Indian Journal of Fibre & Textile Research
Vol. 43, June 2018, pp. 153-157

Effect of yarn fineness and various knitting parameters on ultraviolet resistance of knitted fabrics

Debamalya Banerjee[1], Prithwiraj Mal[2], Anindya Ghosh[3,a] & Abhijit Majumdar[4]
[1]Department of Production Engineering, Jadavpur University, Kolkata 700 032, India
[2]National Institute of Fashion Technology, Hyderabad 500 081, India
[3]Government College of Engineering and Textile Technology, Berhampore 742 101, India
[4]Department of Textile Technology, Indian Institute of Technology, New Delhi 110 016, India

Received 20 November 2015; revised received and accepted 10 August 2016

The ultraviolet protection factor (UPF) for single jersey and 1×1 rib knitted fabrics has been investigated. The influence of yarn fineness, loop length, carriage speed and yarn input tension as well as their interactions are studied. The effect of unavoidable and uncontrolled random variables on UPF has also been investigated for both types of knitted fabrics. Orthogonal block Box and Behnken design of experiment is used to study the effect of uncontrolled random variables as well as controlled variables like yarn fineness, carriage speed, yarn input tension, loop length and their interactions. The results show that the uncontrolled random variables, during preparation of the samples, do not have any significant impact on resultant UPF for both single jersey and 1×1 rib knitted fabrics. The yarn fineness and the loop length have significant influence on UPF for both types of knitted fabrics. This study will be beneficial in engineering/designing fabrics and clothing of desired comfort with minimum damage to human body due to ultra-violet rays.

Keywords: 1×1 rib knit, Knitted fabrics, Orthogonal block Box, Single jersey, Ultraviolet protection factor, Yarn fineness

1 Introduction

An increase in trend of skin cancer due to prolong exposure of ultraviolet radiation from sunlight is a serious problem that leads the scientists to think to protect skin from over exposure. Though UV rays are necessary for Vitamin D synthesis in human body, their overexposure results in erythema, suntanning, photocarcinogenesis, etc[1-3]. Hence, it has become necessity to protect human skin from over exposure to UV rays. Textile clothing is capable to shield the human body against the UV rays. However, over shielding through textiles may also reduce the comfort level of the fabric. Hence, a fabric is desired, that can protect human with minimum resisting of physical activity and comfort. Knitted fabric which has a typical porous structure is preferable for active wear, casual wear and summer wear due to its high comfort characteristics. The porous structure assists the air to transmit through it as well as the air pockets provide warmth to the body. Transmission of air through the fabric increases the breathability of the fabric. Hence, an open fabric structure is preferable for better comfort. On the contrary, more open fabric results more UV rays penetration through the fabric. So, it is desired to engineer a fabric that may contribute maximum comfort without compromising the protection of human body from UV rays. Researchers have tried to investigate the UV resistance of various textile fabrics. The UV resistance of a textile fabric is expressed by UPF (ultraviolet protection factor). A higher UPF value indicates safer fabric from UV damage and vice-versa. Researchers have studied the UPF of various textiles and found that the UV resistance of a textile depends on fibre type, fibre blends, fabric thickness, fabric openness and areal density [4-14]. However, no investigation is reported on the individual and interactive effect of yarn fineness as well as knitting parameters like loop length, carriage speed, input yarn tension, etc. on UPF of knitted fabric. Further, it is utmost important to study the effect of unavoidable uncontrolled random variables on UPF of knitted fabrics. Therefore, an attempt has been made to find out the effect of yarn fineness, loop length, carriage speed and yarn input knitting tension on UPF of single jersey and 1×1 rib knitted fabrics. Also, the effect of random uncontrolled variables on UPF is studied. An orthogonal block experimental design proposed by Box and Behnken is used in this study.

2 Materials and Methods

2.1 Preparation of Samples

To investigate the effect of various controlled and random uncontrolled variables on UPF, single jersey

---

[a]Corresponding author.
E-mail: anindya.textile@gmail.com

and 1×1 rib knitted fabrics were constructed using 100% cotton ring-spun yarns of three different fineness [5 Ne (118.1 tex), 7.5 Ne (78.7 tex) and 10 Ne (59.1 tex)]. All the samples were prepared in a 12 gauge computerized flat knitting machine with 'digital stitch control system' for all the combinations by using four variables orthogonal block factorial design proposed by Box and Behnken. 'Digital stitch control system' in the flat knitting machine helps to maintain the loop length at the desired level throughout the construction of the knitted fabrics. The loop lengths of all the single jersey and 1×1 rib fabrics were measured and compared with the set value and found an absolute error less than 1%. Similarly, the input tensions were checked and compared with the set value and found to be maintained with little absolute error % (<1%).

Table 1 shows the orthogonal block factorial design of four variables and three levels of each. The experimental design has 4 blocks and each block comprises 9 runs, thereby making 36 samples each for single jersey and 1×1 rib types. The actual values of the variables to the corresponding coded levels are given in Table 2. The controlled variables A, B, C and D corresponds to loop length (mm), carriage speed (m/s), yarn input tension (gf) and yarn fineness in English system respectively.

2.2 Testing

All the 72 knitted samples were completely relaxed by washing them in a Washcator washing machine as per EN ISO 6330 standard. The samples were dried and conditioned at standard temperature of 20°±2°C and relative humidity of 65±4% for 48 h. Subsequently, the samples were evaluated for UPF. For each of the 72 knitted samples, 10 readings were taken and the mean values were evaluated for analyses.

The ultraviolet protection factor (UPF) is a rating to indicate how effectively a fabric blocks the UV ray. *In-vitro* method was used to determine the UPF of the knitted samples, as per the AATCC 183:2004 standard. The UV transmittance analyzer (Labsphere 2000F) was used to measure the UPF of the samples. The UV transmittance was measured in a step of 1 nm wavelength by passing ultraviolet rays through the fabric. The UPF was evaluated using the following equation:

$$\mathrm{UPF} = \frac{\sum_{290}^{400} E(\lambda)\mathrm{S}(\lambda)\Delta(\lambda)}{\sum_{290}^{400} E(\lambda)\mathrm{S}(\lambda)\mathrm{T}(\lambda)\Delta(\lambda)} \quad \dots (1)$$

where $E(\lambda)$ is the relative erythemal spectral effectiveness; $S(\lambda)$, the solar spectral irradiance [$\mathrm{W/m^2nm}$]; $\Delta\lambda$, the measured wavelength interval [nm]; and $T(\lambda)$, the average spectral transmittance of the sample.

3 Results and Discussion

3.1 Effect of Uncontrolled Random Variables on UPF

Between blocks ANOVA has been conducted to appraise whether the difference between the four blocks are significant or not. The ANOVA analyses of UPF between blocks are shown in Table 3 for both the single jersey and 1×1 rib knitted fabrics. The observed F value between blocks for the single jersey and 1×1 rib knitted fabrics are 0.21 and 0.26 respectively. The F distribution value for 3 and 32 degrees of freedoms at 0.05 (5% significance level) is

Table 1 — Orthogonal block Box-Behnken design for 4 variables and 3 levels

$$\begin{bmatrix} -1 & -1 & -1 & 0 \\ -1 & -1 & +1 & 0 \\ -1 & +1 & -1 & 0 \\ -1 & +1 & +1 & 0 \\ +1 & -1 & -1 & 0 \\ +1 & -1 & +1 & 0 \\ +1 & +1 & -1 & 0 \\ +1 & +1 & +1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} -1 & -1 & 0 & -1 \\ -1 & -1 & 0 & +1 \\ -1 & +1 & 0 & -1 \\ -1 & +1 & 0 & +1 \\ +1 & -1 & 0 & -1 \\ +1 & -1 & 0 & +1 \\ +1 & +1 & 0 & -1 \\ +1 & +1 & 0 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} -1 & 0 & -1 & -1 \\ -1 & 0 & -1 & +1 \\ -1 & 0 & +1 & -1 \\ -1 & 0 & +1 & +1 \\ +1 & 0 & -1 & -1 \\ +1 & 0 & -1 & +1 \\ +1 & 0 & +1 & -1 \\ +1 & 0 & +1 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} 0 & -1 & -1 & -1 \\ 0 & -1 & -1 & +1 \\ 0 & -1 & +1 & -1 \\ 0 & -1 & +1 & +1 \\ 0 & +1 & -1 & -1 \\ 0 & +1 & -1 & +1 \\ 0 & +1 & +1 & -1 \\ 0 & +1 & +1 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Table 2 — Actual levels corresponding to coded levels for single jersey and 1×1 rib fabrics

Controlled factors	Coded level					
	Single jersey fabric			1×1 rib fabric		
	-1	0	+1	-1	0	+1
Loop length, mm	6.6	7.0	7.4	5.09	5.39	5.69
Carriage speed, m/s	0.25	0.6	0.95	0.25	0.40	0.65
Yarn input tension, gf	6	8	10	6	8	10
Yarn fineness, Ne (tex)	5(118.1)	7.5(78.7)	10(59.1)	5(118.1)	7.5(78.7)	10(59.1)

Table 3 — ANOVA analysis of UPF between blocks

Fabric	Source of variation	Sum of squares	Degree of freedom	Mean of squares	F value
Single jersey	Between blocks	31.22	3	10.41	0.21
	Error	1557.24	32	48.66	
	Total	1588.46	35		
1×1 rib	Between blocks	2150.6	3	716.86	0.26
	Error	87768	32	2742.75	
	Total	89918.6	35		

expressed as $F_{3,32,0.05}$ which have a tabular value of 2.91. Therefore, it is evident that the observed F values for both single jersey and 1×1 rib knitted fabrics are less than the tabular value at 0.05 (5%) level. Hence, it can be concluded that there is no significance difference between the blocks, i.e. the uncontrolled random variables during preparation of the samples do not have a significant effect on the UPF for both types of fabrics.

3.2 Effect of Controlled Variables on UPF

The fitted quadratic regression models of UPF along with coefficient of determination (R^2), error (%), beta coefficients (β) and percentage contributions of significant factors (C) for both single jersey and 1×1 rib knitted fabrics are shown in Table 4. The coefficient of determination (R^2) indicates the proportion of explained variability to the total variability, whereas the beta coefficients are the estimates resulting from an analysis carried out on the variables that have been standardized by subtracting their respective means and dividing by their standard deviations. Standardization of the coefficients appraises the strength of independent variable for determining the response variable in the fitted models, when the variables are measured in different units of measurement. Percentage contributions of significant controlled factors (C) are calculated by converting their corresponding beta coefficients into percentage (%). In the fitted models only the regression coefficient which are significant at 95% confidence level are taken into account. Fig. 1 depicts the effect of loop length and yarn fineness (yarn tex value) on UPF for both types of fabrics. The loop length and the yarn fineness shown in the figure are in their coded levels. It is evident from Fig. 1 that the UPF increases with the decrease in loop length (mm) and increase in yarn fineness (tex) for both the fabrics.

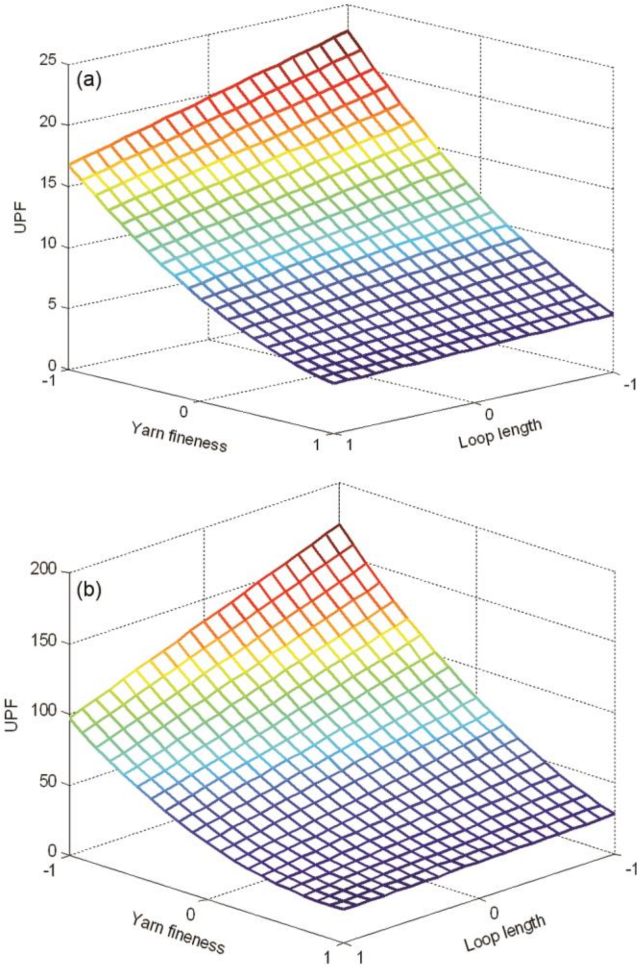

Fig. 1 — Effect of loop length and yarn fineness on UPF (a) single jersey and (b) 1×1 rib fabric (yarn fineness and loop length are in coded levels)

Table 4 illustrates that the coefficient of determination and error (%) are 0.97 and 5.42 respectively for single jersey fabric and that for 1×1 rib fabric are 0.97 and 9.05 respectively. Higher R^2 value and lower error% are corresponding to a good fit of response surface equation to the experimental data for both the single jersey and 1×1 rib knitted fabrics. It is also observed that the yarn fineness (tex) and loop length (mm) has substantial influence on UPF, whereas carriage speed and yarn input tension has little effect on UPF for both types of fabrics. The yarn fineness is the most dominating factor deciding UPF with the percentage contribution of significant factors of 64.39 and 52.67 for single jersey and 1×1 rib fabric respectively. The next dominating factor on UPF is loop length with percentage contribution of significant factors of 14.13 and 18.98 for single jersey and 1×1 rib respectively.

For a given type of fibre, the UPF of a knitted fabric is mainly governed by the two factors, namely

Table 4 — Response surface equations for UPF for single jersey and 1×1 rib knitted fabric

Parameter	Response surface equation	Coefficient of determination (R^2)	Error %	Beta coefficient (β)	Percentage contribution of significant factors
UPF – Single Jersey	$10.052 - 1.6867A - 7.6867D + 1.3169A*D + 2.0483D^2$	0.97	5.42	$\beta_A = -0.21$ $\beta_D = -0.95$ $\beta_{AD} = 0.13$ $\beta_{D^2} = 0.15$	$C_A = 14.13$ $C_D = 64.39$ $C_{AD} = 9.01$ $C_{D^2} = 9.91$
UPF – 1×1 rib	$59.967 - 19.451A - 53.967D + 17.424A*D + 19.967D^2$	0.97	9.05	$\beta_A = -0.32$ $\beta_D = -0.88$ $\beta_{AD} = 0.23$ $\beta_{D^2} = 0.19$	$C_A = 18.98$ $C_D = 52.67$ $C_{AD} = 13.88$ $C_{D^2} = 11.25$

fabric tightness factor and fabric areal density[4–7, 9–10, 15]. With the increase in yarn fineness (tex) and decrease in loop length (mm), the tightness factor and areal density increase and vice-versa. Higher tightness factor of a fabric gives more cover and hence it corresponds to more resistance to UV ray transmission through the fabric and vice-versa. On the other hand, higher areal density of a fabric appraises more absorption of UV ray. The above fact is evident from Figs 2 and 3, which depict respectively the linear dependence of fabric tightness factor as well as fabric areal density with the UPF of single jersey fabric. The tightness factor of a knitted fabric can be expressed as:

$$\text{Tightness factor} = \frac{\sqrt{T}}{l} \qquad \ldots (2)$$

where l is the loop length (mm); and T, the yarn fineness (tex). As per our experimental plan as given in Table 2, the percentage change in yarn fineness (tex) from lower level to the upper level is 49.9% [from 118.1 tex (5 Ne) to 59.1 tex (10 Ne)] which shows a decrease in tightness factor by 29.3% for single jersey fabrics. Again, the percentage change of lower level and higher level of loop length is only 11.8% that corresponds to change of tightness factor by only 10.8% for single jersey fabric. In addition, higher percentage change in yarn fineness (tex) has greater effect on the areal density of single jersey fabric than that of lower percentage change in the loop length. Hence, the effect of yarn fineness on UPF is comparatively more than that of the loop length.

For 1×1 rib fabrics, analogous effects are observed and this may be ascribed to the similar lines as discussed for single jersey fabrics. Yarn input tension and carriage speed have no significant influence on fabric tightness factor and areal density since the loop length is maintained at desired level throughout knitting by using ‘digital stitch control system’.

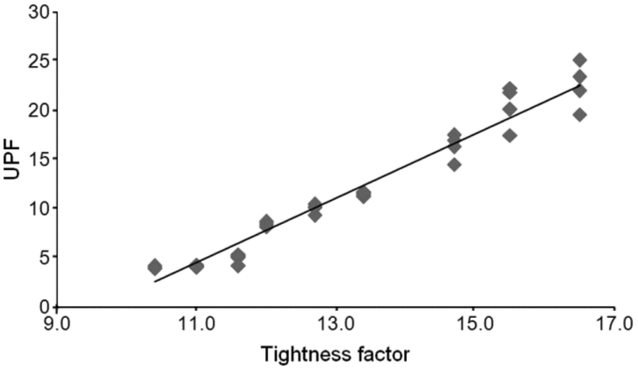

Fig. 2 — Effect of tightness factor on UPF of single jersey fabric

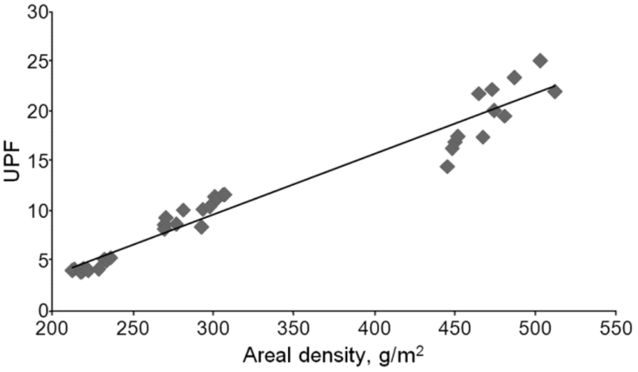

Fig. 3 — Effect of areal density on UPF of single jersey fabric

4 Conclusion

The random factors during preparation of the samples have no significant effect on UPF for both single jersey and 1×1 rib knitted fabrics. The most dominating factor affecting the UPF is yarn fineness. The second major factor that influences UPF is the loop length. Yarn input tension and carriage speed has no significant impact due to constant loop length, irrespective of change in yarn input tension and carriage speed. UPF increases as the loop length decreases and yarn fineness (tex) reduces for both single jersey and 1×1 rib knitted fabrics due to the increase in fabric tightness factor and areal density.

References

1 MacKie R M, *Radiat Prot Dosim*, 91 (2000) 15.

2 Gallagher R P & Lee T K, *Prog Biophys Mol Biol*, 92 (2006) 119.

3 Halliday G M, Norval M, Byrne S N, Huang X X & Wolf P, *Drug Discov Today: Disease Mechanism*, 5 (2008) e20.

4 Algaba I & Riva A, *AATCC Rev*, 4 (2004) 26.

5 Algaba I, Pepio M & Riva A, *Fibres Text East Eur*, 16 (2008) 85.

6 Chong H S, Kan C, Lam J K, Ng S, Hu H & Yuen C M, *J Text Eng*, 59 (2013) 71.

7 Das B R, *Open Text J*, 3 (2010) 14.

8 Dubrovski P D, *Woven Fabric Eng* (Sciyp, India), (2010), 273.

9 Grancaric A M, Penava Z & Tarbuk A, *Hemijska Industrija Serbian Soc Chem Ind J*, 59 (2005) 230.

10 Hatua P, Majumdar A & Das A, *J Text Inst*, 104 (2013) 708.

11 Hatua P, Majumdar A & Das A, *J Eng Fiber Fabric*, 9 (2014) 99.

12 Majumdar A, Kothari V K & Mondal A K, *Photodermatol Photo*, 26 (2010) 290.

13 Majumdar A, Kothari V K & Mondal A K, *Photodermatol Photo*, 28 (2012) 58.

14 Morihiro Y, Eri F Y & Chie T, *J Text Eng*, 55 (2009) 103.

15 Yam E L, Kan C, Lam J K, Ng S, Hu H & Yuen C M, *J Text Eng*, 59 (2013) 83.