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The Ultraviolet Protection and Transmission: Textile Materials

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Transmission,
Textile materials,
Fuzzy logic.

Abstract: From the sun; ultraviolet radiation, which is invisible, insensible and the most dangerous. When light touches a textile surface, some of the light is absorbed by the surface, some of it passes through the surface, and some of it is reflected. Radiation protection may vary in the degree of protection depending on the structural parameters of the materials. There are many parameters that affect the behavior of fabrics against light, such as fiber structure (cotton / polyester), thread structure (count), and fabric geometry (tightness). The study aims to present a relationship between the UV permeability properties of cotton and polyester materials. In the study, the UV transmittance of polyester/cotton fabric was estimated by the fuzzy logic method. The analysis shows the results obtained in comparison with the UV transmittance of polyester/cotton fabrics. The aim of this study is to model the UV transmittance of woven fabrics made of polyester and cotton fibers. 5 different fabric structures with varying structure parameters were tested, the data obtained were used to develop the Fuzzy Logic prediction model of the selected variables for the development of the prediction model. The model showed satisfactory predictability when applied to unseen data. The developed model can be effectively used for the prediction of UV transmittance of woven fabrics.

Ultraviyole Koruma ve Geçirgenlik: Tekstil Malzemeleri

Anahtar Kelimeler
Ultraviyole koruma,
Geçirgenlik,
Tekstil malzemeleri,
Bulanık mantık.

Öz: Güneş ışığının en tehlikeli bileşeni olan ultraviyole radyasyon, görünmez ve hissedilmez. Tekstil materyalleri, güneş ışığının etkilerinden korunmak için önemli bir rol oynar. Işık, bir tekstil yüzeyine temas ettiğinde, bir kısmı yüzey tarafından emilir, bir kısmı geçer ve bir kısmı da yansır. Bu koruyucu özellikler, kumaşların yapısal özelliklerine bağlıdır. Bu çalışma, pamuk ve polyester materyallerinin UV ışınlarını geçirme özellikleri arasındaki ilişkiyi incelemeyi amaçlar. Kumaşların UV geçirgenliğini etkileyen faktörler arasında lif yapısı (pamuk/polyester), iplik yapısı (numara) ve kumaş geometrisi (sıklık) gibi birçok parametre bulunmaktadır. Bu çalışmada, bulanık mantık yöntemi kullanılarak polyester/pamuk karışımlı kumaşlardaki UV geçirgenliği tahmin edilmiştir. Analiz sonuçları, polyester/pamuk kumaşların UV geçirgenliği açısından karşılaştırmalı bir değerlendirme sunmaktadır. Bu çalışmanın amacı polyester ve pamuk elyaflarından dokuma kumaşların UV geçirgenliğini modellemektir. Değişen yapı parametrelerine sahip 5 farklı kumaş yapısı test edildi, tahmin modelinin geliştirilmesi için seçilen değişkenlerin Fuzzy Logic tahmin modeli için elde edilen veriler kullanıldı. Model, görülmeyen verilere uygulandığında tatmin edici bir tahmin edilebilirlik gösterdi. Geliştirilen model, dokuma kumaşların UV geçirgenliğinin tahmini için etkili bir şekilde kullanılabilir.

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1. Introduction

The atoms or molecules of the textile material are interacted with by the ray reaching it. As a consequence of this interaction, the material either allows the beam to pass through or undergoes absorption, reflection, or scattering by it. Ultraviolet (UV) waves possess wavelengths shorter than those of visible light, rendering them invisible to the human eye. While there exist numerous artificial sources emitting ultraviolet radiation (UVR), the principal source remains the sun. Among the structural parameters characterizing woven fabric used in clothing are tear strength, thermal conductivity, and air permeability. Yet, studies on UV transmittance, a potentially crucial property of woven fabrics, remain relatively scarce.

Within the literature, extensive studies delve into examining the light transmittance of fabrics. Haleem et al. demonstrated the dependency of light transmittance in cotton/polyester blend fabrics on the pores between threads[1]. Stankovic et al. illustrated how the UV protection properties of knitted fabrics are influenced by yarn twist and surface properties[2]. Alvarez et al. explored whether fiber types could serve to determine UV transmittance and noted an association between light passing through the woven fabric structure[3]. Gambichler et al. suggested that the level of light transmittance might stem from the geometric properties of textiles and radiation passing through inter-thread gaps[4]. Wilson et al. determined the impact of fabric type and color on UV transmission through fabrics using a spectrophotometer[5]. Khazova et al. presented the effects of fabric stretch on the Ultraviolet Protection Factor (UPF) rating of children's clothing[6]. Gabrijelčič et al. employed digital image analysis techniques to analyze the UV protection level of fabric structural parameters[6]. Investigating the application of UV absorbers for sun protective fabrics, Oda, H., explored their potential benefits[8]. Hoque et al. discovered lower UV transmittance in polyester fabrics[9]. Abidi et al. determined fabric UV transmittance based on experimental and theoretical analyses[10]. Rashid et al. scrutinized fabric properties using light-reflected image analysis[11]. Riva et al. highlighted that the determination of UV transmittance is influenced by the fiber type of the fabric and its structural properties, among other fabric parameters[12].

Fabric permeability, while not a feature dictating fabric aesthetics or quality, correlates strongly with the UPF (ultraviolet protection factor) of clothing and garments, relevant to specific health concerns. Prolonged exposure to UV light can result in severe health issues. Gradual degradation of skin structure due to long-term or repeated UV exposure leads to photoaging, skin thickening, and various age-related disorders in sun-exposed areas. Skin deformations, dehydration, sagging, coarsening, capillary collection, premature pigmentation, yellowish skin tone, and tumors are observed consequences of photoaging. Skin cancer is a chronic effect of UV, with excessive sunlight exposure increasing cancer risk significantly, especially if experienced before the age of 18. Sunburn, while not indicative of health, significantly elevates the likelihood of developing skin cancer later in life[13-15].

Regarding solar permeability in textile materials, when ultraviolet radiation encounters textile material, UV light distribution manifests as reflection, absorption, or transmission. Fibers absorb a portion of incoming radiation, converting it into another form of energy. Another portion passes directly into the fabric through fiber and thread gaps, termed 'transfer'. Some radiation is reflected or scattered by fibers, potentially contributing to transmitted radiation if not absorbed. The quantity of radiation traversing the fabric is termed spectral transmittance ($T\lambda$). While a small portion of the incident beam passes through the fabric without dispersion, a larger portion disperses within the material, emerging in a different direction from the incident beam[16-18]. In this study, a fuzzy logic method was developed to estimate UV transmittance, there is no study in the literature about this method.

2. Material and Methods

Fabric samples were woven from Polyester and cotton yarns on the weaving machine. The fabrics were developed by controlled changes in yarn linear densities and fabric yarn densities. The weaving pattern of the fabrics is 3/1 S Twill weave. The structural parameters and some physical properties of the samples used in the research are given in Table 1.

Tablo 1. Constructional and physical parameters of the fabrics investigated

No.	Weave	warp thr./cm	**weft** thr./cm	g/m2	CV %
1	3/1 S Twill	40	46	148	0.8
2		38	42	136	1.1
3		36	40	132	0.9
4		32	28	128	1
5		30	22	86	2

Woven fabrics light transmittance captures backlit digital images of woven fabrics through a digital camera and processes them to detect areas and calculate the light transmittance through them. Figure 1 shows the image of the cotton fabric measured with a digital camera.

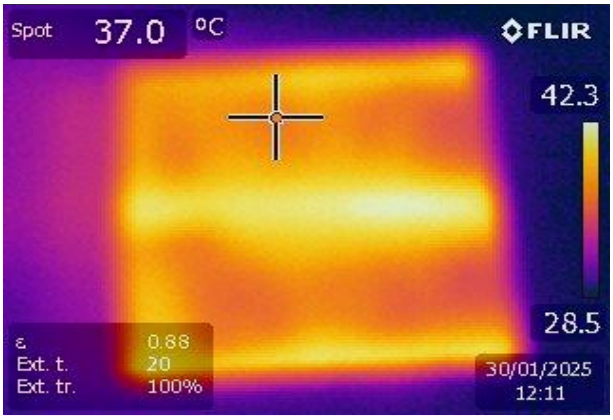

Figure 1. Image of cotton fabric measured by digital camera.

Figure 2 shows the image of the polyester fabric measured with a digital camera.

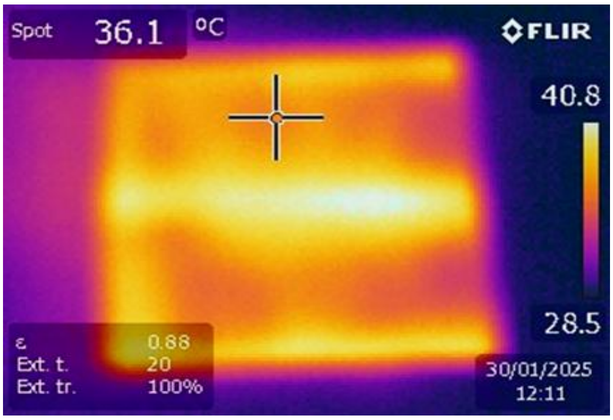

Figure 2. Image of polyester fabric measured by digital camera.

It can be concluded that light transmittance is an important fabric property that can provide information about certain structural aspects of the fabric. For this purpose, Light transmittance can be successfully correlated with the light transmittance of woven fabrics parameters and can also be used for accurate estimation. It can be useful for measuring the transmittance of fabrics by weavers who can provide a good estimate of the light transmittance of cotton and polyester fabrics by transmitting light through woven fabrics.

All garments inherently offer some level of UV protection. The efficacy of clothing in minimizing UVR exposure is influenced by various factors. Apart from garment design, fabric characteristics play a crucial role in determining UV transmission through clothing[19-21]. These properties encompass composition (such as fiber type), structure (including weave density), weight, and thickness. Additionally, factors like color and processing techniques (e.g., bleaching, utilization of UV absorbers) can impact a garment's ability to block UVR. Other considerations include parameters related to usage and wear, like moisture, stretch, heat, or chemical treatments. Understanding clothing behavior under UVR is further complicated by the interplay of multiple factors, including fiber, yarn, fabric, processing methods, and finishing techniques[22-23]. However, fabric open porosity and the physicochemical nature of fibers, often described by terms like cover factor, fabric tightness, or fabric openness, emerge as pivotal factors influencing UV protection capacity. To facilitate analysis, estimation guidelines have been formulated for all fabric structures within the yarn count range of 10-60 tex.

Figure 3. Fabrics made of cotton and polyester[15]

The ability of a particular material to protect from radiation is primarily related to its absorption capacity. This absorption is provided by the material molecular structure.

UV transmittance analysis developed based on fuzzy logic estimation techniques in MATLAB was carried out. In the process of processing the data through the fuzzy system, the fuzzy system starts to work by first including the input data of Yarn number (TEX), Time (minutes), fabric tightness. The rule base is defined as 450 that the fuzzy system will use to make inferences. Thus, the membership degree of each input value to the fuzzy set is calculated. The inference system works in collaboration with the knowledge base and tries to create the transmission (%Tλ) value with the results it draws from the fuzzy values. Finally, the fuzzy values produced by the fuzzy reasoning mechanism are subjected to the defuzzification process to transform them into real values, and the resulting fuzzy values are converted into real values. It shows that realistic data can be obtained when the selected variables are applied to data that cannot be determined by experiment with the prediction model. The developed model can be effectively used to predict UV transmittance.

3. Results and Discussion

The UV transmittance results for both types of textile materials are presented separately in Figures 3 through 6. These graphical representations depict the direct relationship between yarn count, fabric density, time, and transmission (%), showcasing realistic estimated outcomes. The observed trends indicate that variations in yarn count and fabric density significantly influence the transmission (%) variable, leading to notable increases or decreases in UV transmittance.

3.1. Transmission of textile fabrics made from cotton fibers

Due to the absence of double bonds in its fiber's chemical structure, cotton exhibits a limited intrinsic capacity for UV absorption. Consequently, textile fabrics crafted from cotton typically offer relatively modest UV protection properties.

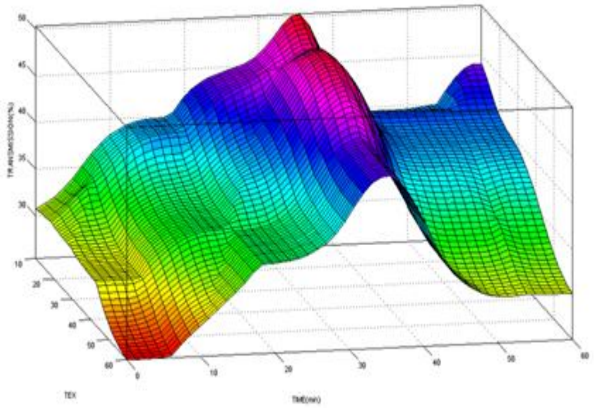

Figure 4. Relationship between yarn count and permeability in cotton fabric

As the yarn count increases (TEX), the fabric thickens, the pores close and prevent the passage of UV light. This means that the amount of light passing through the fabric decreases. It causes a decrease in UV transmittance as the yarn count values increase, the average UV transmittance was found to be between 29.62 %.

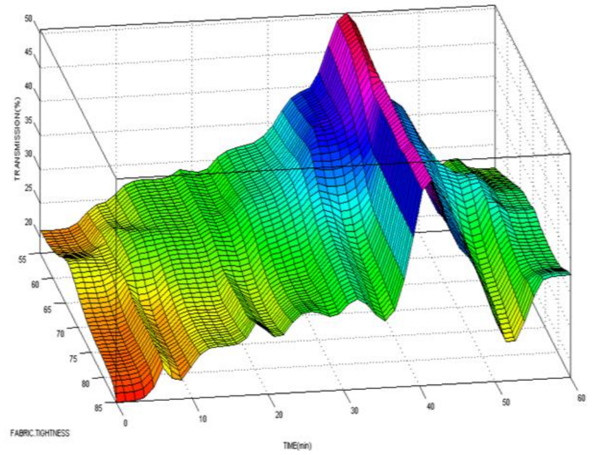

Figure 5. Relationship between fabric tightness and permeability in cotton fabric

It was found that the average permeability was between 28.74 % as the fabric tightness increased. Ultraviolet radiation is insufficient to provide protection due to the molecular properties of the cotton fabrics used in this study to prevent permeability. Therefore, since all cotton fabrics block some of the ultraviolet radiation, a high amount of radiation passes through the textile surface. Since fabrics produced with fine threads have lower covering capacity, they contain more pores than thick threads of the same fabric structure. In other words, as the fabric thickness decreases, the fabric solar transmittance increases. Thin fabrics with a loose structure provide less protection than fabrics with a tighter texture.

3.2. Transmission of textile fabrics made from polyester fibers

Artificial fibers containing polyester fiber conjugated aromatic polymer chain system are more effective in UV absorption. Textile fabrics made from polyester provide higher UV protection properties.

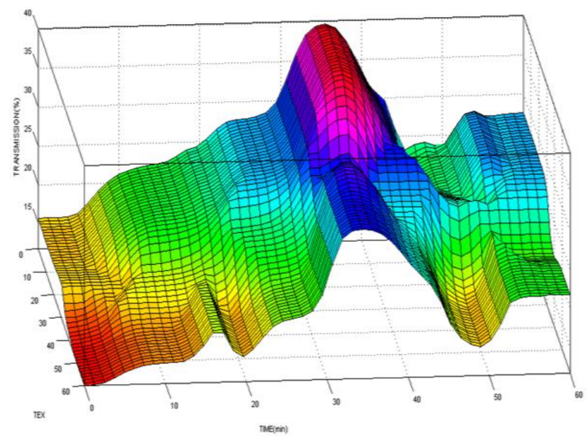

Figure 6. Relationship between yarn count and permeability in polyester fabric

Surface graphs were made between yarn count, time and fabric density. These variables are basically three: surface graphics, dimensional graphics of the effect of the input, transmission (%) value, which is the output variable, interactions based on the developed model are shown in Figure 5. Polyester fabrics have lower ultraviolet transmission, the average transmittance was found to be 26.84 %.

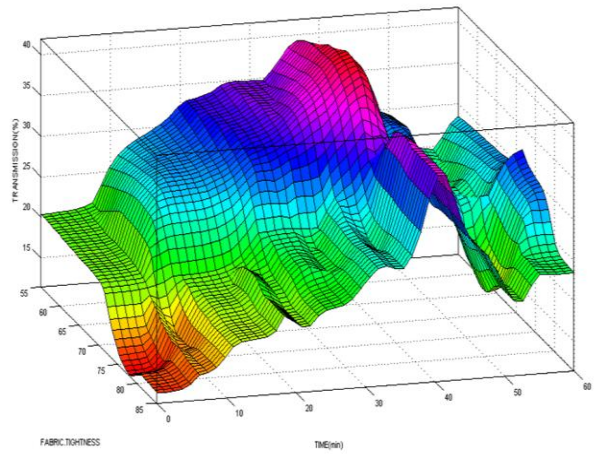

Figure 7. Relationship between fabric tightness and permeability in polyester fabric

With increasing fabric density, UV transmittance values fluctuate between 20.63 % and 38.28 %. Notably, polyester fabrics exhibit superior UV blocking compared to cotton counterparts, owing to their inherent properties. Fabrics woven with finer threads tend to possess higher porosity due to their reduced covering capacity relative to thicker threads of the same structure. Consequently, as fabric thickness decreases, solar transmittance increases. The porous nature of fabrics depends on factors such as density, yarn twist, yarn hairiness, and thickness. Enhanced fabric density and thickness contribute to reduced fabric porosity, subsequently lowering UV transmittance.

Surface plots of various parameters reveal logical correlations between UV transmittance and inputs, aiding in determining fabric parameters with UV transmittance characteristics. An increase in yarn diameter leads to decreased pore size within the fabric, while higher thread counts result in closer thread spacing and reduced porosity. These alterations hinder light flow, resulting in decreased UV transmittance.

The curvature observed in the graphs stems from the utilization of non-linear input values during fuzzy model development. Incorporating non-linear data is essential for realistic model application, minimizing prediction errors. By correlating relative contribution percentages of input parameters, the fuzzy model suggests UV transmittance percentages corresponding to fabric behavior across its range. This methodology offers a more accurate prediction of fabric UV transmittance behavior, enhancing our understanding of fabric properties.

4. Discussion and Conclusion

In this study, we assessed the UV transmittance of woven fabrics using the fuzzy logic method. Our results underscore the superiority of this estimation technique, revealing a strong correlation with experimentally measured UV transmittance values and enabling the derivation of previously unattainable data. Notably, this method stands out for its simplicity, eschewing complex algorithms while ensuring robust and reproducible outcomes.

Our findings affirm the significance of UV transmittance as a critical fabric property, offering insights into structural aspects and correlating well with air permeability. Engineers can leverage this correlation for accurate predictions, potentially facilitating non-destructive assessments of fabric porosity and air permeability.

Considering the escalating exposure to UV radiation in modern conditions, consumer interest in UV-protective clothing is anticipated to surge. Our evaluations demonstrate that fabric weight and thickness increase with density, inversely affecting light transmittance.

Utilizing the fuzzy logic method, we achieved a permeability value of 50.6 % in 35 minutes due to cotton yarn count and 40 minutes for fabric density. Similarly, polyester thread count yielded a permeability value of 38.28 % in 35 minutes, extending to 40 minutes when considering fabric density. Our developed model exhibits excellent predictability with a minimal error rate of approximately 3.1 %.

Surface analysis reveals the pivotal role of fabric density in UV transmittance, while fiber type significantly influences UV protection. Fabrics composed of polyester fibers outperform cotton counterparts in UV transmittance, albeit both necessitate UV absorbers for heightened protection levels.

In conclusion, our study highlights the potential for refining UV transmittance predictions and developing tailored materials using alternative modeling techniques. While our estimation model utilized raw fabrics, future iterations could encompass dyed, printed, and finished fabrics for real-world applicability and broader generalizability.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

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