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Structural parameters effect on UVR transmission of weft knitted fabrics

Fatemeh Taghipoor[a], Hossein Hasani & Haleh Khalili
Department of Textile Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran

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Effects of knit structure, knit density, material type and presence of elastic yarn in weft knitted cotton/ polyester and polyester fabrics on UVR transmission have been investigated. According to the Taguchi method used for determining the combination of selected variables and their levels, 16 knitted samples have been produced on a single jersey circular knitting machine. After relaxation, samples have been kept in sunlight simulator and exposed to sun radiation. Finally, the amount of UV transmitted by every sample is measured by spectrophotometer. The results analyzed using Minitab software show that all the controllable variables have a significant effect on UV transmission. Also, according to the signal to noise analysis, the factor 'presence of elastic yarn' shows the strongest effect on UVR transmission. The second effective factor is found 'fabric structure' which is followed by the other two factors, viz. 'material type' and 'knit density' respectively.

Keywords: Cotton/ polyester yarn, Elastic yarn, Polyester yarn, Taguchi method, UVR transmission, Weft knitted fabrics

1 Introduction

Among many types of radiation emitted by the sun, ultraviolet (UV) radiation is more concerned due to its negative effects on human health. UV radiation is an electromagnetic radiation of a wavelength shorter than that of the visible region, but longer than that of X-rays[1]. The effect of UV radiation on human health depends on the emitted wavelength range. Generally, the UV radiation is divided into three categories, namely ultraviolet type-A (380-315 nm), ultraviolet type-B (315-280 nm) and ultraviolet type-C (under 280 nm)[1,2]. The UVA radiation (ultraviolet type-A) is the most commonly encountered type of UV light. Over exposure to UVA has been associated with toughening of the skin, suppression of the immune system, and cataract formation. UVB (ultraviolet type-B) is typically the most destructive form of UV radiation because it has enough energy to cause photochemical damage to cellular DNA. Among the variety of harmful effects associated with this type of UV radiation, erythema (sunburn), cataracts, and development of skin cancer are the more concerned diseases. Although the UVC (ultraviolet type-C) radiation is almost dangerous but is absorbed completely in the atmosphere and doesn't reach the earth[1,3].

Although the mentioned problems caused by the UV-radiation are serious, almost all of them can be preventable by covering the body with sun-protective clothing[4,5] by reducing sun exposure. As stated in literatures[6,8], clothing has been recognized as an effective means of photo-protection. Consequently, in past many studies have been focused to examine the effects of fabric characteristics[4,6,9] (fabric structure, thickness, weight, fibre type, fabric extensibility, and wetness), as well as finishing treatments[4,10] (UV absorbers and colorants) on fabrics UV transmission behavior. For investigating the degree of UV protection of clothing, the ultraviolet protection factor (UPF) is commonly used[1]. In some other studies, the information about fabrics with good UV protection is available[11,12].

Fabrics UV protection is found to be affected by numerous factors including fibre type, fabric construction (woven or knitted), colorant (dye), mass per area, thickness and yarn fineness. There are a lot of researches on how the fibre content influences clothing protectiveness against UVR[4,13,15]. It is difficult to conclude about the effect of fibre type on UVR individually. This is because the UVR values are also affected by some other construction factors, such as weave or knit, thread count and fabric mass which cannot be controlled effectively. Davis *et al.*[13] found that polyester fibres provide a high level of UV protection properly while the cotton fibres present UPF values 3-4 times lower

[a] Corresponding author.
E-mail: f.taghipoor@tx.iut.ac.ir

than polyester. The results also indicated that the blends of cotton/polyester provide significantly better protection than cotton fibres alone. Many researchers[4,14,16,17] believed that the fabric construction, especially the tightness or looseness of woven/knitted fabric, is the primary factor affecting the UVR. Fabrics with a tight weave/knit usually have a high level of UVR protection. The high protection ability of tighter structures is due to the fact that UV radiation is mainly transmitted through the hole between yarns rather than by penetration through the yarns. Generally, the spaces between yarns are larger in a knitted fabric than in a woven fabric. Also, a plain weave has a lower porosity than other weaves[18]. Welsh and Diffey[17] studied the effect of thickness measurement on UVR. They concluded that thickness is a poor determination factor for sun protection. Sliney *et al.*[15] stated that the thicker fabrics with denser structure are superior to thinner and looser fabrics in blocking UVR. The mass of fabrics was not found to be very effective against UVR. Gies *et al.*[19] reported that a lightweight fabric with denser structure could provide more protection against UV radiation than a heavy fabric with loose weave although they have the same mass. Cover, is a factor used to describe the porosity of fabrics which depends not only on yarns density in fabric structure but also on their regularity, hairiness, fibre composition, twist, and the finish treatment applied to the fabric[20].

It is also believed that dark colors generally provide greater UV protection than light colors[4,19,21]. This may be as a result of dyes absorbing radiation and modifying transmission differently. Dry finishes that make yarns to become shorter or coarser or even cause fabric shrinkage will increase the cover factor of the fabric[4]. Pailthorpe[21] have reported several dry finishes that affect the fabrics UV protection ability.

Although the studies relating to effect of structural parameters of woven fabrics on the protection against UV transmission are available, there are limited studies about the effect of knitted fabrics characteristics on UV transmission. Wong *et al.*[22] studied the influence of different knit structures upon the UPF with the three main knit stitches incorporated in the knitted fabric constructions, namely the knit, tuck and miss stitches. They concluded that fabrics with miss stitches possess a higher UPF than fabrics with tuck stitches. The double-knitted fabrics have better UV protection than the single-knitted fabrics overall, but bleaching has different impacts on the UPF of single- and double-knitted fabrics. Akaydin[23] investigated the effect of three knitted fabric structure, namely RL-jersey, RR-ribbed and RR-interlock knit constructions, (knitted with 100% cotton yarn) on the UV transmission. He reported that interlock knitted fabric has the best UV protection, and UPF values increase with the increase in fabric grams.

In this investigation, the effects of knit structure, knit density, blend ratio and the presence of an elastic yarn in the fabric structure on UPF of single jersey weft knitted fabrics have been studied.

2 Materials and Methods

In this study, two different yarns, namely 20 tex cotton/polyester (30/70) spun yarns and 100 den polyester filament yarn were used. Polyester fibre (1.5 den and 38 mm mean length) and cotton fibre (3.5 µg/inch and 28 mm mean length) were used in blended spun yarns structure. The spun yarns produced on ring frame machine possess twist coefficient α_e = 3.8. Specified spun yarns are used as ground yarn and plating yarn was a 40 den Lycra ® monofilament plated at every feeder by using an elastane feeder and a plating roll fixed on the ground yarn guide.

Four different structures of single jersey knitted fabrics were knitted using these yarns on a single jersey circular knitting machine (Falmac, 18 inch, E22, 48 feeders). The fabric structures are shown in Fig. 1. These structures can be used as summer suits and can protect the human body against the UV. Tension of elastane yarn was kept constant at 9 cN. For this reason, the 40 den Lycra yarn was fed to the single jersey circular knitting machine equipped with electronic positive feeding system.

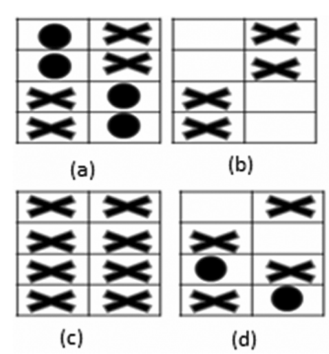

Fig. 1—Structures of knitted fabrics (a) double cross tuck, b) double cross miss, (c) plain single jersey fabric, and (d) compound design

To prepare the wash-and-dry relaxation samples, the fabrics were washed in a domestic washer at 40°C for 30 min with commercial detergent and tumble dried at 70°C for 15 min in an electrically heated dryer after getting dry relaxed. This procedure was repeated three times. Before the measurements were taken, the samples were conditioned for 24 h in a standard atmosphere. Wale and course counts per 100 cm of fabric were measured and then converted to wale and course counts per centimeter.

The effect of many different factors on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. The controllable factors considered in this research project are material type, fabric structure, knit density and the elastane presence. An orthogonal array L_{16} (Table 1) was chosen because it requires only 16 runs for combinations of four controllable factors (Table 2). Three factors varied at two levels, while one varied at one level. Table 3 shows the specifications of the knitted fabrics.

In order to investigate the effect of knit density on UV transmission, two different levels named as high and low densities were used for each fabric structure. The Taguchi method provides 16 design points that are given in Table 1. Details about the variation levels for each factor are also listed in Table 2.

Samples were kept under standard conditions according to ASTM standard practice for conditioning textiles (ASTM D 1776) for not less than 24 h prior to testing. Porosity values were calculated using the equation given below:

Table 1—Taguchi arrays

Sample	Fabric structure	Lycra yarn	Material type	Knit density
1	1	1	1	1
2	1	2	1	1
3	1	2	2	2
4	1	1	2	2
5	2	1	1	2
6	2	2	1	2
7	2	1	2	2
8	2	2	2	2
9	3	1	1	1
10	3	2	2	1
11	3	2	1	2
12	3	1	1	2
13	4	1	2	1
14	4	2	2	1
15	4	1	1	2
16	4	2	1	2

$$P = \left(1 - \frac{m}{\rho} \cdot h\right) \times 100 \qquad ...(1)$$

where P is the porosity; m, the fabric weight (g/ cm^2); ρ, the fibre density (g /cm^3); and h, the fabric thickness (cm). Table 3 shows the specifications of the knitted fabric samples. Three readings (corresponding to the three replications) are recorded for each experimental condition in Taguchi technique, the variation in response is also examined using an appropriately chosen S/N ratio. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). In Taguchi method, three standard S/N equations are used to specify the objective function as 'larger the better', 'smaller the better', or 'nominal the best'. However, irrespective of the type of performance characteristics, a larger S/N ratio is always desirable. UV transmission factor belongs to the smaller-the-better quality characteristics. For the case of minimizing the performance characteristic, the following definition of the loss function should be calculated[19]:

$$L_j = \left(\frac{1}{n}\sum_{k=1}^{n} y_i^2\right) \qquad \ldots (2)$$

$$\eta_j = -\ 10\log L_j \qquad \ldots (3)$$

where n is the number of tests; and y_i the experimental value of the i_{th} quality characteristic; L_j, the overall loss function; and η_j, the S/N ratio. By applying Eqs (2) and (3), the η corresponding to the overall loss function for each experiment of $L16$ was calculated.

For measuring the UV transmission of knitted fabric samples, the light sensitive woolen samples dyed by Methylene Blue (cationic dye with poor light fastness) was used. These samples were placed under the knitted fabric samples and then exposured to simulated sunlight radiation in Xenotest device for 24 h. So, any color changes of blue background can be measured by spectrophotometer. In addition, two (calibrated samples) testifier light sensitive

Table 2 — Controllable factors

Parameter	Level 1	Level 2	Level 3	Level 4
Fabric structure	Double cross tuck	Double cross miss	Plain	Compound
Material type	Polyester filament	Cotton/Polyester (30/70)	-	-
Knit density	High	Low	-	-
Lycra yarn	Present	Absent	-	-

Table 3—Physical properties and UV transmissions of sample

Samples	CPI	WPI	Porosity coefficient %	Thickness mm	Weight g/m²	%UV transmission= R
Sample 1	41	33	74.96	0.71	245.33	1.583
Sample 2	37	26	80.50	0.54	145.33	2.299
Sample 3	28	23	83.81	0.57	132	2.288
Sample 4	25	33	79.33	1.15	328	1.334
Sample 5	30	49	72.48	0.79	300	1.406
Sample 6	40	35	74.56	0.45	158	2.141
Sample 7	47	40	77.78	0.73	232	1.377
Sample 8	39	40	77.92	0.53	167.33	1.783
Sample 9	50	42	72.46	0.6	228	1.805
Sample10	37	35	80.46	0.42	117.33	2.070
Sample11	34	32	77.66	0.32	98.67	2.727
Sample12	41	39	80.94	0.36	94.67	2.348
Sample13	39	34	74.23	1.24	307.67	1.810
Sample14	26	26	85.86	0.62	125.33	2.219
Sample15	44	36	77.55	1.05	325.33	1.481
Sample16	30	24	81.04	0.53	138.67	3.225

samples were produced, one was uncovered (100% exposed to light) and the other one was covered by black cardboard (0% exposed to light). Using the spectrophotometer device, many characteristics such as amount of UV transmission were measured. The UV transmission (R) of every fabric sample was calculated using following equation:

$$R = \sum_{k=0}^{n} (D_r - D_k) \quad \ldots (4)$$

where D_r is the light reflection from the blue fabric covered by blackbody; and D_i, the light reflection from the blue fabric placed under the specified sample. In Eq. (4), n is the 16 different wave lengths in which the measurements were carried out. Higher level change in blue fabric indicates the higher transmission of light and UV rays.

3 Results and Discussion

A level S/N ratio analysis (Table 4) has been used to identify the strongest effects and to determine the best factor levels for UV transmission of the weft knitted fabrics. The empirical relationships between UV transmission and controllable factors are analyzed using Minitab-14 software [20]. Moreover, the optimum conditions are assigned to each controllable factor.

Table 4—Signal to noise of variables

Level	Fabric structure	Density knit	Material type	Lycra
1	34.77	34.72	33.82	36.09
2	35.66	34.10	35.17	32.73
3	33.11	-	-	-
4	34.11	-	-	-
Delta	2.55	0.62	1.35	3.37
Rank	2	4	3	1

This analysis is based on combining the data associated with each level for each factor. The difference between the highest and the lowest S/N ratio (delta) determines the impact of that factor on UV transmission. The greatest value of this difference is related to the strongest effect of that particular factor.

According to the S/N ratio analysis, the factor related to Lycra shows the strongest effect on UV transmission with a delta of 3.37. Fabric structure is the second factor with a delta of 2.55

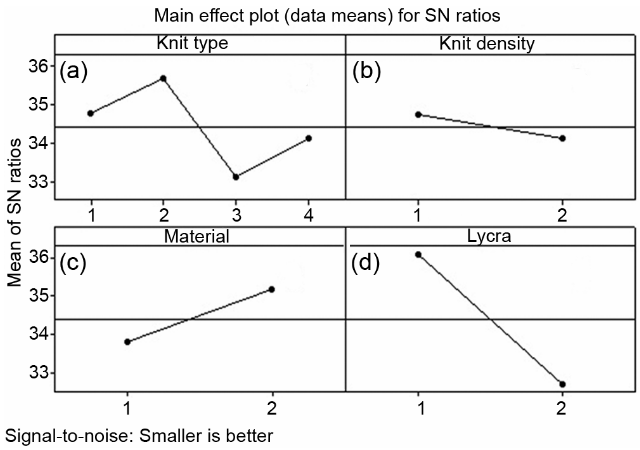

Fig. 2—Signal to noise diagrams of controllable factors (a) knit type, (b) knit density, (c) material type, and (d) Lycra presence

and is followed by other factors material type a nd knit density with delta of 1.35 and 0.62 respectively.

Figure 2(a) shows that the second level of fabric structure (double cross miss) has the maximum SN value, and hence the minimum UV transmission. Due to the maximum shrinkage in this structure during relaxation, the stitch density of fabric and cover factor increase. In accordance to mentioned relations it causes the increase of fabric UPF. Figure 2(b) expresses that high weft density decreases the UV transmission. The low slope of diagram shows the low effectiveness of density variable on fabric UV transmission. Figure 2(c) shows the maximum SN ratio for the second level of material variable (35/65 cotton/polyester yarn), so it has a positive effect on samples UPF. But in different studies, it is found that 100% polyester yarn creates a larger UPF than blended cotton/polyester yarn. The reason for this inconsistency can be found in yarn's count. In this work, the blended yarn count is 20 tex, while the used polyester filament yarn is 100 denier. It means that, not only the coarser count of blended yarn negates the effect of fibre content, but also it has more effect on UV transmission. So using coarser cotton/polyester yarns we can create a much more UPF and better wearing comfort properties. Figure 2(d) shows that the presence of Lycra yarns due to decrease of fabric width during relaxation causes the increase in weft density and thickness. So, it increases the cover factor and S/N value. In other word, the presence of Lycra yarn increases the UPF value. The high slope of diagram represents that 4th variable has a maximum effect on UV transmission. As it has been mentioned before, not only the fabric construction, but also some other parameters including fabric weights, porosity and thickness have their individual effects on UV-transmission. The results are depicted in Fig. 3.

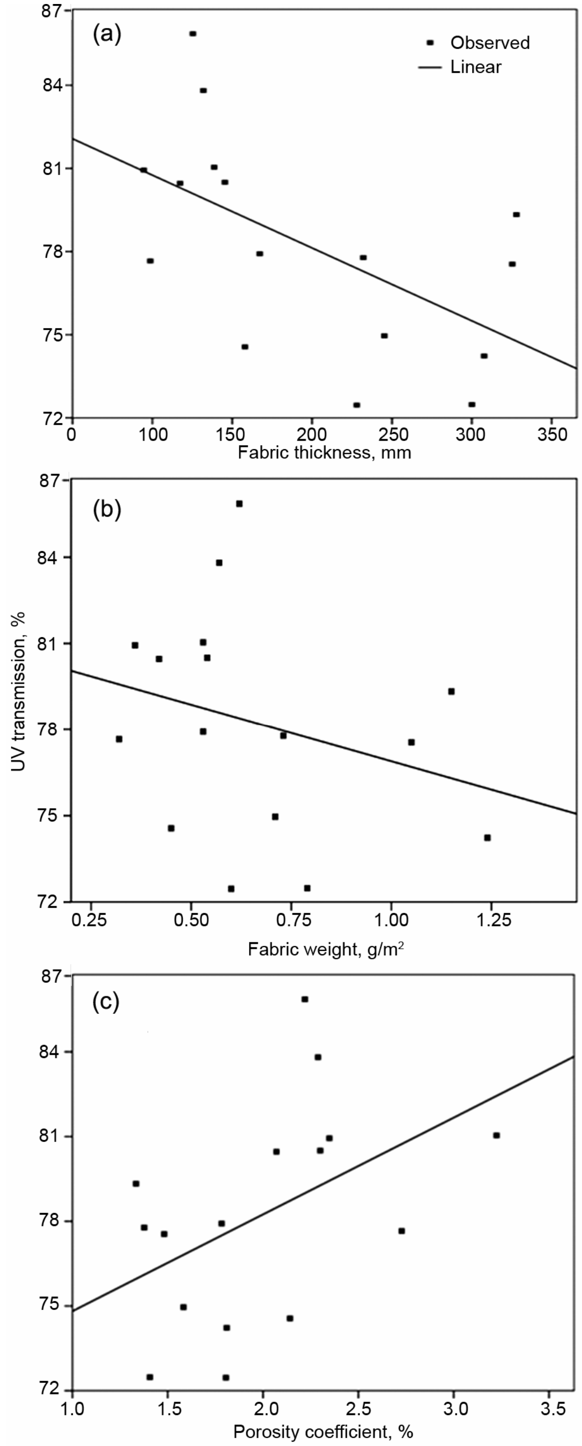

Fig. 3–Relations between UV transmission and (a) fabric thickness (R^2=0.325), (b) fabric weight (R^2=0.078), and (c) porosity (R^2=0.218)

4 Conclusion

The findings show that all the used variables in knitting the fabrics have a significant effect on UV transmission. The presence of Lycra yarn has a larger effect, showing the significant decrease in UV transmission. Among the defined fabric structures, the double cross miss structure, due to decrease in width during relaxation, creates a high covering, thereby showing the significant reduction in UV transmission. The uses of miss stitch due to fabric width reduction, and tuck stitch due to increase of fabric thickness cause decrease in fabric UV transmission. The high density of fabric because of increasing the cover factor, reduces the UV transmission. In order to increase the UPF, blended cotton/polyester yarns with coarser count can be used instead of 100% polyester yarns. In this way, the fabrics UPF improves along with the wearing comfort properties of fabric. Use of double cross tuck structure reduces the fabric UV transmission by increasing the fabric thickness. Also, in double cross tuck structure with elastane yarn, the decrease in width due to Lycra yarn is more than the increase in width due to tuck stitch. Finally, it causes the width reduction and results in the decrease in UV transmission.

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