penetration, which is the chemical flow through the textile structure by wicking or pressure effects in air permeable structures, or through imperfections or seams and closures in impermeable structures.
• Chemical permeation, which is the molecular flow of chemicals through the material of the structure.
• The chemical may not interact but evaporate and the vapor will either go into the atmosphere or enter the garment.

Chemical protective clothing can be designed as encapsulating or non-encapsulating based on covering of the body. Table 2 shows the different chemical protective clothing designs associated with different areas of body protection [3].

<table>
<thead>
<tr>
<th>Body area (s)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire body</td>
<td>Totally encapsulating suit</td>
</tr>
<tr>
<td>Torso, head, arms, and legs (excluding hands, feet, and face)</td>
<td>Hooded coveralls</td>
</tr>
<tr>
<td>Torso, arms and legs</td>
<td>Coveralls</td>
</tr>
<tr>
<td>Top torso and arms</td>
<td>Coat or jacket</td>
</tr>
<tr>
<td>Bottom torso and legs</td>
<td>Lab coat</td>
</tr>
<tr>
<td>Torso (front) and arms</td>
<td>Sleeved apron</td>
</tr>
<tr>
<td>Torso (front)</td>
<td>Hood with visor</td>
</tr>
<tr>
<td>Head and face</td>
<td>Hood</td>
</tr>
<tr>
<td>Head</td>
<td>Booties</td>
</tr>
<tr>
<td>Foot</td>
<td>Boot or shoe cover</td>
</tr>
</tbody>
</table>

In general, chemical protective clothing that protects against gases and vapors will also protect against liquids and particulates, and chemical protective cloths effective against liquids will also prevent penetration of particulates. However, there are exceptions. For example, some chemical protective clothing based on adsorptive materials (such as those using air-purifying respirator cartridges) may prevent penetration of gases and chemical vapors, but not when exposed to liquids if the chemical protective clothing is splashed by or immersed in liquid chemical. Other performance features may be related to the non-chemical hazards in the workplace, the durability of the chemical protective clothing in different use environments, or the impact of the chemical protective clothing [3].

Chemical protective clothing can have different service life. Service life of chemical protective clothing is based on the useful life of the chemical protective clothing item. Service life of chemical protective clothing can be divided into three groups:

• Disposable after a single use (relatively inexpensive, cannot be cleaned, reserviced, or maintained after use)
• Limited use (limited cleaning, care is possible, the product is eventually degraded by use and maintenance processes
• Reusable (can be readily cleaned and maintained)

Ordinary textile materials are not proper for developing chemical protective clothing. Two predominant examples of non-woven fabrics are flash spun polyethylene (Tyvek) and spunbond/meltbond/spunbond (SMS) polypropylene (Kleenguard). These textiles are used because of their relatively low cost and because the materials provide a structure of microfibers that filter out dry particulates and many water-based liquids [3].

Normally, chemical protective clothing materials include supporting textile fabrics to provide strength. However, there are some chemical protective clothing materials that do not include a fabric substrate. The rubber material or plastic is thick enough to provide sufficient strength for clothing use. Polyvinyl chloride and chlorinated polyethylene are the sample polymers used in these materials. They offer a barrier to liquids and can be used in the construction of chemical protective clothing against liquid and gases.

Microporous film-based materials can be used for chemical protective clothing. Microporous films have millions of microscopic pores per square inch of the film structure. In most cases, the pores are irregularly shaped and these pores are small enough to prevent the passage of most liquids. However, vapors and gases can pass through the material.

Pesticide-resistant clothing is an interesting development for chemical protective clothing (Fig. 3). Exposure of skin to pesticide is a major health hazard to farmers. Pesticides can enter the body through the skin, the eyes, the mouth, and the lungs. All pesticides are toxic, differing only in the degree of toxicity, and are potentially dangerous to people if exposure is high. Dressing appropriately and using personal protective equipment can help minimize pesticide exposure and reduce the risk of pesticide poisoning. Protective clothing including coveralls, apron, broad-rimmed waterproof hat, boots, rubber gloves, goggles or face shields, and respirators provides protection against pesticide exposures [62,63]. Cloths made of butyl rubber, neoprene, PVC, or laminated polyethylene fabrics can be appropriate for pesticide protective clothing. Table 4 shows characteristic of some commonly used pesticide protective clothing [64].
Figure 3. Illustration of protective clothing to wear while working with pesticides [64]

### Table 3. Characteristics of pesticide protective clothing [64]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempro®</td>
<td>IV</td>
<td>(none)</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>LOW</td>
</tr>
<tr>
<td>ProShield2®</td>
<td>I</td>
<td>III</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>LOW</td>
</tr>
<tr>
<td>Tyvek®</td>
<td>I</td>
<td>III</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>LOW</td>
</tr>
<tr>
<td>Tyvek® QC / sewn seams</td>
<td>I</td>
<td>II</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>LOW</td>
</tr>
<tr>
<td>Tyvek® QC / sealed seams</td>
<td>I</td>
<td>II</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>Moderate</td>
</tr>
<tr>
<td>Kleenguard® LP</td>
<td>I</td>
<td>III</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>LOW</td>
</tr>
<tr>
<td>Tychem® SL / surged seams</td>
<td>I</td>
<td>I</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>Moderate</td>
</tr>
<tr>
<td>Tychem® SL / sealed seams</td>
<td>I</td>
<td>I</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>HIGH</td>
</tr>
<tr>
<td>PVC coverall</td>
<td>I</td>
<td>I</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>HIGH</td>
</tr>
<tr>
<td>PVC suit</td>
<td>I</td>
<td>I</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

*Protection Class* is determined by the “Signal Word” on the pesticide label:

- **Class I** = Signal words “DANGER” or “DANGER/POISON” (highly toxic)
- **Class II** = Signal words “WARNING” (toxic)
- **Class III** = Signal word “CAUTION” (less toxic)
- **Class VI** = Signal word “CAUTION” (least toxic)

### 6 BIOLOGICAL PROTECTION

Textiles are known to be sensitive to microbial attack as they have a large surface area and absorb moisture and these factors promote microbial growth [65]. Most natural textile fibers such as wool, silk and cellulosic are subject to biological degradation by bacteria,
dermatophytic fungi, etc. [3]. Moreover, natural fibers allow bacterial growth and multiplication, by providing basic requirements such as nutrients (in the form of protein or cellulose), moisture, and appropriate conditions of oxygen and temperature [66]. Fortunately, various chemicals and finishing techniques are available that can protect the textile and the wearer from biological attacks. Textiles designed for biological protection have two functions: first, protecting the wearer from being attacked by bacteria, yeast, dermatophytic fungi, and other related microorganisms which cause aesthetic, hygienic, or medical problems; secondly, protecting the textile itself from biodeterioration caused by mold, mildew, and rot-producing fungi and from being digested by insects and other pests [3].

It was reported that the antimicrobial properties of silk have been used for many years in medical applications. Natural fibers contain lignin and other substances that have inherent antimicrobial properties. Generally, textiles made from natural fibers have better antimicrobial properties than man-made fibers due to the presence of substances such as lignin and pectin. Chemical finishing is most commonly used for imparting anti-microbial properties to natural and man-made textiles by applying functional finishes onto the surface of the fabric or by making fibers inherently resistant to microorganisms [3].

Many situations exist where the permeability of materials and garments to micro-organisms is important, first to wearers in health-related workplaces and, second, in a range of industrial processes (e.g., laundries, filtration plants). The subject is increasingly important as employers and manufacturers grapple with health and safety requirements for protective clothing that really provides protection, and attempts are made to manage diverse features of the environment using various forms of fabrics and garments [67].

The permeability of apparel and apparel fabrics to micro-organisms needs to be considered in relation to the flow of air and liquids (e.g., air, water, blood, serum, urine, other body fluids, varying in viscosity), dimensions of the microorganism, and where relevant, dimensions also of its carrier such as dust particles and skin debris (e.g., diameter of bacteria 300–10 000 nm, virus 30–300 nm, water 0.2 nm; weight), properties of fabrics and fabric layers, and test conditions (differences in temperature, pressure, number of layers) [68].

6.1 Antimicrobial Finishing

Apart from medical textiles, antimicrobial finishing are also of interest for clothing textiles worn close to skin, e.g. socks, stocking, soles, underwear and sport clothing in general. Antimicrobial finishing prevents pathogenic microorganisms from spreading as bacteria and fungi are deprived of their habitat. The antimicrobial finishing, moreover, prevents the development of nasty odors when sweat is degraded by bacteria [2]. Antimicrobial agents are those that kill or inhibit the growth of microorganisms. To effectively inhibit microorganism growth, the antimicrobial agent must interrupt the growth cycle.

Textiles are treated with various compounds, including organic compounds such as triclosan, quaternary ammonium compounds, polybiquanides, N-halamines, chitosan, and inorganic
materials such as silver and titanium oxide (TiO₂) for antimicrobial functionality [68-77]. Inorganic salts, organometallics, iodophors, phenols, thiophenols, heterocyclics with anionic groups, nitro compounds, urea, formaldehyde derivatives, and amines are also used as antimicrobial finishing [74].

Some researchers used natural extract for antimicrobial activity. Koh at al applied gallnut extract for cellulose and protein fibers to obtain antimicrobial protective textiles [77]. Organosilicon, as one of the most popular softeners in the textile industry, not only can impart unique softness, smoothness, elasticity and silk and cotton like hands to treated fabrics, but also confer the fabrics with a perfect drape, anti wrinkle, wettability and breathability. In recent years organosilicon antimicrobial agents were prepared though chemical grafting or physical blending of the microbicidis and organic silicon [78].

It was reported that a composition consisting of polyvinyl pyrrlidone, silver ion solution and benzoic acid for the antimicrobial finishing of cotton fabrics can be developed. This composition has an ability to prevent fouling with mould fungi and is not deteriorated by microorganism under operation conditions [79].

7 CONCLUSION

For thousands of years all clothing is protective to weather conditions or routine work conditions but with the developing technology, globalization, changes in climates in 21st century the main object of the protective textiles is to improve people safety especially in their workplaces and they are designed to have further value in protection to some risks or hazards. Protective textiles can be against to heat and flame, weather conditions (cold, moisture, wind etc.), chemical materials, radioactivity, UV radiation and so on, and protective functional clothing is one of the more interesting segments of the technical textile market [1-79].

8 REFERENCING


