342 *Egypt. J. Chem.* **Vol. 63,** No. 11 pp. 4369 - 4378 (2020)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Effect of Some Construction Factors of Bi-layer Knitted Fabrics Produced for Sports Wear on Resisting Ultraviolet Radiation

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Abstract

Ultraviolet rays represent a very low fraction of the solar spectrum which damages all living organisms and their metabolisms. Such radiations can cause a variety of symptoms, from basic tanning to extremely malignant skin cancers, fabrics with correct design specification, absorbers, and finishing methods, can play a very important role as a shielding system against the deterious effects of Ultraviolet rays.

This study will stress on bi-layer knitted fabrics because knitted goods of all kinds are widely popular due to their flexibility ability to adjust, stretch when worn to a specific shape and their general comfortable wear. Knitted fabrics are widely used in Sportswear, summer clothes, under wears and Childs' clothes due to their excellent stretch and recovery, porosity, air permeability. Also knitted fabrics especially weft knitted fabrics are easier to be produced, and less cost compared to woven fabrics. Because of this fact, most previous research concerns woven structures that are typically less porous and offer higher protection against UV. The possibility of obtaining knitted fabrics with sufficient UV protection factor is of great interest, however, as knitted fabrics are more suitable for both sports and casual summer fashion garments. Current literature on the UV protection factor of knitted fabrics is very small and mostly concerns fabrics developed in machines with relatively large gauges This study is trying to find a solution for this problem by studying the Influence of weft knitted fabrics Construction with its' different parameters for Protection against Ultraviolet Radiation in sportswear applications.

Keywords: Ultraviolet protection; blended Bamboo and cotton yarn; knitting fabrics; bi-layer knitted fabrics

1. Introduction

Protective textiles have become an integral part of technical textiles. Protective textiles apply to garments and other fabric-related items designed to protect the wearer from adverse effects on the environment that can result in injury or death. as protective fabrics often have to withstand the effects of many harsh environments, such as extreme heat and cold, **[1-4]** fire retardant, **[5-7]** water and oil repellent, **[8]** toxic chemicals and gasses, **[9]** bacterial/viral protection, **[10-14]** mechanical hazards, wound dressing, **[15-18]** pH, Thermo-Sensitive, **[19]** radiation, etc. **[20, 21]** In some situations these textiles may be used to protect the environment from pollution, such as clean rooms, **[22]** and dust adsorption. **[9]** Developing new technologies to improving performance and comfort in sportswear design need to be addressed from second skin clothing to outerwear. **[23]**

1.1. Sports wear

Outdoor fitness helps people to feel healthier on a physical, emotional and social context, because low stress rates and high level of physical exercise can reduce common health issues including elevated blood pressure, obesity, heart disease, cancer and psychological disorders. Spending time in natural environments is now considered an important

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Receive Date: 15 March 2020, Revise Date: 31 March 2020, Accept Date: 06 April 2020
DOI: 10.21608/EJCHEM.2020.25922.2514

preventive medicine activity due to the positive physical, emotional, social and environmental effects of Ultraviolet Radiation. [24]

Consumers expect high performance from sportswear. Developments in active sportswear fabrics are aimed at achieving high versatility and comfort. Sportswear must protect the wearer against rain, snow, cold, heat and UV rays. Sportswear manufacturers use innovative textile technologies to meet the demands for better performance of athletic and leisure activities such as drape, comfort, fitness and ease of movement, as well as the versatility of sportswear customs in sports such as skiing, mountaineering, snowboarding and alpine running. [25, 26]

Ultraviolet ray protection has become an essential practical prerequisite for anyone to spend long hours in outdoor sports such as warming up outdoor, golf, cricket and tennis. A little reduced drag force can improve performance in high-speed games and make a difference in a highly competitive environment, so that textile movement analysis and health tracking during sport training can provide precise and detailed performance enhancement results. [27]

1.2. Effects of Ultraviolet Radiation

Ultraviolet Radiation is described as "the portion of the electromagnetic spectrum between the x-ray and the visible light". **[28]** The ultraviolet radiation band is composed of three regions 1) UV-A (320 – 400 nm) which produces few visible reactions on the skin but has been shown to decrease the immune response of skin cells, 2) UV-B (290 – 320 nm) which is the one most responsible for skin cancer growth and 3) UV-C (200 – 290 nm) which is completely absorbed by the ozone which prevent it to reach Earth. **[29]**

In the early 1990s, effects of ultraviolet solar (UV) radiation on human skin were recognised. High UV radiation can lead to skin damage such as sunburn, allergies, premature aging of the skin, and even skin cancer. [30]

1.3. Ultraviolet Protection using Textiles

Apart from a drastic reduction in sun exposure, the most frequently recommended form of UV protection is the use of sunscreens, hats and proper clothing selection. Since cloth is made of absorbable fibres, which can absorb and block most of the radiant energy incident, and prevent it from reaching the skin by reflect or scatter radiant energy.

The capability of a fabric to block UV depends on several parameters including fibre chemistry; fabric construction, in particular porosity weight and thickness, moisture content and fabric wet processing history such as dye concentration, fluorescent whitening agents, ultraviolet absorbers and other finishing chemicals which may have been applied to textile material [24, 25, 29, 31]

Quantitative testing to determine how a garment should be used to protect skin from UV ray, either by in vivo laboratory experiments or by in vitro experimental measurements Two terms are used: 1) Sun Protection Factor (SPF) for in vivo analysis and 2) UV Protection Factor (UPF) for in vitro instrument assessment. [31]

UV-protective shields are classified into various UPF level categories based on their measured UPF according to international standards (In compliance with the Australian/New Zealand standard (AS/NZS 4366-1996), the UV Protection Factor (UPF) for blank and examined fabrics has been determined using the UV-Vis spectrophotometer. The UPF values of examined fabrics was measured through absorption spectroscopy. The link to control has been taken as rain. The UPF value was calculated using the following equation from the transmission spectra of the examined fabrics within the range 280–400 nm. [19, 36-39]

$$\mathrm{UPF} = \frac{\int_{\lambda_1}^{\lambda_2} (E_\lambda \times S_\lambda \times \Delta\lambda)}{\int_{\lambda_1}^{\lambda_2} (E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda)}$$

where λ_1 and λ_2 are 280 and 400 nm respectively, E_λ is the relative erythema spectral effectiveness, S_λ is the solar spectral irradiance in $Wm^{-2}nm^{-1}$ (E_λ and S_λ values were obtained from the National Oceanic and Atmospheric Administration database (NOAA)), T_λ is the spectral transmission of the sample obtained from UV spectrophotometric experiments and $\Delta\lambda$ is the difference between measurable wave length between measurable wavelength

1.4. Mechanism of UV protection

If a fiber surface is subjected to radiation, it may be reflected, absorbed, transferred or conveyed via the fibers. The total amount of radiation that is emitted, absorbed or transferred depends on a variety of factors, including fiber thickness, fabric cover factor, fiber surface smoothness, and the presence or absence of fiber debutants, UV absorbers, and colors. The effect of the type of fiber on the sun protection factor (SPF) is different. Cotton and silk, for example, have no protection for UV radiation, because light can pass through them without being completely absorbed.

In the other hand, polyester and wool have higher SPF as these fibers can absorb UV radiation, while Nylon is among these extremes. If the fibers absorb all the incident radiation, then the only source of the emitted rays is the distance between the yarns, and

Table 1). [32-34] When an untreated normal fair skin begins to show signs of erythema (reddening) after 10 minutes of continuous exposure to UV solar light, a protective shield with UPF equal to 15 raises the exposure time by 15 times, i.e. 150 minutes. [35] Higher UPF values above 40 (40 +) or 50 (50 +) are considered safe "sun-blocks".

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then the effective SPF can be determined according to the following equation: SPF (max)= 1/1-cover factor, and hence near microfibers have better UV protection than normal-sized fibers of the same weight and structure. [40-42]

UV-resistant fabrics ' general requirements are UV resistance agronomic nature, comfort, light weight, longevity, easy maintenance, dimensional stability, colour fastness and the appearance of preservation after repeated washing. It is very important to have a proper choice of fibres, fabric size, weight and finishes so that the fabric meets these requirements. [20]

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Table 1: UPF rating categories according AS/NZS, ASTM and European standards

	AS/NZS 4399:1996 and ASTM D6603			EN 13758-2:2003		
Protection	% UVB Transmittance	UPF Range	UPF Ratings	% UVB Transmittance	UPF Range	UPF Ratings
Excellent	less than 2.5	above 40	40, 45, 50, 50+	less than 2.5	above 40	40+
Very good	4.1–2.6	25–39	25, 30,35	3.3–2.5	30-40	30
Good	6.7–4.2	15-24	15, 20	5.0–3.4	20-29	no value

2. Experimental

2.1. Materials and methods

The bi-layer knitted structures were prepared using Polyester microfiber (75/144 diner) with lycra 20 detex in bonding layer, cotton (40 Ne), Modal (40 Ne) and blended yarn of 50/50 and 70/30 bamboo/cotton (40 Ne) back), in the face were prepared using two groups first polyester75/35 + viscose75/24 and the second 70/30 bamboo/cotton (30 Ne) in face. All samples were produced in circular multi-track weft knitting machine (TERROT I3P 148) with 28 inch diameter, 48 feeders, 18 gauge and 1680 × 2 needles. In this experimental work, the bi-layer fabric is developed in which the inner layer is made of polyester that is hydrophobic and has good wicking rate. The outer layers is made up of regenerated fibre such as Modal or bamboo or viscose which has more absorption character and rapid evaporation. The yarn which has to form as an upper layer is fed into the dial needle and as an under layer is fed into the cylinder needle. And the bonding layer using a needle from dail and needle from cylinder like interlock gating.

The two bi-layer knitted structures were

Table 2. The sample code and the specifications of produced samples under study are mentioned below in **Table 3**.

2.3. Characterization

The physical properties of produced fabrics were monitoring and evaluated using standard test methods. The Mass per Unit Area (weight) of fabrics was evaluated using ASTM Standard Test Method

developed: one is 6 course repeat in which dial needles knit at 2^{nd}, 5^{th} feeders and cylinder needles knit at 1^{st}, 4^{th} feeders. The bonding layer takes place 3^{rd}, 6^{th} feeders like interlock gating.

2.2. The second structure is developed with 6 course repeat the tuck frequency takes place at 1^{st} and 4^{th} feeders, the cylinder needles form tuck stitch at first needle in first feeder and the second needle in of 4^{th} feeders every repeat. The visual appearance of the structures and the graphical representation of the bi-layer knitted fabric is shown in ***Figure 1*** *and Characterization*

The physical properties of produced fabrics were monitoring and evaluated using standard test methods. The Mass per Unit Area (weight) of fabrics was evaluated using ASTM Standard Test Method (D3776/D3776M – 09a (Reapproved 2017). **[43]** The Thickness of Textile Materials was evaluated using ASTM Standard Test Method D-1777 – 96. **[44]** Evaluation and Classification of Sun protective clothing (UPF) was measured using Australian/New Zealand Standard method AS/NZS 4399:1996. **[45]** Air Permeability of produced fabrics was measured using ASTM Standard Test Method C33 (ASTM D 737 - 18) **[46]**

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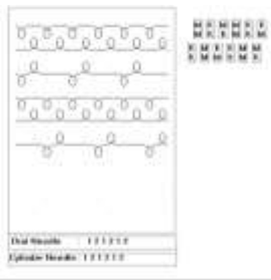
Table 2: The graphical representation of the bi-layer knitted fabric

<table>
<tr>
<td>Structure 1</td>
<td>
<table>
<tr><th></th><th>F1</th><th>F2</th><th>F3</th><th>F4</th><th>F5</th><th>F6</th></tr>
<tr><td>DN1</td><td>-</td><td>X</td><td>-</td><td>-</td><td>X</td><td>X</td></tr>
<tr><td>DN2</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>-</td></tr>
<tr><td>CN1</td><td>X</td><td>-</td><td>X</td><td>X</td><td>-</td><td>-</td></tr>
<tr><td>CN2</td><td>X</td><td>-</td><td>-</td><td>X</td><td>-</td><td>X</td></tr>
</table>
Dial needles: Two tracks
DN1-Dial Needles Track 1; DN2-Dial Needles Track 2
Cylinder needles: Two tracks
CN1-Cylinder Needles Track 1; CN2-Cylinder Needles Track 2
Feeders F1, F2 and F6
X Knit stitch; o Tuck stitch; - Miss stitch
</td>
<td></td>
</tr>
<tr>
<td>Structure 2</td>
<td>
Dial needles: Two tracks
<table>
<tr><th></th><th>F1</th><th>F2</th><th>F3</th><th>F4</th><th>F5</th><th>F6</th></tr>
<tr><td>DN1</td><td>-</td><td>X</td><td>-</td><td>-</td><td>X</td><td>X</td></tr>
<tr><td>DN2</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>-</td></tr>
<tr><td>CN1</td><td>O</td><td>-</td><td>X</td><td>X</td><td>-</td><td>-</td></tr>
<tr><td>CN2</td><td>X</td><td>-</td><td>-</td><td>O</td><td>-</td><td>X</td></tr>
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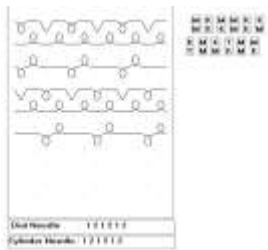
<td></td>
</tr>
</table>

Table 3: sample code and specifications of produced sample

Sample No.	Code	F1, F4	F3, F6	F2, F5	Fabric structure
1	B1	polyester 75/35 + viscose 75/24"	polyester 75/144 + lycra 20 detex	Cotton 40/1	Structure 1
2	B2			Modal 40/1	
3	B3			Bamboo-Cotton (40-60%) 40/1	
4	B4			Bamboo-Cotton (70-30%) 40/1	
5	F1			Cotton 40/1	Structure 2
6	F2			Modal 40/1	
7	F3			Bamboo-Cotton (40-60%) 40/1	
8	F4			Bamboo-Cotton (70-30%) 40/1	
9	D1			Cotton 40/1	Structure 1
10	D2	bamboo -cotton (70-30%) 30/1		Modal 40/1	
11	D3			Bamboo-Cotton (40-60%) 40/1	
12	D4			Bamboo-Cotton (70-30%) 40/1	
13	H1			Cotton 40/1	Structure 2
14	H2			Modal 40/1	
15	H3			Bamboo-Cotton (40-60%) 40/1	
16	H4			Bamboo-Cotton (70-30%) 40/1	

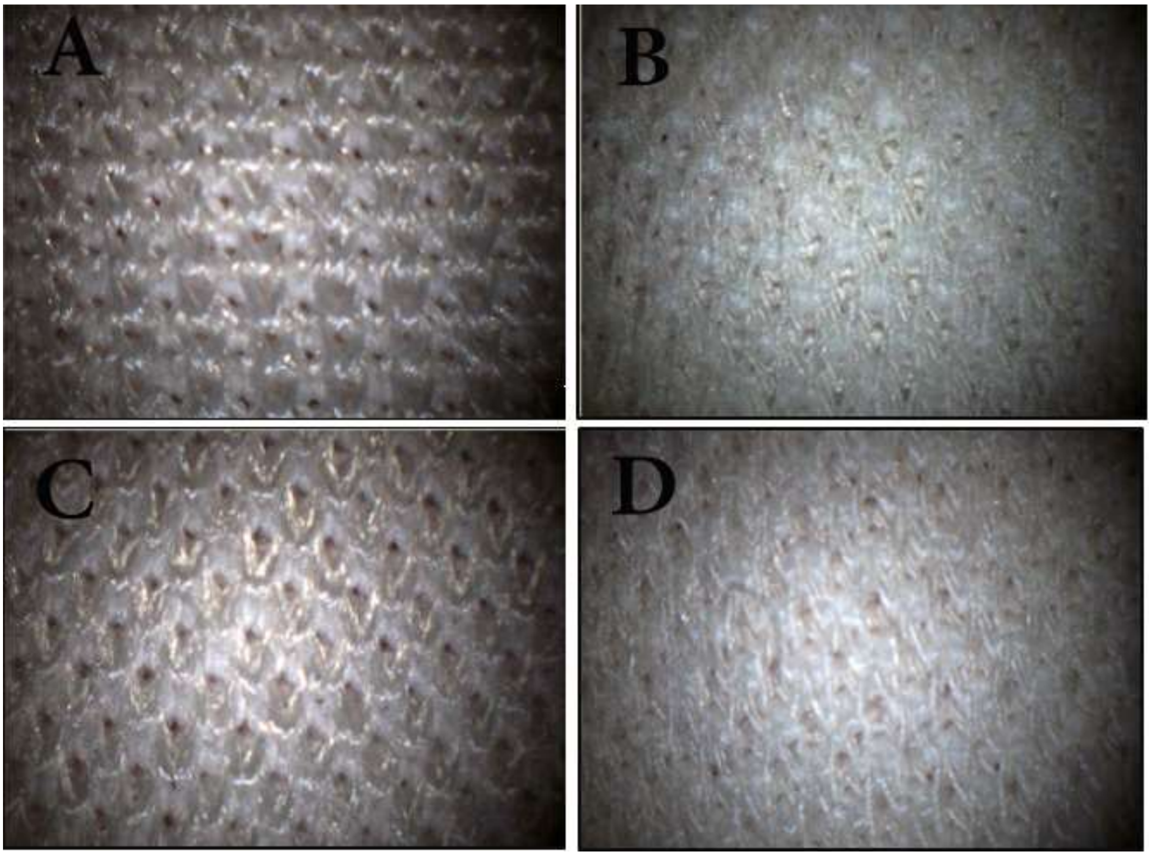


Figure 1: photo image of the bi-layer knitted fabric

a) face of Structure 1 b) back of Structure 1 c) face of Structure 2 d) back of Structure 2

3. Results and Discussion

3.1. Effect of produced fabric structure on weight and thickness

The effect of fabric structure on the both fabric weight and thickness are shown in

Table 4 and the data showed that, fabrics with structure 1 is heavier and thicker than fabrics with structure 2 which is due to the tuck stitch in the structure 2 which make accumulation of yarn in stitches at tucking laces, that make the fabric heavier in weight per unit area and thicker in thickness.

Furthermore, changing the yarn in feeders F1 and F4 for the fabric face from "polyester 75/35 + viscose 75/24" to "bamboo -cotton (70-30%) 30/1" led to increasing the weight of producing fabrics, that is due to bamboo -cotton (70-30%) is heavier than polyester 75/35 + viscose 75/24.

3.2. Effect of produced fabric structure on bursting strength

Fabrics' construction has an effect on fabrics' burst resistance which shown in **Figure 2**. The bursting strength of the samples with Structure 1 is higher than that of samples with Structure 2, because structure 1 consist of plain (knit) stitch which are diminishing the loop length compared with tuck stitch and held stitches, the form and diameter of plain stitches of tuck stitch. That is meaning that, structure 1 construction give samples a high strength, high dimension stability than structure 2.

In addition, for back materials, samples with cotton fibres have the highest value of bursting strength compared with other samples. Samples with bamboo-cotton (70-30%) have the lowest value of bursting strength, followed by modal and then bamboo-cotton (60-40%). The lower bursting strength of fabrics with bamboo fibres, due to the lower strength of bamboo fibres. [47] Furthermore, for face materials, samples with face Polyester 75/35 + viscose 75/24 are higher in bursting strength than samples with face bamboo-cotton (70/30) due to the lowest values in elongation at breaks of bamboo fibres than polyester fibres. [48]

3.3. Effect of produced fabric structure on air permeability

Fabrics' construction has an effect on fabrics air permeability which shown in

Figure 3. The air permeability of the samples with structure 2 is higher than the air permeability of the samples with structure 1, because structure 2 consist tuck stitch which is more porous and open than the knit stitch. This mean that structure 1 construction give samples high strength and high dimension stability than samples with structure 2.

Furthermore, for back materials, samples modal have the highest value of in air permeability compared with other samples. Samples with bamboo-cotton (60-40%) has the lowest value of air permeability, followed by samples cotton and then samples with bamboo-cotton (70-30%). In addition, for face materials, samples with face (polyester 75/35 + viscose 75/24) are is higher in air permeability than samples with bamboo-cotton (70/30) in face. So that, Air permeability of the fabrics was decreases due to increasing fibre hairiness. This increasing in hairiness resists the air flow and hence decreases the air permeability.

Table 4: Standards Test methods of the properties measured in this study

Code	F1, F4	F3, F6	F2, F5	Fabric structure	Thickness (mm)	Weight (g/m^2)
B1	polyester 75/35 + viscose 75/24"	polyester 75/144 + lycra 20 detex	Cotton 40/1	Structure 1	0.701	240.4
B2			Modal 40/1		0.710	243.6
B3			Bamboo-Cotton (40-60%) 40/1		0.717	245.8
B4			Bamboo-Cotton (70-30%) 40/1		0.721	255.1
F1			Cotton 40/1	Structure 2	0.785	247.8
F2			Modal 40/1		0.777	243.3
F3			Bamboo-Cotton (40-60%) 40/1		0.799	247.3
F4			Bamboo-Cotton (70-30%) 40/1		0.793	251.7
D1			Cotton 40/1	Structure 1	0.824	252.0
D2	bamboo -cotton (70-30%) 30/1		Modal 40/1		0.810	262.5
D3			Bamboo-Cotton (40-60%) 40/1		0.809	265.1
D4			Bamboo-Cotton (70-30%) 40/1		0.810	269.9
H1			Cotton 40/1	Structure 2	0.821	256.8
H2			Modal 40/1		0.810	269.5
H3			Bamboo-Cotton (40-60%) 40/1		0.831	268.6
H4			Bamboo-Cotton (70-30%) 40/1		0.841	272.6

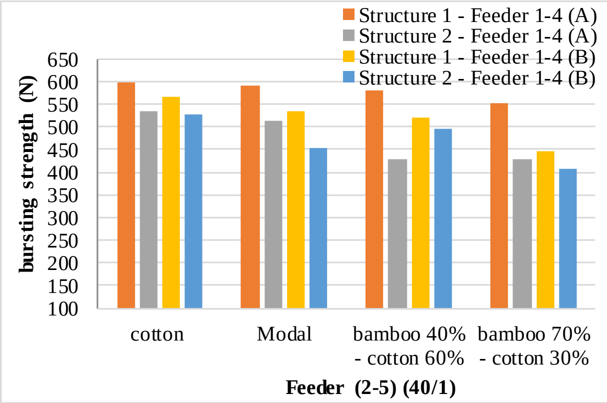


Figure 2: Influence of different weft knitting structures, face types and yarn materials on fabrics' bursting strength

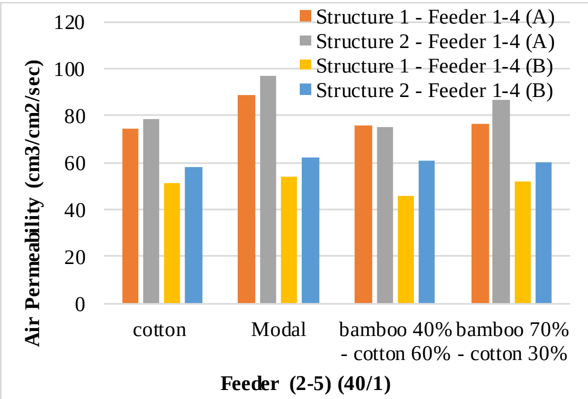


Figure 3: Influence of different weft knitting structures, face types and yarn materials on fabric s' air permeability

3.4. Effect of produced fabric structure on UV protection factor

Fabrics construction has an effect on fabrics UV protection factor, as shown in **Figure 4**, samples with structure 2 had the lowest rates of UV protection factor compared to samples with structure 1, because structure 2 consist of Tuck stitch which has more porous and open voids compared to knit stitch which make it less compacted and hence allow the free passage of UV radiation through the fabric compared to samples of structure 1.

On the other hand, for back materials, samples of cotton yarns have scored the highest values of UV protection factor compared with other samples, where samples with bamboo-cotton (70-30%) had the lowest values of UV protection factor, followed by sample of modal yarns and bamboo-cotton (60-40%). In addition, for face materials, samples face polyester 75/35 + viscose 75/24 were higher in UV protection factor than samples with face bamboo-cotton (70/30) due to higher in hairiness effect in face bamboo-cotton (70/30) than face with polyester 75/35 + viscose 75/24, resulting in spinning technique, which help in blocking the fabric voids and decrease the free passage of UV radiations through the fabric, compared to face with polyester 75/35 + viscose 75/24 which are filament yarns**.**

3.5. Effect of produced fabric structure on water vapour permeability

Fabrics' construction has an effect on fabrics' water vapour permeability which shown in **Figure 5**. The water vapour permeability of the samples with structure 2 is lower than the water vapour permeability samples with structure 1, because structure 2 consist of tuck stitch which make it heavier in weight per unit area and thicker in thickness. For face materials, samples with face polyester 75/35 + viscose 75/24 are higher in water vapour permeability than samples bamboo-cotton (70-30%) due to polyester 75/35 is a synthetic material which are filament and haven't hairiness and It absorbs little water vapour.

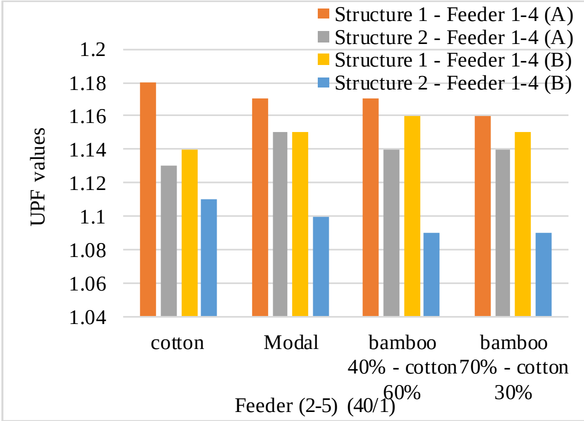


Figure 4: Influence of different weft knitting structures, face types and yarn materials on fabric s' UV protection factor

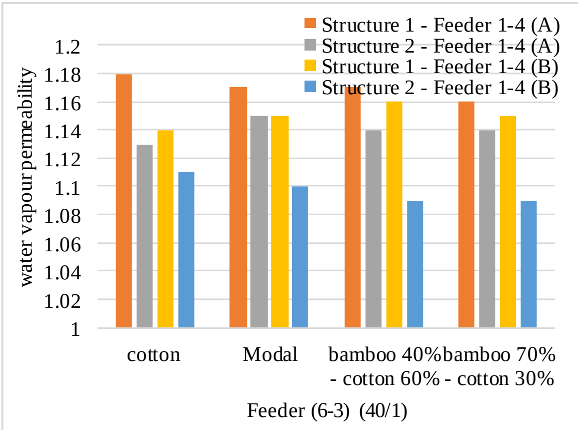


Figure 5: Influence of different weft knitting structures, face types and yarn materials on fabric s' water vapour permeability

3.6. Quality measurements

Quality was measured by radar chart as shown in **Figure 6** and **Figure 7**.

Quality Assessment of samples in the study was measured by using radar chart (**Figure 6**) which means comparing the spaces of Radar (**Figure 7**) which represents some physical and mechanical properties of each sample and that also determine its quality while using. By comparing the spaces of all samples, we arranged them from the largest space to the lowest one as in both diagram. It can conclude that, sample (D4) achieved the highest space of in the radar chart flowed by B2, B3, B4.

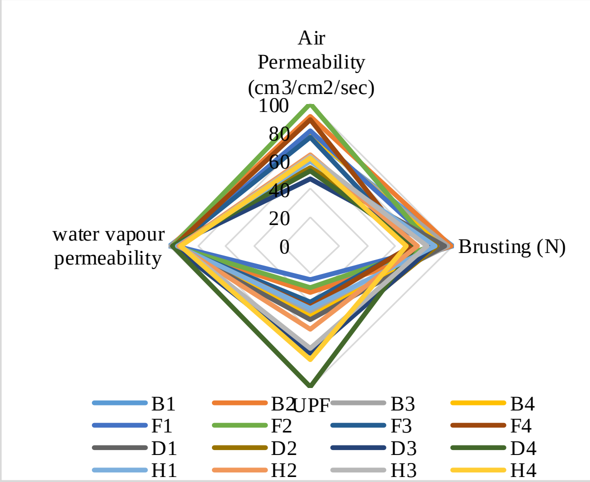


Figure 6: Influence of radar chart of fabrics properties

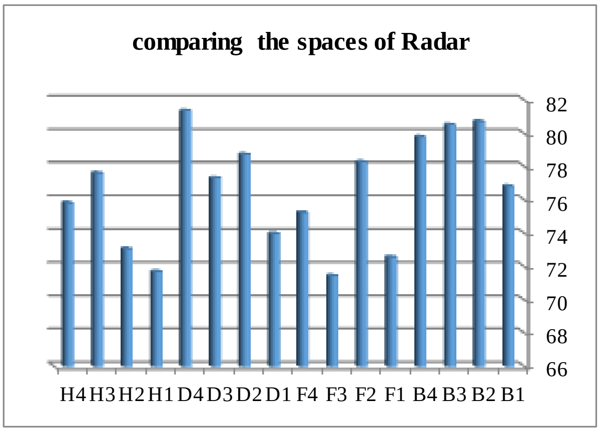


Figure 7: space radar effect of different fabrics properties

4. Conclusion

Effect of different fabrics' material on UV protection properties: bamboo fabrics gave better protection against UV radiations than cotton and modal fabrics. Knit fabric structure has the greatest influence in the UPF. Tuck stitches, although are generally associated with low UPFs, may have a positive or negative effect depending on how they are combined and repeated within the knit structure and positive effect for air permeability and negative effect bursting strength.

All samples have been found with UPF > 15, with six of them reaching UPF values above 40 (D2, D3, D4, H2, H3 and H4). This is because bamboo is used in different proportions between samples. By using one of these samples we can be pretty sure that the final knitwear will have a high UPF, taking into consideration that coloration and post-knitting wet treatments, like washing, will further increase the UPF. Sample (D4) achieved the best results among the research samples to produce UV-resistant sportswear fabrics.

5. Conflicts of interest

"There are no conflicts to declare".

6. Acknowledgments

The authors wish to express their great thanks to National Research Centre, Egypt, Faculty of Applied Arts, Helwan University, Egypt and Delta Jockey Industry for giving them the chance to complete this work and to have some new experiences.

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