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Mathematical Model of Optimally Designed Sun Protective Workwear Fabric

S.S.Bhattacharya[1], C.N.Joshi[2]
[1]*Textile Engineering Department, M.S.University, Baroda, India*
[2]*Textile Technology Department, Sarvajanik College of Engineering and Technology, Surat, India*

Abstract:- The aim of present work was to develop the fabric which provides sufficient protection from ultraviolet rays present in the sunlight specially for those who are exposed to sunlight for long time due to their occupation. Carded Polyester/Viscose Ring yarns with Blend ratios 75/25, 60/40, and 55/45 and Polyester/Viscose/Lycra Ring yarns with blend ratio 70/25/5 having weft linear density of 37Tex were produced. Polyester/Viscose yarn with warp linear density of 20 Tex was produced from blend of 75/25. The fabric samples were woven with constant warp density of 125 ends per inch and for each blend three weft densities (55, 65, 70 picks per inch) were selected. Combining all, twelve different samples of fabric were prepared. These fabrics were first treated with pre-treatment process and then characterization of all samples were carried out. The UPF of the fabric was determined by the in vitro method using an Ultraviolet Transmittance Analyser UV-2000F. Results show excellent UPF along with good air permeability for all fabric samples and provides best protection from UVB and UVA rays and can be appropriate for workwear fabric. Statistical analysis of Mathematical model helps to study influence of thickness, weight and air permeability on UPF.

Keywords:- Polyester, Viscose, Lycra, Woven fabric, Sun Protective

I. INTRODUCTION

Most of us understand the need for suntan lotion to help protect the skin against harmful ultra violet (UV) light rays. What we may not realize is the need to protect the skin under our clothing. Exposure to minimal dose of the sun is beneficial for the organism since it contributes to the development of bones and the assimilation of vitamins and invigorates the metabolism and improves resistance to various pathogens.

However overexposure to the sun increases the risk of permanent damage to the skin caused by ultraviolet radiation. Other effects includes premature ageing of skin, roughening, blotches, sagging, wrinkles, squamous cell and basal cell cancer. Experts in dermatology suggest protecting the body from excessive exposure to ultraviolet radiation. Occupational exposure is significant, there is a growing interest in reducing the UVR exposure of outdoor workers. This necessitates the development of fabric which provides best protection towards longer exposure and at high UV index [1,2].

Outdoor workers can receive much higher UVR doses as well as higher fractions of ambient, although the UVR exposures depend on their occupations. For a range of different occupations in the building and construction industry, outdoor workers had measured UVR exposures of 3-33% and a median of 30% of available ambient UVR, with occupation that spend more time in the sun having the highest exposures. So outdoor workers need to be provided with garments that have high UVR protection i.e. UPF 50+ along with use of personal protective equipment (PPE) such as sunscreen products, hat and sunglasses etc [3,4]. Clothing is our first line of defence against the sun’s UV rays which are harmful. Sun protective clothing is clothing specially designed for sun protection and is produced from a fabric rated for its level of ultra violet protection. Sun protection fabrics are designed to absorb and reflect the sun’s UV radiations [5].

Solar UVR can reach on the ground from three sources: Directly from sun; scattered from the open sky and reflected from the environment. Outdoor workers are exposed to UV radiation both directly and indirectly as it reflects or scattered from surrounding surfaces, which in the construction industry include concrete, glass, metal surfaces, sand and large bodies of water. Workers therefore potentially exposed to great deal of UV radiation from the sun, even when working in the shade or under overhead protection. Workers should continue to wear sun protection in the shade for maximum protection [6].

Aim of the present study was to engineer a blended yarn of correct linear density from different blend ratios which contain synthetic fibre (Polyester) for providing sun shielding property and Viscose fibre to obtain its benefit of cotton like properties in giving comfort to the wearer and optimization of fabric parameters like type of weave, warp density and weft densities to develop a fabric which can be suitable as work wear fabric.

II. MATERIALS AND METHODS

For this work Carded Polyester/Viscose Ring yarns with Blend ratios 75/25, 60/40, and 55/45 and Polyester/Viscose/Lycra Ring yarns with blend ratio 70/25/5 having linear density of 37 Tex were produced as a weft. Polyester/Viscose yarn with warp linear density of 20 Tex was produced from blend of 75/25. The fabric samples were woven on Dornier make Rigid Rapier Loom with constant warp linear density of 20Tex & weft linear density of 37 Tex. Also the warp density of 125 ends per inch was kept constant for all samples. For each blend three weft densities (55, 65, 70) picks per inch were selected. Combining all, twelve different fabric samples were prepared. Table I shows the experimental design of the woven samples. These fabrics were first treated with pre-treatment process. All fabrics samples were conditioned and tested in a standard atmosphere. The characterization of all samples were carried out on ready for Dyeing (RFD) samples.

A. *Test methods*

Weight per surface unit, g/m^2: The weight per surface unit of the fabric was determined according to ASTM:D 1777:197, IS:77021975 using Mettler make measuring balance , model PB 602-5.
Thickness, mm: Fabric thickness was determined according to standard ASTM:D 1777:197, IS:77021975 using Baker Make J02 Thickness Tester.

Determination of permeability of fabric to Air: Air permeability of fabric was measured by SDL Atlas make Air Permeability tester Model: MO21A according to ASTM: D737-1996.

Ultraviolet Protection Factor UPF: The UPF of the fabric was determined by the in vitro method using an Ultraviolet Transmittance Analyzer UV-2000F according to standard BSEN 13758-1:2002. The UV-2000F Ultraviolet Transmittance Analyzer is the most recent and highly application specific ultraviolet spectroscopy. The instrument operates by measuring the diffuse transmittance of a fabric sample as a function of wavelength in the ultraviolet spectrum (250 nm to 450 nm) and does the automatic calculations of spectral transmittance, UPF, critical wavelength and UVA:UVB ratios. Each fabric sample were tested for five different location to cover entire length and width of fabric, the measuring area was 0.67 cm^2 and wavelength accuracy to +1 nm.

***Calculation of UPF*:** The UPF of a textile material is determined from the total spectral transmittance. The total spectral transmittance is measured by irradiating the sample with monochromatic or polychromatic UV radiation and collecting the total (diffuse and direct) transmitted radiation. In the case of polychromatic incident radiation, the transmitted radiation is collected monochromatically. The apparatus shall either irradiate the sample with a parallel beam and hemispherically and collect a parallel beam of transmitted radiation [7, 8,9,10,11, 12, 13, 14].
Calculation of the Ultraviolet Protection Factor for each specimen I is as follows:

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

Where E (λ) = CIE erythemal spectral effectiveness, S(λ) = solar spectral irradiance in Wm^{-2} nm^{-1}, T(λ) = spectral transmittance of fabric, Δλ = the bandwidth in nm, and λ = the wavelength in nm [15].

III. RESULTS AND DISCUSSIONS

Table II shows fabric properties and experimental air permeability values of RFD Sateen Samples. As weft density increases, weight increases which reduces the total fabric porosity and results in the reduction of the direct transmission of UV rays through the pores of fabric, in addition to that blended yarn is used which contains the component of Polyester and Viscose in different proportion. Polyester due to its large conjugated aromatic polymer system is very effective in blocking UVB radiation [16]. Polyester is less effective against the UVA radiation because its UVR transmission increases significantly at 313 nm which is close to the boundary between the UVB and UVA spectral regions. However, researchers succeeded in rectifying this drawback by increasing the weft density to optimum value and by addition of small percentage of Lycra (5 percent) which is quite evident from the results obtained. Table III shows UPF values of Sateen Samples. Figure 1 shows the bubble plot of UPF versus thickness, figure 2 shows the bubble plot of UPF versus weight and figure 3 shows the bubble plot of UPF versus air permeability.

A. Effect of construction and grams on UV Permeability of fabric

For blend ratio of 75/25, 60/40 and 45/55 (Polyester/Viscose) of RFD samples as weft density increases from 55, 65, 70 picks per inch respectively the effect on thickness does not show clear trend but fabric weight increases which shows good correlation with air permeability values by following a decreasing trend and also offers better protection from UV rays emitted by sun, as UPF value is also showing increasing trend which relates well with established fact. For blend ratio of 70/25/5 (Polyester/Viscose/Lycra), fabric sample woven with pick density of 65 picks/inch is the thickest, heaviest fabric with maximum UPF value among all.

All the samples offers best protection from UVA and UVB but Fabric woven with Lycra are very less permeable to UVA and UVB rays both as can be seen from their very low % transmittance value.

By addition of 5 percent lycra to 75/25 blend it has been observed that UPF increases drastically for 55, 65, and 70 picks per inch weft density. The UPF value increased to 593.55, 667.99 and 654.83 from 211.87, 255.07 and 372.58 respectively as addition of lycra reduces the pore area.

B.Effect of blend ratio on UV Permeability of fabric

For 55 ppi & 70 ppi as blend ratio changes from 75/25, 60/40 and 45/55 even though the thickness and weight increases respectively, but the sample of 75/25 blend exhibits highest UPF which may be attributed to higher proportion of polyester. For 65 ppi, sample with 45/55 blend exhibits maximum value of UPF compare to 77/25 and 60/40 blends which is rather surprising.

C.Mathematical model and Statistical Evaluation

To address a mathematical relationship between the fabric thickness, fabric weight and air permeability on Sun protective property of fabric Multiple Regression analyses were made between sun protective property and fabric parameters. Sun protective property are defined as dependent variable (Y), and fabric thickness, fabric weight and air permeability are defined as independent variables (X). Multiple linear regression analysis have been applied to the measured values and obtained the best fit equation using MINITAB16.

The best regression equation for UPF for fabric is given in Table IV. Statistical evaluation are shown in Table V. Together, thickness, weight and air permeability accounted for 98.11% of the variance in the UPF. As per regression analysis it was found that the equation obtained is a good equation as the R^2 value is 98.11%.

IV. CONCLUSIONS

For all blend ratio chosen for study, it has been observed that with increase in weft density weight increases, air permeability decreases and UPF value increases. It has been observed that for every blend ratio chosen the percentage transmittance decreases for every wavelength with increase in weft density and shows best protection in UVB region than UVA.

All the samples exhibit excellent UPF (greater than 100) with adequate air permeability. Air permeability is a critical parameter as it contributes to the comfort level of the wearer [17]. Addition of Lycra by just 5 percent increases the UPF value significantly for all the samples. Yarn produced with all four blend ratios exhibits better performance in terms of sun protective properties. All the samples provides extremely good protection from UVB which are rather more health hazards even where proportion of polyester and viscose is almost equal (45/55).

The combination of fabric structural properties (weave, fibre type, linear density and fabric sett) has great direct and indirect effect on thickness, weight, porosity of fabric and so in the transmission of UV radiation through the fabric. The UPF of fabric is highly influenced by its structure and thus provides physical barrier that will oppose the passing the ultraviolet radiation.

Researchers succeeded in engineering yarn as well as fabric from medium to heavy weight which can be very useful as a work wear fabrics for people who have to remain long time in outdoor due to their occupation like persons from defence, construction industry, farmers, fishers, skiers etc. and is capable of protecting the wearer even with highest UV index of (10-12).

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Table I: Experimental Design of Woven Samples

Categorial variable / Fabric Code	Fibre Composition	Blend ratio	Weave Structure	Weft Density (PPI)
RS_1	Polyester/Viscose	75/25	Sateen	55
RS_2	Polyester/Viscose	60/40	Sateen	55
RS_3	Polyester/Viscose	45/55	Sateen	55
RS_4	Polyester/Viscose/Lycra	70/25/5	Sateen	55
RS_5	Polyester/Viscose	75/25	Sateen	65
RS_6	Polyester/Viscose	60/40	Sateen	65
RS_7	Polyester/Viscose	45/55	Sateen	65
RS_8	Polyester/Viscose/Lycra	70/25/5	Sateen	65
RS_9	Polyester/Viscose	75/25	Sateen	70
RS_{10}	Polyester/Viscose	60/40	Sateen	70
RS_{11}	Polyester/Viscose	45/55	Sateen	70
RS_{12}	Polyester/Viscose/Lycra	70/25/5	Sateen	70

Table II: Fabric Properties and Experimental Air Permeability Values for RFD Sateen Samples

Fabric Code	Thickness, (mm)	Weight, g/m^2	Air permeability, (l/m^2/s)
RS_1	0.561	212.25	463.8
RS_2	0.593	211.62	521
RS_3	0.600	218.13	488.8
RS_4	0.842	347.46	109.2
RS_5	0.584	234.76	236.2
RS_6	0.581	233.79	253
RS_7	0.589	235.82	225.4
RS_8	0.854	382.61	43.72
RS_9	0.545	244.26	164
RS_{10}	0.581	247.07	166.6
RS_{11}	0.654	249.62	145.8
RS_{12}	0.814	357.93	40.6

Table III: UPF and UVA, UVB Permeability of Sateen Samples

Fabric Code	UPF			UVA			UVB		
	Mean	Standard Deviation	Coefficient of Variation (%)	Mean (%)	Standard Deviation (%)	Coefficient of Variation (%)	Mean (%)	Standard Deviation (%)	Coefficient of Variation (%)
RS_1	211.87	46.02	21.72	5.40	0.84	15.37	0.05	0.00	1.95
RS_2	209.18	3.28	1.57	5.09	0.15	2.96	0.05	0.00	1.28
RS_3	199.36	10.90	5.47	5.34	0.37	6.95	0.05	0.00	1.32
RS_4	593.55	74.73	12.59	2.20	0.4	18.32	0.05	0.00	0.00
RS_5	255.07	33.72	13.22	4.92	0.54	11.05	0.05	0.00	0.00
RS_6	262.03	24.49	9.35	4.65	0.45	9.62	0.05	0.00	0.00
RS_7	297.80	37.59	12.62	4.01	0.53	13.01	0.05	0.00	0.00
RS_8	667.99	56.76	8.5	1.89	0.22	11.77	0.05	0.00	0.00
RS_9	372.58	18.51	4.97	3.45	0.18	5.32	0.05	0.00	0.00
RS_{10}	311.39	16.31	5.24	3.99	0.22	5.55	0.05	0.00	0.00
RS_{11}	352.18	25.89	7.35	3.49	0.25	7.06	0.05	0.00	0.00
RS_{12}	654.83	36.2	5.53	1.92	0.14	7.3	0.05	0.00	0.00

Table IV: General Regression Analysis: UPF Versus Thickness, Weight, Air Permeability

Regression Equation

UPF = -261.349 - 126.33 Thickness + 2.79002 Weight - 0.122484 Air Permeability

Table V: Regression Analysis: UPF Versus Thickness, Weight, Air Permeability

Predictor	Coefficient	SE Coefficient	T	P	
Constant	-261.349	74.075	-3.52818	0.008	
Thickness	-126.330	329.503	-0.38340	0.711	
Weight	2.790	0.769	3.62935	0.007	
Air Permeability	-0.122	0.103	-1.19490	0.266	
S = 28.0782	R^2 = 98.11%	R^2 (adj) = 97.40%			
Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	327192	109064	138.338	0.000000
Residual Error	8	6307	6307	788	
Total	11	333499			

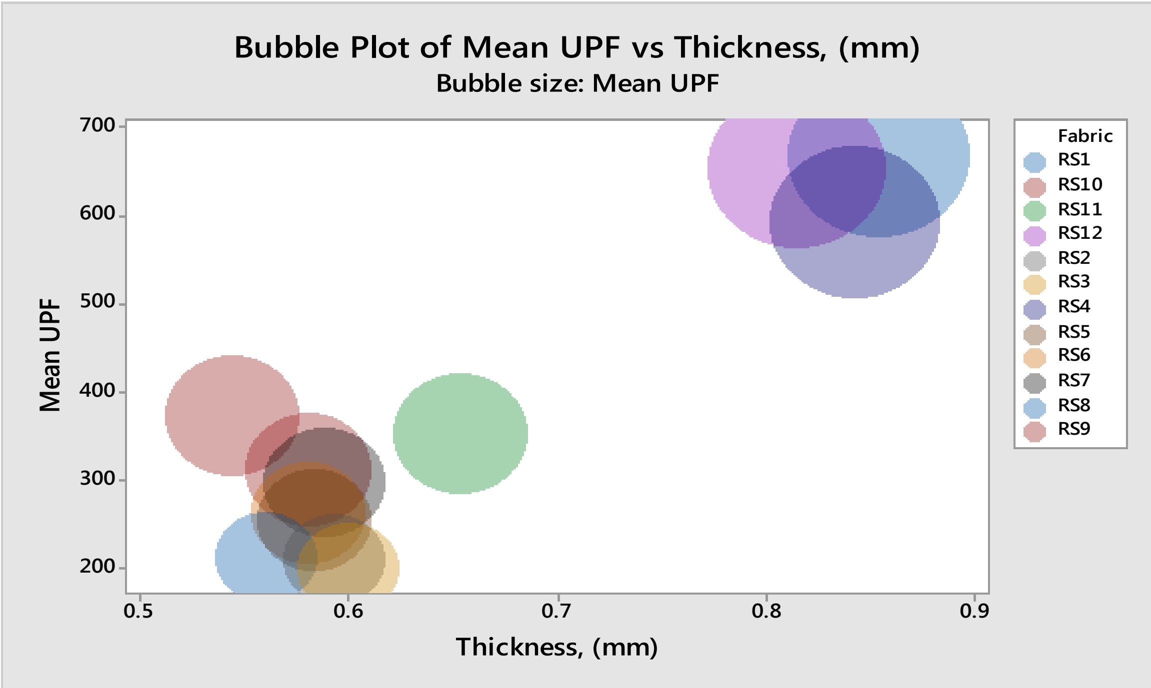

Fig. 1: Bubble plot of Mean UPF versus thickness

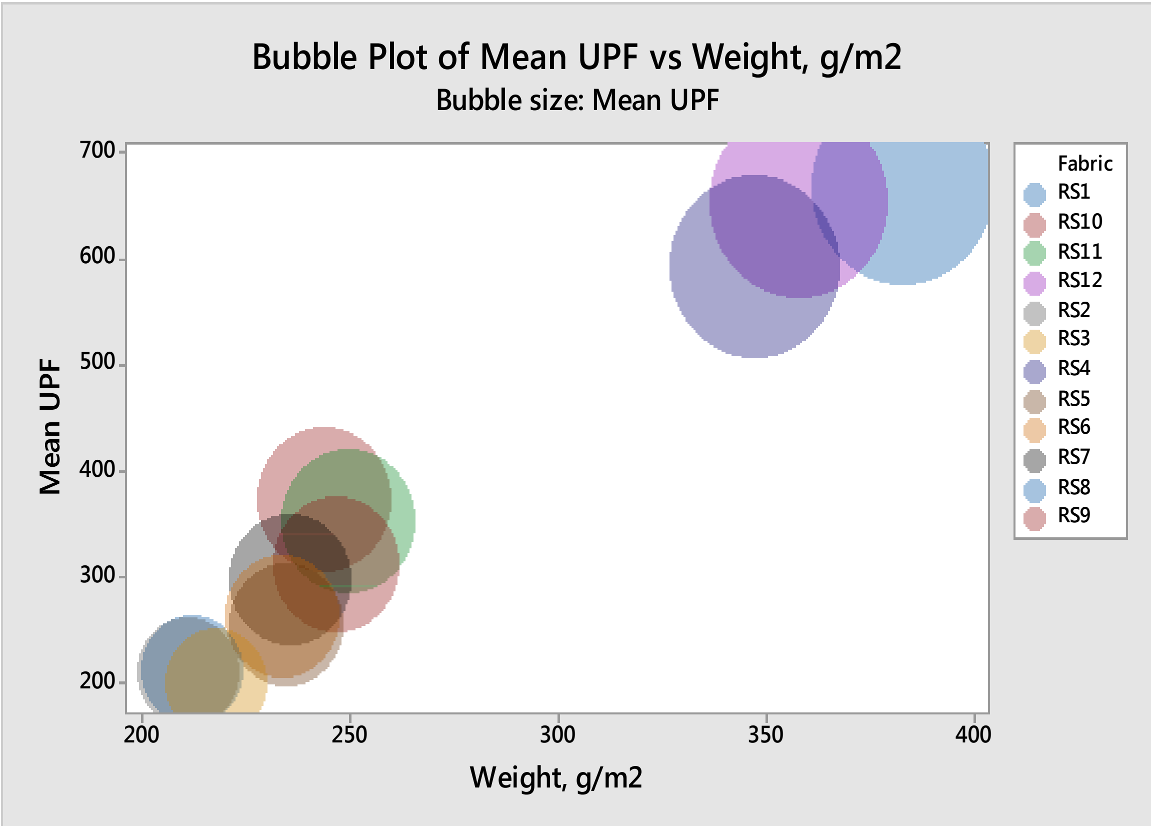

Fig. 2: Bubble plot of Mean UPF versus weight

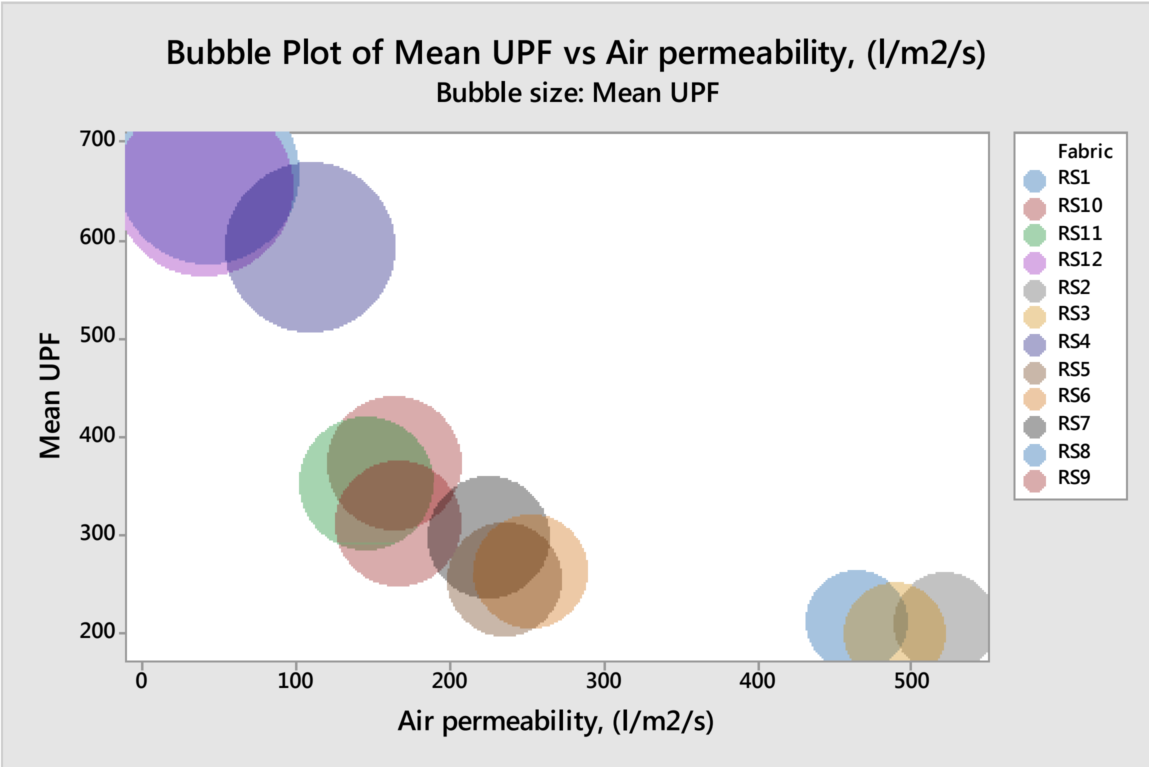

Fig. 3: Bubble plot of Mean UPF versus air permeability