

Characterisation of Interlock Knitted Fabric with Different Feed Patterns to Improve Thermal and Sensorial Comfort

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¹ National Textile University,
Faculty of Engineering & Technology,
Protective Textile Group,
Faisalabad, Pakistan

² BZU College of Textile Engineering,
Technical Textile Research Group,
Multan, Pakistan,
* e-mail: waqar.rajpout@bzu.edu.pk

³ NED University of Engineering and Technology,
Textile Engineering Department,
Karachi – 75270, Sindh, Pakistan

⁴ Technical University of Liberec,
Faculty of Textile Engineering,
Czech Republic

Abstract

This study reports an investigation of the effect of different cellulose materials and yarn feeding patterns on thermo-physiological comfort, sensorial comfort, serviceability/pilling and ultraviolet properties. An interlock structure with a combination of hydrophilic and hydrophobic material was developed in such a way that each material was prominent in consecutive wales or courses. The yarn feed pattern in interlock fabric overcomes the limitation of plaited single jersey fabrics. Cellulose – based hydrophilic natural and regenerated fibres were used i.e cotton, modal and viscose rayon, as well as hydrophobic synthetic fibre i.e. polyester for manufacturing fabric samples. By comparing the results, it became clear that wale-wise alternate yarns provide better overall moisture management properties than course-wise. Similarly, for fabric handle and pilling properties, wale-wise alternate yarn provides better properties. Interlock fabrics with the TransDRY® Technology effect are liable for use in protective textiles, medical textiles and in other functional textiles/children's clothing.

Key words: knitted fabric, interlock structure, comfort, feed pattern.

Introduction

Knitted fabric is mostly used for casual wear because of its comfort and easy wear properties. The need for innovative fabrics has rapidly increased in recent years, owing to their cost effectiveness along with good aesthetic and comfort properties. Weft knitted fabrics are widely used for undergarments, sportswear etc. as they are more flexible and cost-effective. Knitted fabric performance can be varied using different types of yarn and structures. The interlock structure was originally derived from rib but requires a special arrangement of needles that perform the knitting mechanism back-to-back in an alternate sequence. Interlock has the technical face of plain fabric on both sides, but its smooth surface cannot be stretched out to reveal the reverse meshed loop wales because the wales on each side are exactly opposite each other and are locked together [1]. It is a balanced, smooth, stable structure that lies flat without curling.

Abhijit Majumdar et. al. investigated the thermal properties of plain, rib and interlock knitted fabrics and concluded that the thermal conductivity and thermal

resistance values of interlock fabric was the maximum, followed by rib and plain fabrics, while the air permeability and water vapour permeability values were higher than for plain fabrics [2]. In another study Abhijit Maunder et al. studied the effect of bamboo, cotton and their blend on the comfort properties of interlock, rib and plain single knit. The thermal conductivity and thermal resistance values were higher for interlock than for the remaining structures [3]. In another study it was concluded that hydrophilic fibres, such as cellulose-based fibre, are good in terms of moisture absorption but poor with respect to moisture transport and release, due to the presence of hydrogen-bonding sites for water molecules. On the other hand, hydrophobic fibres, such as polyester, are poor in terms of moisture absorption but have a better chance to transport moisture because of few bonding sites for water [4]. Nida Oğlakcioğlu et al. investigated the thermal properties of cotton and polyester blended based single jersey, rib and interlock structures. Interlock and rib fabrics have a remarkably high thermal conductivity and thermal resistance value. On the other hand, single jersey fabrics have higher relative water vapour permeability values than 1 × 1 rib and interlock fabrics, and give a warmer feeling with lower thermal absorptivity values [5]. R. Fanguero, et al. studied plaited single jersey fabric with Outlast, coolmax, polypropylene and polyester for moisture management properties and concluded that polypropylene was the worst at moisture transfer but had better drying

capability [6]. Single knit plaited fabric has the ability to transfer moisture from the skin to the environment due to two types of yarns [7]. Similarly, H. Shabaz et al. investigated the single jersey plaited knitted structure using cotton and modal yarns on the face/top and polyester, micro-polyester yarns in the back/bottom layer for thermo-physiological comfort properties [8].

The literature shows that most of the research for improving comfort properties has been done on single jersey plaited knitted fabric. The basic aim of this study was to investigate the effect of the yarn feed pattern and material type on interlock fabric. In the present research, an attempt was made to develop Interlock fabrics with the trans dry effect using two types of yarn i.e. hydrophilic and hydrophobic yarn in alternate wales in the first case and then in the alternate course direction in the second case. Consequently, in this study interlock fabric was developed with different feed patterns of yarn to manage the comfort properties of knitted fabric. To further explore the properties, an investigation was made on handle properties. Besides these, serviceability and UV protection properties were also studied. Also, control samples were developed to compare the hybrid fabrics.

The interlock fabric structure is more stable and compact. Such fabrics do not curl at the edges nor ravel like single jersey fabric. The Interlock fabrics developed can be used for winter clothing and especially in sportswear shirts.

Materials

Cotton (C), modal (M) and viscose rayon (VR) were used as hydrophilic materials in the present study, while polyester(spun) (PET) yarn was used as hydrophobic materials. All the yarns had the same count i.e Ne 30 (19.7 tex). A total of eight samples were prepared, out of which two were control samples i.e 100% C and spun PET, while the remaining ones were with two different feed patterns, as shown in **Table 1**. Three samples were prepared in such a combination that three cellulose-based fibres i.e cotton (C), modal (M), and viscose (VR) were inserted in odd numbers of wales of the fabric, while polyester (PET) was inserted in even numbers of wales of the fabric, as shown in **Table 1.a**. The other three samples were prepared in such a combination that there was a complete course of hydrophilic yarns, while the next complete course was of hydrophilic yarn and so on, as shown in **Table 1.b**. All the fabrics were knitted on an interlock circular knitting machine of 26" diameter with an E of 20, Fukuhara Japan. After preparation of the samples, scouring, bleaching, washing and tumble drying were performed. Parameters like loop length and areal density were measured after conditioning these samples for 24 hours in atmospheric conditions, shown in **Table 2**. The measurements were taken with the samples in a wet relaxed state, as reported by Marmarali [9].

All the machine parameters/settings were kept constant for all samples developed by maintaining the stitch length at $0.32 \text{ cm} \pm 0.04$ and tightness factor at 14 ± 1 in all samples.

Testing

Thermo physiological comfort

Comfort is a basic requirement for human beings. During normal wear, the body generates insensible perspiration

Table 1. Yarn feed pattern.

	Feeders ⇔	1	2
	Tracks ↓	Hydrophilic yarn	Hydrophobic yarn
Dial	1	K	M
	2	M	K
Cylinder	1	M	K
	2	K	M

(a) 1x1 Feed pattern

	Feeders ⇔	1	2	3	4
	Tracks ↓	Hydrophilic yarn	Hydrophilic yarn	Hydrophobic yarn	Hydrophobic yarn
Dial	1	K	M	K	M
	2	M	K	M	K
Cylinder	1	M	K	M	K
	2	K	M	K	M

(b) 2x2 Feed pattern

continuously, creating steady heat and moisture vapour fluxes, which must be removed to maintain thermoregulation and a feeling of thermal comfort. The behaviour of clothing may be predicted by certain measurable fabric properties, including moisture transport, thermal insulation and air permeability.

The thermal insulation test was performed by measuring thermal resistance on a sweating guarded hot plate on a M259B/SDLATLAS according to standard test method ISO-11092. The mean and standard deviation were calculated for 3 readings of each sample. Thermal conductivity can be evaluated by the mathematical equation given below:

$$R(\text{m}^2\text{K}/\text{W}) = h/\lambda(\text{W}/\text{m}/\text{K}) \quad (1)$$

Where, R = thermal resistance
 h = thickness
 λ = thermal conductivity

An air permeability test was performed on an M021/SDLATLAS to find the rate of air flow through a known area of the fabric according to standard test method ASTM-D737. A pressure of 100 Pa was

applied on 20 cm^2 of fabric at a temperature of $20 \pm 2 \text{ }^\circ\text{C}$ and relative humidity of $65 \pm 4 \%$. The mean and SD of 10 repeats were calculated for each sock sample.

Moisture management values were measured on a moisture management tester – M210/SDLATLAS according to Standard AATCC 195-2009.

Tactile comfort/sensorial comfort

These properties are very important from a consumer prospective and are interconnected with the fabric surface and mechanical properties, commonly known as "fabric handle". When a person experiences mechanical interaction between the fabric and the body, a tactile sensation is felt. The complex concept of fabric handle may be defined as the interaction between simple attributes of fabric quality such as firmness, fullness, crispness, hardness, smoothness and sleekness.

Subjective evaluation had always been practiced before objective measurement technology appeared for fabric. The tactile comfort test was performed to find out the bending, compression and roughness of the fabric. A Fabric Touch Tester

Table 2. Fabric knitting parameters.

Sample ID	Hydrophilic material	Count, Ne	Hydrophobic material	Feed pattern	Arial density, g/m ²	Thickness, mm
1	Cotton	30/1	Polyester (spun)	1/1	266	1
2	Modal	30/1	Polyester (spun)	1/1	245	0.99
3	Viscose	30/1	Polyester (spun)	1/1	252	1.11
4	Cotton	30/1	Polyester (spun)	2/2	267	0.99
5	Viscose	30/1	Polyester (spun)	2/2	251	1
6	Modal	30/1	Polyester (spun)	2/2	271	1.1
7	Cotton	30/1	–	1/1	260	0.8
8	–	30/1	Polyester (spun)	1/1	265	1.5

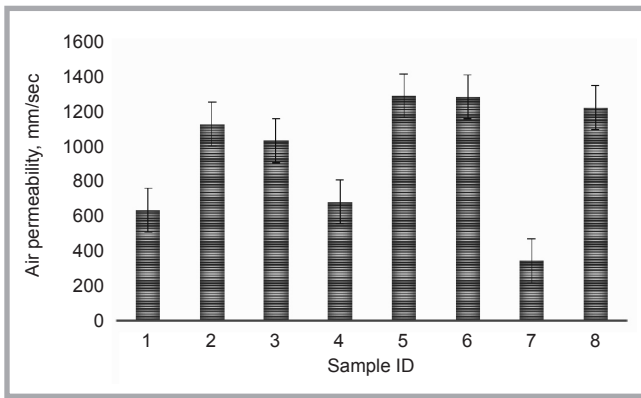


Figure 1. Air permeability of samples developed.

different materials in two different positions to get the trans dry effect.

Thermo-physiological comfort

Air permeability

The air permeability of a fabric is a measure of how well it allows the passage of air through it and is defined as the volume of air passed in. From Figure 1 it can be seen that control sample C, due to the natural fibre, has higher hairiness, which blocks the passage of air, as reported by other authors as well [10]; thus, it has the least AP value. While the control sample made of synthetic fibre PET has fewer protruding fibres, and hence the highest AP value. When C is used as hygroscopic yarn in combination with PET, the AP value is also less compared to M and VR, due to the reason mentioned before.

When we compared the effect of the feed pattern, it can be seen from Figure 1 that the AP value of samples [4-6] developed with the 2/2 feed pattern is higher than for the 1/1 feed pattern no matter which combination of material is used. As in feed pattern 1/1, hydrophilic and hydrophobic yarns were fed alternately on even and odd feeders, which signifies the pattern of wales in such a way that one complete wale was of hydrophilic yarn and the next of hydrophobic yarn, while in feed pattern 2/2 for two consecutive feeders hydrophilic yarn was used, and for the next two hydrophobic yarn was used, which formed the pattern of the complete course of the first material and the next course of the other material on the face as well as on the back of the fabric. Thus, due to the same material courses on both sides, gaps increase, which allow more passage of air. Voids containing a large volume of air have a significant effect on the air permeability property. P-values from ANOVA for

(FTT) of SDL ATLAS, was used to investigate tactile comfort. With this device the bending average rigidity (BAR) and compression average rigidity (CAR) were calculated.

Pilling

Pilling in fabric was measured by a Martindale Tester as per ASTM D-4970. This test method covers determination of the resistance to the formation of pills. The procedure is generally applicable to all types of fabrics. The resistance to pilling observed is reported using an arbitrary rating scale ranging from 5 to 1, with 5 being no pilling to 1 – very severe pilling.

Ultraviolet protection factor (UPF)

UPF testing was done to measure the amount of protection provided to skin by the fabric. This was evaluated using the AATCC-183:2004 standard in vitro method, and the machine used for

measuring the UPF value was a Double Beam UV/Visible Spectrophotometer M-550. 10 readings were taken for UPF and their average values determined.

Statistical analysis

Data were expressed as the mean \pm standard deviation. An analysis of variance (ANOVA) test was applied to determine the significance of the variables under study. ANOVA is best employed where more than two populations are compared. The effect of the feed pattern and fibre/material type on the thermo-physiological and sensorial comfort properties was investigated, where values less than 0.05 were considered as statistically significant.

Results and discussion

The main focus of this study was to compare the properties of fabrics made from

Table 3. P-values from ANOVA for the effect of variables on comfort properties. Note: P = Significant at 0.05 level.

Comfort properties	Air permeability, mm/sec.	Thermal resistance, m ² KW	Thermal conductivity, W/mk	OMMC	CAR	BAR
Feed pattern	0.125	0.157	0.139	0.013	0.969	0.266
Material type	0.027	0.001	0.006	0.001	0.018	0.019

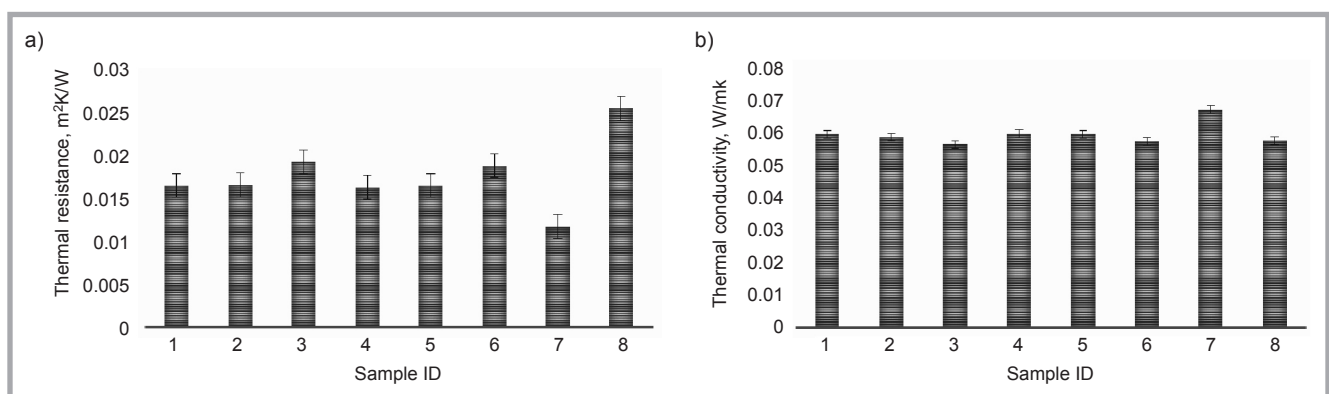


Figure 2. a) Thermal resistance of samples developed, b) Thermal conductivity of samples developed.

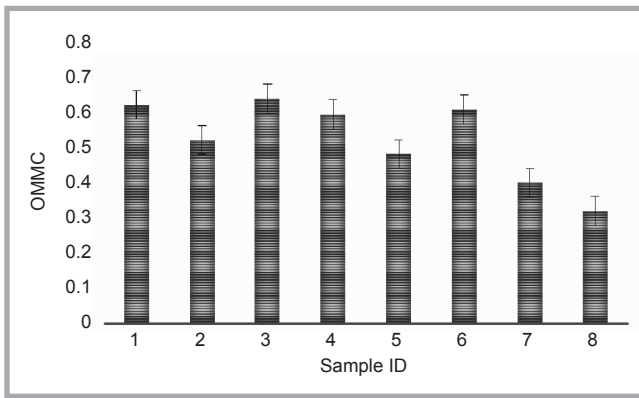


Figure 3. Overall moisture management capacity of samples developed.

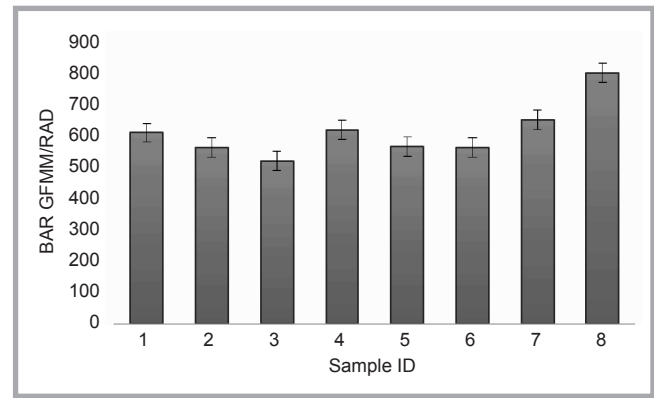


Figure 4. BAR of samples developed.

the effect of feed patterns and material type are shown in **Table 3**, which clearly shows that material type has a significant effect on air permeability.

Thermal properties

Thermal resistance is an intrinsic property of textile material, being a measure of the insulation value and reciprocal of thermal conductivity. Thermal conductivity represents the transfer of heat, which is mainly dependent on the fabric structure and conductivity of fibre. The greatest determinant of fabric conductivity is the entrapped air, which is still air with the lowest thermal conductivity value compared to all fibres ($\lambda_{air} = 0.025$) [11]. The thermal conductivity of the control sample made from 100% C is the highest and that of the 100% PET (staple) sample the least due to the fibre conductivity value [12]. Overall, there was not a significant effect of the feed pattern on the thermal resistance properties as the clogging of pores was almost same. The difference within the same feed pattern is in values due to the fibre effect, as confirmed in **Table 4**, where only the effect of material type on thermal properties was statistically significant at 95% confidence intervals.

Moisture management test

The results obtained from the moisture management test (MMT) are presented in **Figure 3**. It can be seen that fibre type also affects moisture management properties. 100% C and PET both have a lower OMMC value than all other samples. By using hydrophilic and hydrophobic material together, it helps to reduce the absorbent capacity of hydrophilic fibre and moves moisture away from the body due to the hydrophobic content, which is the requirement the trans dry effect.

VR/PET shows the highest value as VR has a higher moisture regain, as a result of which its ability to take moisture is the highest; and due to the wicking effect PET has good moisture transfer. The combination of viscose and polyester lets the moisture spread quickly rather than accumulating at one point.

It can be seen that the feed pattern has a significant effect on OMMC values. The 1/1 feed pattern shows higher OMMC values than the 2/2 feed pattern, which is due to complete courses of same materials creating more gaps and allowing more passage of air, which leads to lower moisture management properties i.e. increased wetting time, decreased absorption rate and spreading speed, and max. wetted radius, which have been attributed to higher air permeability by other researchers as well (4).

The main reason behind this could be that there are comparatively more connecting points between hydrophilic and hydrophobic yarns in the 1/1 feed pattern as both are exactly opposite each other i.e. in the back wale, which means that it provides faster wicking action. It can be concluded that when hydrophilic and hydrophobic materials are used alternately in the interlock structure, it provides better moisture management/trans dry properties irrespective of the material type. The samples are in the good (0.4-0.6) and very good grade range (0.6-0.8) as per Yom. B et.al [13]. From **Table 4**, it can be seen that both the feed pattern and material type affect OMMC values significantly.

Tactile comfort

Fabric handle is gaining increasing attention in the textile and clothing industry.

However, a lot of fabric parameters affect handle properties.

Bending average rigidity (BAR)

Stiffness describes fabric resistance against bending. Stiffness is related to the bending property. It is a measure of how easily a fabric can be bent. The bending behaviour of material is expressed in terms bending rigidity, which is very important in apparel where body parts bend, like the knee, elbow, sleeves etc. Bending at low stress is more important because it has a direct relationship and greater association with fabric handle. The higher the rigidity, the lower the fabric handle value. FTT measures the moment or work needed to bend one radian of the sample, which means the more work or moment needed to bend the sample, the stiffer the fabric is.

From **Figure 4**, among the hybrid fabrics it can be seen that C/PET has a higher BAR value while cotton has the highest modulus among the other hydrophilic fibres, which resists fabric bending.

The 2/2 feed pattern has higher bending rigidity (BAR) as compared to the 1/1 feed pattern, because in the 2/2 feed pattern's porosity is reduced due to the complete course, as mentioned before, which results in low bending and vice versa. In the 2/2 feed pattern there is an overall high areal weight, which means more force is required to bend it; and hence a higher BAR.

Compression average rigidity (CAR)

The compressional property of fabric handle is closely related to fabric, i.e., the softness and fullness of the fabric, and also to the fabric surface smoothness [14]. This property is dependent upon the

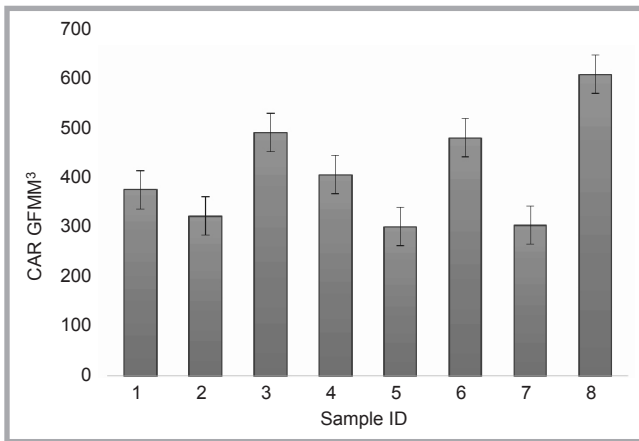


Figure 5. Compression average rigidity (CAR) of samples developed.

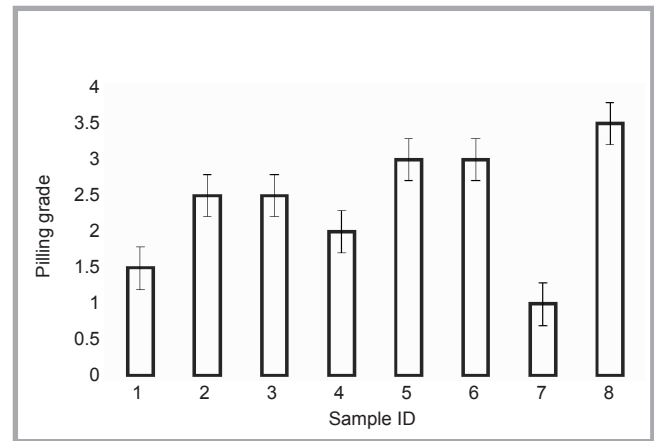


Figure 6. Pilling grade of samples developed.

springy feature of the fabric. Springy behaviour stimulates a fullness and softness sensation of touch.

From **Figure 5**, it can be seen that M/PET samples have the lowest compression average rigidity values, which means that it is the softest/most compressible of all samples and could be compressed with minimum force, while the V/PET shows the highest values, leading to the interpretation of it being a comparatively harsh fabric. Overall, 100% PET has the highest value because it has a rigid hand feel.

In the 2/2 feed pattern, due to the high areal weight, CAR values are higher compared to the 1x1 feed pattern; but overall this effect is not significant.

The beauty of interlock is that it has both sides exactly the same. Therefore, the values of sensorial comfort is same for both sides. The p-values in **Table 4** show that material type has a significant effect on both sensorial comfort properties studied (p-value < 0.05).

Table 4. UPF of samples developed.

Sample code	UPF
1	25.4
2	23.5
3	22.6
4	23.9
5	27.2
6	22.4
7	34
8	45

Pilling

Fabric pilling is a serious problem for the apparel industry. Pilling in a fabric is caused by protruding fibre entanglement. Hairiness plays an important role in the formation of pilling. There are some factors which cause to produce hairiness, such as if there are a large number of short fibres, then they will not be tightly bound to the yarn surface, leading to an increase in fibre migration toward the surface. Once fibres accumulate on the surface of the yarn, then it is easier for them to become entangled with each other to form pill. From **Figure 6** it can be seen that, due to the hairiness of cotton, it has severe pilling as compared to the others, where pure polyester fabric has the lowest. The 2 × 2 feed pattern has the higher pilling resistance due to greater porosity, as pilling tendency is greatly affected by pore size and porosity. Additionally, the results display that an increase in the weight of samples increases the resistance to pilling, as concluded by other researchers [15]. It was observed that pilling resistances were the same (2-3, from moderate to severe pilling) for all fabric types tested.

Ultra violet protection factor

The ultraviolet protection factor (UPF) is computed as the ratio of the ultraviolet radiation (UV-R) irradiance at the detector with no specimen to the UV-R irradiance at the detector with a specimen present.

From the **Table 4** it can be seen that all the samples are in a good range of protection as UPF values are in the range of 22-30 (UV class = good when UPF values are between 15-24; UV class = very good when UPF values are between 25 and 39)

[16]. The PET control sample shows the best results and can be used for different applications. PET and blends of polyester with other fibres can be used for good UV blocking applications, which are important when long sun exposure work is required.

Conclusions

In this study, thermo-physiological comfort, sensorial comfort, serviceability and ultraviolet protection properties were studied for interlock fabrics produced using different combinations of hydrophilic and hydrophobic materials.

The moisture transport property is important for active wear fabric as it decides the comfort level thereof. From this study, it is clear that the moisture management properties of interlock fabrics basically depend upon the properties of the materials from which they are made. In this study, viscose rayon and modal in combination with spun polyester represented the highest OMMC values. The combination of synthetic and regenerated fibres proved to be the best for moisture management properties. It keeps you cooler and drier and removes odours. The yarn feeding effect was also studied in this investigation, which showed that in the 1x1 feed pattern, due to the trans dry effect, both materials come in contact with the skin, which does not let the moisture accumulate in one place; instead it spreads the liquid rapidly by faster wicking action. Furthermore, fabric handle properties are also better in the 1x1 feed pattern, which is important for tactile comfort. Fabric serviceability i.e pilling is also good for the 1 × 1 feed pattern. Besides this, the comfort and UV properties were

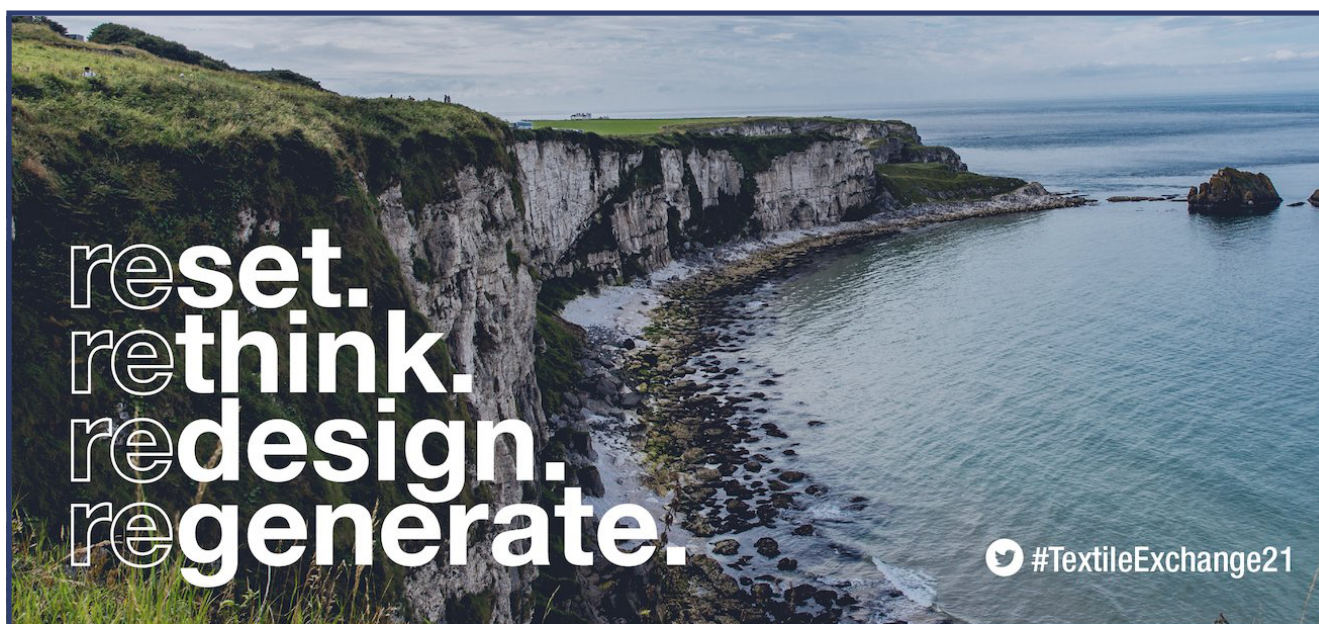
also studied, where all the fabrics were in a good range. Thus, overall the 1×1 feed pattern is better than the 2×2 feed pattern. While for w.r.t materials, OMMC, BAR and CAR, V/PET is best among all the hybrid samples developed. Due to the 95% confidence interval, a material type with $p < 0.05$ values indicates that the effect of it on all the comfort properties is statistically significant.

It is concluded from the results of the tests applied that the feeding pattern and material have a significant effect on the properties of the fabrics. An attempt was made to understand the effect of the material and feeding pattern to develop a comfortable interlock fabric for children suiting, ladies fashion clothing, men's casual wear, and modern knitted fashion articles.

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