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Some Comfort Properties of Spacer Fabrics from Recycled and Umorfil Polyamide Fibers for Sportswear Applications

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ABSTRACT

Sportswear, the clothing including footwear, worn during sports or physical exercise, has an increasing demand and the sports apparel with improved comfort properties have become more popular than ever. Enhancing the wearer's comfort is possible by engineering fabric structures by incorporating suitable fibers. For doing so, in this study, bilayered spacer fabric samples were produced from sustainable fibers namely, recycled PA66 and PA6-Umorfil yarns, together with 44 dtex elastane. A PA6 FDY monofilament yarn was employed as the spacer yarn. The results showed that comfort properties of sports apparel can be improved by using recycled and Umorfil poliamide fibers in different parts of the garments depending on the intended use and purposes. Use of such sustainable fibers in the fabric structure is not only suitable for achieving active sportswear comfort but also is respectful to the environment.

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Knitted spacer fabric, Umorfil, recycled PA, Comfort, Sustainable fiber

1. INTRODUCTION

Textiles have been used for centuries to meet apparel and domestic needs. Conventional textiles are used for common applications and decorative or aesthetic purposes. Technical Textile, on the other hand, is the term which refer to technical and high-performance, high-added-value products for particular end-use rather than conventional ones [1,2]. Sports textiles are a sub-branch of technical textiles and also one of the high-performance apparel used to protect the human body during sports. Sports clothing, particularly the base layer of the garments which are next to the skin, are important for providing the thermo-physiological comfort of a person and for keeping their performance high [3,4]. In all kinds of sports, which mainly are winter sports, summer sports, outdoor games, indoor games, football, cricket, climbing, cycling, flying and sailing sports, athletics, etc, several textile materials are used having different functionalities [5].

Users' main problems when using sportswear are considered as sweating, feeling hot during exercise, low stretching ability, extra weight of the fabric, injuries during falling, excessive movements, hard contact with the ground [3, 5, 6]. Depending on the type of the sports activity, the human body produces about half to one liter of sweat per hour. Sportswear apparel is expected to absorb and simultaneously disperse heat and moisture to achieve a high level of comfort [7]. Major performance requirements for sportswear are listed as follows:

- High comfort properties, easy to wear, good handling,
- Good thermal properties; cool in summer, warm in winter,
- Lightweight, high elasticity, good compressibility, movement freedom,
- Good moisture management, remove and distribute the moisture from the body and quick dry,
- High perspiration fastness, high strength and durability, good abrasion resistance,
- Easy-care
- Good skin-care; protect skin from UVA, UVB, anti-bacterial, and gentle feeling to skin.

Both natural (e.g. cotton, wool) and man-made fibers (widely polyester and, nylon, acrylic, elastane) are used in sportswear and a wide variety of woven, knitted and nonwoven fabrics are commercially available. These

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fabrics' performance vary depending on the entrapped air, pore shape and size, volume and surface properties, etc. Hence, knitted fabrics are widely preferred for sportswear since they have more elasticity and stretching properties compared to woven ones, providing vast freedom of movement. In general, sportswear fabrics are made from single-layer knitted fabrics.

There are studies which focus on moisture related comfort properties of single layered fabrics, in the form of plain jersey, plaited jersey, single pique, honeycomb, from natural, synthetic and regenerated fibers [8, 9,10, 11]. Çeven and Günaydın also studied the comfort and mechanical properties of single jersey fabrics from various regenerated cellulosic fibres, among which Umorfil fiber took place [12]. They observed that the knitted fabrics made of Umorfil® yarns indicated the lowest thermal conductivity and provided the maximum air permeability.

Knitted fabrics made of cotton are considered comfortable when used under normal conditions while the ones from polyester, nylon, polypropylene and acrylic are suitable for strenuous activities because they do not retain moisture and therefore do not get heavy upon sweating like cotton does. Besides polyester, which is popular and commonly used in active wear and sportswear, nylon is also often used in sportswear because it is durable and easy to care for, dries quickly and, does not hold onto sweat or odor. Nylon, being a lightweight fiber, is an ideal option to stay comfortable and cool under hot weather conditions. These characteristics of nylon fibre make it preferable to be used in sportswear applications. [13,14]. Developments in synthetic fibre processing have opened up broad possibilities for their use in sportswear and speciality nylon fibres such as Hygra fibre, which is a core-sheath type of filament yarn composed of a water absorbing polymer and nylon, Killat N (from Kanebo Ltd.) a nylon hollow filament, Naiva yarn which is composed of 55% Eval and 45% nylon have been engineered [15]. Recycled nylon is also a preferred fiber in the production of sportswear. The reduced energy consumption for the production of the fibre, the reduced dependence on oil and the possibility of recycling the final product at the end of its life are the main benefits of recycling nylon [16]. Protection of skin against bacteria, and gentle feeling to skin also offer a high level of comfort and personal hygiene during sports activities. Umorfil N6U is a new generation sustainable protein fiber that is obtained by integrating the purified collagen peptide (amino acid) from waste fish scales with regular nylon 6 polymerization technology. The bionic nylon fiber is claimed to have better moisture regain in comparison to regular nylon, in addition to some other properties such as good hand-feeling with deep dyeable features, natural cooling effect, anti-UV function, and skin friendliness [17].

Spacer fabrics comprise two layers that are joined together and kept apart by a spacer yarn which is mostly monofilament. The distant placing of the outer surfaces creates a ventilated layer that results in good moisture and thermal performance. Spacer fabrics also provide an advantage of having low weight in proportion to their large volume [18]. The unique structure of spacer fabrics fulfills the expectations from sportswear by offering good thermal and moisture management properties as well as lightweight, high elasticity, good compressibility.

In order to meet so many aforementioned features expected from sportswear, the right fiber and structure choice such as layered (bi-layer and/or tri-layer) fabrics, is of utmost importance. In Table 1, a summary of the studies that focused on comfort properties of layered structures, namely knitted spacer fabrics, is presented.

As the literature survey suggests (Table 1), there is lack of study on multi-layered knitted structures from sustainable synthetic fibers such as recycled and Umorfil Nylon for sportswear though spacer fabrics have the potential to meet the main performance requirements for sportswear. Accordingly, the work under discussion aimed to investigate the effect of recycled and Umorfil nylon fibers in the design and development of spacer fabrics for sportswear applications.

2. MATERIAL AND METHOD

2.1 Material

78/60x1 dtex, S and Z twisted, Recycled-PA66 textured yarn (P), which was obtained from Fulgar with the relevant traceability certifications, and 78/72 dtex, and S and Z twisted, Umorfil PA6 (N6U) textured yarn (U) were used for knitting either both or one side of the spacer samples. In order to prevent the spirality problem, one S and one Z twisted yarn was placed onto the knitting machine creel consecutively. A 22/1 dtex PA6 FDY monofilament yarn was employed as the spacer yarn and a 44 dtex elastane was used while knitting front and back sides of the samples. Based on the preliminary works of the study, elastane yarn was introduced to the samples not only to facilitate efficient knitting process but also to enhance dimensional stability of the spacer fabrics. The fabric samples produced are composed of 72% recycled PA or Umorfil PA, 22% elastane, and 6% PA monofilament.

2.2 Method

The samples were produced on a Mayer & Cie Relanit 28 fine circular interlock knitting machine that is 30 inches in diameter and is equipped with 92 feeders. During the production, 90 systems were used such that 30 feeding systems were reserved for front yarns, 30 systems were employed for back and elastane yarns and finally 30 systems were used for the spacer yarn. The stitch notation of the samples is given in Figure 1.

Table 1. Studies on comfort properties of knitted spacer fabrics

Reference	Weft Spacer Fabric	Warp Spacer Fabric	Fiber Types	Air Permeability	WVP*	Drying Rate	Wicking/Wetting/ MMT	Thermal Properties
[19]		✔	Polyester (PET), meta-aramide	✔	✔			✔
[20]	✔		Polypropylene (PP), PET, viscose				✔	✔
[21]	✔		Cotton, Bamboo, high performance fiber	✔	✔			✔
[22]	✔		PET, Poliamide, Polypropylene micro filaments, soy fiber, cotton	✔	✔			✔
[23]	✔		PET	✔	✔			✔
[24]		✔	PP, PET	✔	✔			✔
[25]	✔		PET	✔	✔			✔
[26]		✔	PET, cotton, elastane			✔	✔	
[27]		✔	PET	✔	✔			✔
[28]		✔	PET		✔			
[29]	✔		Viscose, modal, bamboo, PP, micro-fiber PET and PET				✔	
[30]	✔		PET, PP, Cotton				✔	
[31]	✔		PET, PP, Cotton	✔	✔			✔
Current work	✔		Recycled PA, Umorfil	✔	✔	✔	✔	

* Water Vapour Permeability

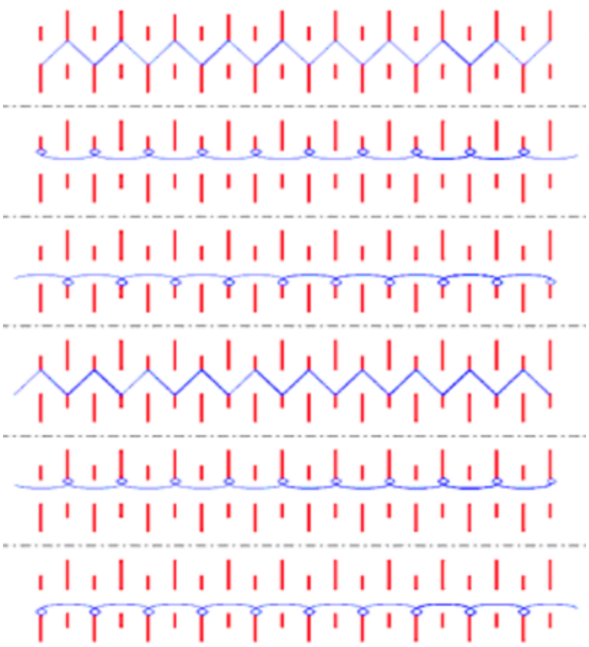

Figure 1. Stitch notation of the samples (adapted from [32])

The Recycled-PA66 textured yarn and the N6U-Umorfil textured yarn were used on both sides of the spacer samples or only on one of the sides (Table 2).

The samples were pre-washed, heat set and dyed under the following commercial conditions:

- Washing at 80 °C with wetting agents.
- Heat-setting in 10 chambers stenter machine at 90 °C for 45 sec.
- Dying in Beam Dyeing Machine at 102 °C for both Umorfil and Recycled-PA66 dyeing process.

All the tests, both for the greige and dyed fabrics, were conducted after conditioning the samples under standard atmospheric conditions (20 °C ±2, 65 % ±5%).

Coding of the samples are given in Table 2 where;

P, U, G, and D are for the recycled PA66 textured yarn, the PA6-Umorfil textured yarn, the greige fabrics, and the dyed fabrics, respectively.

Yarn count, breaking force and elongation of the yarns were tested in accordance with ISO 2060 and ISO 2062 standards, respectively. Course and wale densities were measured with a counting glass as described in TS EN 14971. Weight of the fabrics were determined according to TS EN 12127 standard. Thickness measurements were taken under a pressure of 20 g/cm^2 using R&B Cloth Thickness Tester according to ISO 5084.

When it comes to the fabric bulk density, it was calculated using equation 1 [33]. The porosity of the spacer samples was determined according to the equation 2. For the calculations, the density of the fibers employed i.e. PA, Recyled PA 66 and Umorfil PA were taken as 1,14 g/cm^3, elastane density 1,3 g/cm^3.

Table 2. Coding of the samples

Fiber Content	Greige Fabric	Dyed Fabric	Explanation
Recycled-PA66/ Recycled -PA66	PPG	PPD	Both sides of the spacer are from Recycled-PA66 yarn.
Umorfil / Umorfil	UUG	UUD	Both sides of the spacer are from Umorfil yarn.
Recycled -PA66 / Umorfil	PUG	PUD	One side of the spacer is from Recycled-PA66 yarn and the other side is from Umorfil. The front side is considered as the Recycled-PA66 side.
Umorfil / Recycled -PA66	UPG	UPD	One side of the spacer is from Recycled-PA66 yarn and the other side is from Umorfil. The front side is considered as the Umorfil side.

Bulk density (g/cm^3) = Areal density (g/m^2) /Thickness (t) (1)

Porosity (%) = [1-Fabric density (g/cm^3) /Filament density (g/cm^3)] x 100 (2)

Air and water vapor permeability tests were carried out on a 20 cm^2 test area with 200 Pa pressure according to ISO 9237 and according to BS 7209:1990 standards, respectively. During the water vapor and air permeability tests, for the PU samples, the fabric layer from Recyled PA66 was considered as the outer side whereas the layer from Umorfil was considered as the inner side of the structure. While testing the UP samples, the fabric sides were reversed.

The vertical wicking tests were applied in both course and wale directions. For the tests, 5 mm of the samples (25 mm x 200 mm) were immersed in distilled water and the rising height of the water on each side of fabric is recorded after 1 min, 5 min, 10 min, 15 min, 20 min, 25 min, and 30 minutes.

So far as evaluating transverse (lateral) wicking behavior is concerned, Sampath et al.'s approach was employed such that each sample of 10 cm diameter was mounted on an embroidery frame and 1 ml of water was dropped on the fabric surfaces with the help of a burette placed 6 mm above the surface of the fabric to measure the spreading area [34].

Contact angle of all the samples were measured using Cam 101 contact angle goniometer (KSV INSTRUMENTS). To determine the drying rate of the fabrics, similar method used by Coplan and Fourt et al. has been used [35,36].

As a final note, the analysis of variance (one way ANOVA) was used to determine the significance of the yarn combination and moisture related comfort qualities at a 95% confidence level by using IBM SPSS (Version 28) Statistical software package.

3. RESULTS AND DISCUSSION

The tested properties of the yarns and fabrics are given in Tables 3 and 4.

As may be seen in Table 3, the yarns used for knitting both layers of the spacer structure were of the same yarn count and had similar tenacity properties which means that all the samples can be knitted using the same knitting parameters.

Table 3. Yarn Properties

Yarn Type	Yarn Count dtex-(CV%)	Tenacity cN/Tex-(CV%)	Elongation %-(CV%)
Recycled-PA66 S	76-(1)	37-(3)	30,76-(9)
Recycled-PA66 Z	77-(1)	35-(2)	29,63-(6)
Umorfil-PA6 Z	76-(1)	38-(3)	39,57-(6)
Umorfil-PA6 S	77-(1)	37-(3)	31,15-(4)
Monofilament PA6	19-(3)	38-(5)	51,28-(17)
Lycra	44	-	-

Table 4. Fabric properties

Samples	Course Density (courses/cm)	Wale Density (wales/cm)	Stitch Density (loops/cm^2)	Weight (g/m^2)	Thickness (mm)	Bulk density (g/cm^3)	Porosity (%)
PUG	21,6	41	902,9	404	1,36	0,293	60
UPG	21,6	41	902,0	404	1,36	0,293	60
UUG	21,8	41	902,9	405	1,34	0,298	60
PPG	22,2	41	915,8	391	1,35	0,291	60
PUD	**21,7**	**32,8**	**711,8**	**347**	**0,69**	**0,508**	**42**
UPD	**21,7**	**32,8**	**711,8**	**347**	**0,69**	**0,508**	**42**
UUD	**21,6**	**32,0**	**682,4**	**335**	**0,68**	**0,490**	**42**
PPD	**21,7**	**31,6**	**694,5**	**346**	**0,65**	**0,536**	**40**

A comparative study of greige and dyed fabric properties showed that stitch density, weight and thickness of the samples significantly decreased after the finishing and dying processes (Table 4). This is mainly due to the stentering process which is used to fix the dimensions of the samples. Accordingly, bulk density of the samples, being the measure of fabric weight per unit volume, increased and in turn influenced the porosity values of the dyed samples. The t-test analysis conducted for the bulk density and porosity values of each fabric group (i.e. the greige and dyed samples) revealed that there is no statistically significant difference in 95% confidence limit among the samples. This enabled the comparative study of the influence of fiber type on moisture related properties of the samples.

Air Permeability

Air permeability of the samples are presented in Figure 2.

Generally speaking, fabrics' comfort properties are determined by the air circulation between the inter-yarn voids to greater extent, and accordingly the yarn type has a significant impact on how permeable a fabric is to air. As may be seen from Figure 2, irrespective of greige or dyed, the samples having Umorfil layers on both sides had the highest air permeability performance. The finer filaments in the Umorfil yarns may result in more inter-yarn voids that in turn influence the air flow through these pores. One way ANOVA test conducted to investigate the effect of yarn type on air permeability did confirm that irrespective of the processes applied,the air permeability performance of the samples are significantly effected by the yarn type employed for the work (Table 5).

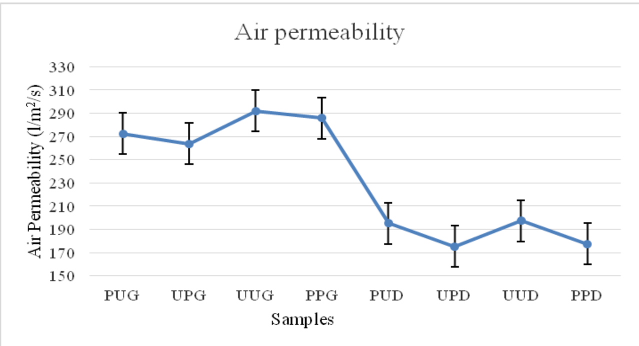

Figure 2. Air permeability of samples

The fabric's air permeability is also highly influenced by the fabric weight, porosity, and thickness. The results (Figure 2) showed that the air permeability of the greige samples was recorded to be higher than that of the dyed ones, which might be due to their higher porosity and lower density values. The air permeability performance of the dyed samples, however, markedly dropped despite the fact that they are much thinner than the corresponding greige ones (Table 4 and Figure 2).

Finally, for both the greige and dyed samples, the layer facing the air flow appears to determine the air permeability of the spacer structure. When the Umorfil layer (i.e. PU samples) faced the air flow during testing, slightly higher air permeability values were displayed than the ones for UP samples. This result is also compatible with the findings of Çeven & Günaydın who found that the dyed Umorfil sample in their study provided the highest air permeability while this was not the case for the greige ones [11]. Thus, it might be suggested that the fabric layer from Umorfil can be used as the outer side in a sportswear clothing to contribute its comfort properties.

Water Vapour Permeability

Water vapour permeability of the samples are presented in Table 6. As is well known, since the water vapor permeability is an indication of the ability of fabrics to transfer water vapour from the skin to the outer surface, it is regarded as one of the most important moisture related comfort properties. And the better WVP, the higher wearer's comfort is. As may be seen from table 6, the dyed samples demonstrated higher WVP performance than the greige ones did, and among all of the fabrics the PUD sample gave the highest WVP. A comparative study of the WVP results of the dyed samples with their air permeability ones depicted an opposite behaviour such that the air permeability of the dyed samples is much lower than that of the greige ones (Figure 2). Unlike water vapor that diffuses through not only the air spaces among the yarns but also through the structure of the fibres via free convection, air permeability takes place in the form of forced convection and hence the relatively higher porosity of the greige fabrics may have been good for air transport in these fabrics.

Table 5. One-Way ANOVA results for Air Permeability

	Sum of Squares	df	Mean Square	F	Sig.*
Between Groups	73087,218	6	12181,203	35,714	0,000
Within Groups	9550,210	28	341,079		
Total	82637,428	34			

*p value for 95 % significance ≤ 0.05

Table 6. Water Vapor Permeability results

Samples	Water Vapor Permeability (g/m^2/day)
PUG	5119
UPG	5211
UUG	4903
PPG	5161
PUD	**6100**
UPD	**5406**
UUD	**5594**
PPD	**5556**

Water vapour transmission depends on the moisture absorption capacity and hygroscopic properties of the constituent fibres [37]. Umorfil® N6U is a bionic nylon fiber with higher moisture regain in comparison to regular nylon fibers. The differences in moisture absorption capacity of the fibers are expected to influence the water vapour permeability of the samples. For the greige fabrics, the lowest water vapour transmission was recorded for the UU fabrics whereas for the dyed ones the UPD sample showed the lowest performance. Mishra et. al claimed that the main points of water vapour permeability results were the wetting and wicking properties of fiber type and there were no correlation between air permeability and water vapour permeability [38]. Rajan et. al stated in their study that WVP behaviour of spacer fabrics was correlated with wicking behaviour [28]. In that respect, the WVP of the Umorfil samples that had the highest and faster wicking behavior, appeared to be in aggrement with the findings of the literature. Finally, irrespective of the processes applied on the fabrics (e.g. dying) one way ANOVA analysis showed that yarn type was an effective factor on water vapour permeability for the samples.

Vertical Wicking

Vertical wicking performance of the samples in coursewise and walewise directions are given in Figure 3 and 4, respectively. As may be seen from the figures, the wicking height for all of the samples increased sharply until the end of 20 minutes, which slightly decelerated for the last 10 minutes of the test. The data given in Figure 3 and 4 shows that independent of the testing direction, the wicking heights measured from the greige samples have been higher, when compared to those from the dyed samples. This might be due to the higher porosity, thickness and lower bulk density of the greige samples. Also, as far as the greige samples are concerned, the horizontal placement of spacer yarn, i.e. PA6 monofilament, in the middle layer appears to be influencial on the coursewise wicking performance in particular. The results also revealed that the dyed samples depicted higher wicking rates in the walewise direction, though such a tendency was not observed for the greige ones. This may suggest that the stentering (or heat-setting) as well as dyeing process, could generate more continual and less torturous pore paths in the samples which in turn caused higher capillarity in the dyed samples.

The results obtained for the samples reflected the contribution of fiber properties to the wicking behavior of the fabrics such that irrespective of the test direction, the UU fabrics, having Umorfil PA6 on both layers had the highest wicking performance, whereas the PP samples presented the lowest one. Also the PU and UP samples, layers of which were knitted from r-PA66 and Umorfil PA6, consistently showed higher wicking heights on their layers containing Umorfil PA6. The samples in which both the front and back side of the fabric is made of the same fibre, the wicking heights are comparable for both sides. During wicking, water flows through inter-fiber spaces in the yarn by the interfacial tension between the liquid and the fiber surfaces. So, the rate of wicking not only depends on the spaces among the fibers in the yarn and but also on the surface energy of the fiber [34]. Higher number of filaments in the Umorfil yarns might have resulted in higher capilarity in the yarn structure. Also, Umorfil fibers seem to contribute to vertical wicking performance due to its inherent properties. One way ANOVA analysis also demonstrated that the fiber type was statistically significant factor on vertical wicking ability of the samples (Table 8).

Table 7. One-Way ANOVA results for Water Vapour Permeability

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3184946,720	7	454992,389	5,890	0,002
Within Groups	1235939,700	16	77246,231		
Total	4420886,420	23			

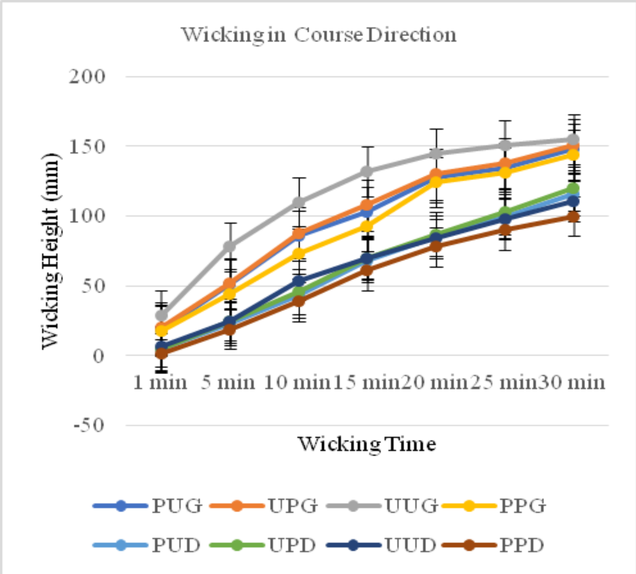

Figure 3. Vertical wicking of the samples in coursewise direction

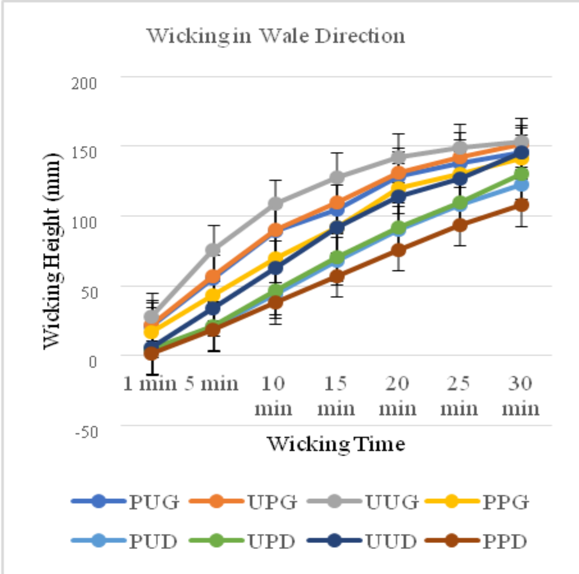

Figure 4. Vertical wicking of the samples in walewise direction

Table 8. One-Way ANOVA results for vertical wicking of the samples

Coursewise direction					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	5571,292	7	795,899	32,431	0,000
Within Groups	392,667	16	24,542		
Total	5963,958	23			
Walewise direction					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	5156,958	7	736,708	35,504	0,000
Within Groups	332,000	16	20,750		
Total	5488,958	23			

Transverse Wicking

Transverse (lateral) wicking of fabrics is important because the perspiration transfer from skin involves the movement of sweat through the thickness of the fabric in the lateral direction. The transverse wicking results of the samples are given in Figure 5 and 6. Contact angle measurements are also presented in Table 9.

As may be seen from figure 5, the water absorption time is much shorter for the greige samples than that for the dyed ones, which indicated that the moisture is transferred fast between the top and bottom layers. Furthermore, the UU samples gave the shortest absorption time, which was followed by the other Umorfil PA6 containing samples (e.g. UP and PU). As a final note regarding the greige samples, the wetting areas measured from the Umorfil containing layers of the PU and UP samples were larger than the ones from the PP sample. The fibres' water holding capacities (Umorfil PA6 fibers 7,8 %, PA6 fibers 4,7%), together with the fabric properties (i.e areal density, thickness, etc.) (Table 4), appeared to influence the wetting time of both the top and bottom surfaces as individual or in interaction. Also, the higher porosity of the samples contributed to the fabrics' transverse wicking performances. The relatively lower contact angles (Table 9) of the UPG and UUG samples, did support the aforementioned interpretations.

Table 9. Contact angle results

Samples	**Contact angle (◦)**
PUG	110
UPG	56
UUG	55
PPG	94
PUD	**97**
UPD	**84**
UUD	**82**
PPD	**96**

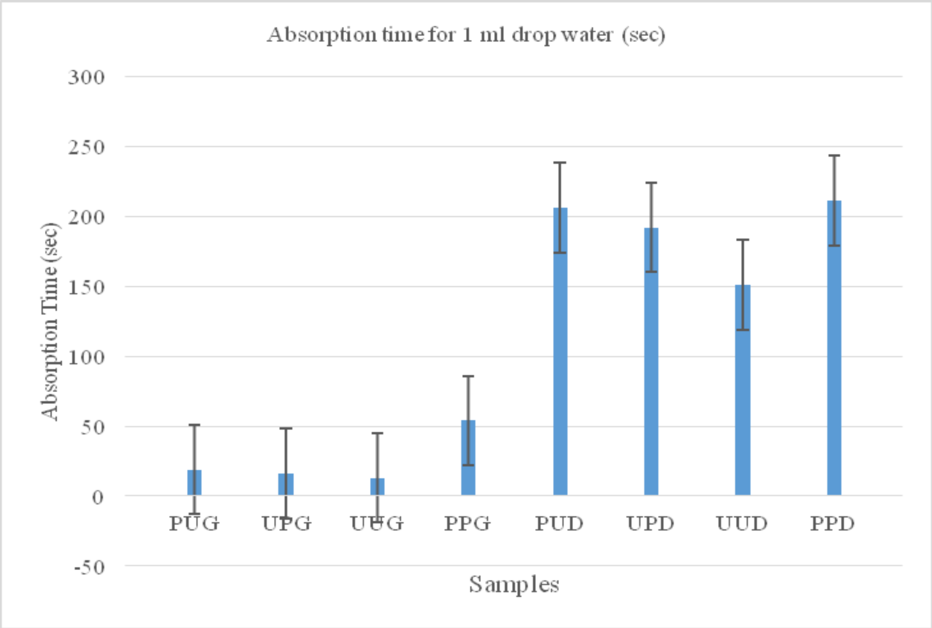

Figure 5. The time needed to absorb 1 ml of water by the samples

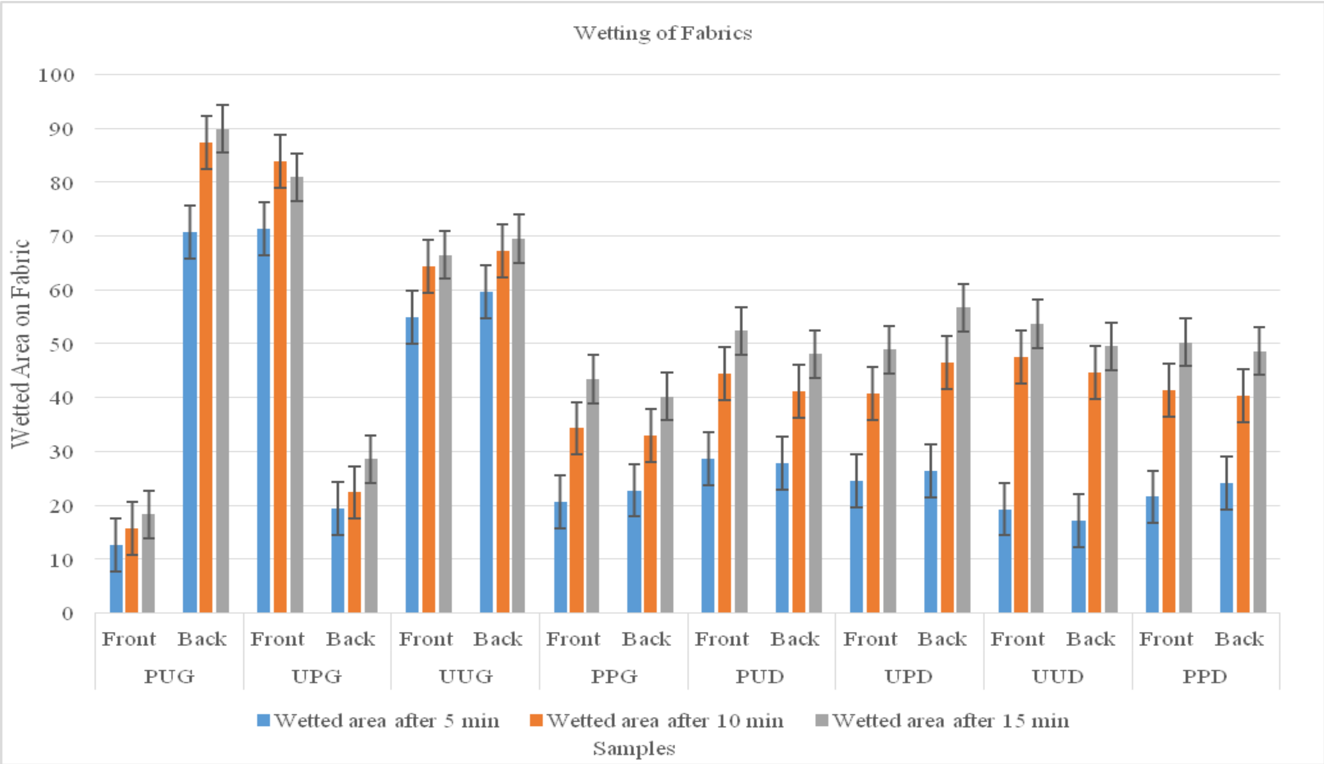

Figure 6. Wetted area on the front and back layers of the samples

Table 10. Drying rate of the samples

Samples	Thickness (mm)	Dry sample (g)	Wet Sample (g)	Drying Rate ($g/m^2/h$)
PUG-UPG	1,35	4,04	8,61	114
UUG	1,3	4,07	8,63	113
PPG	1,4	3,91	8,17	137
PUD-UPD	**0,69**	**3,47**	**6,66**	**108**
UUD	**0,71**	**3,33**	**6,69**	**112**
PPD	**0,63**	**3,41**	**6,04**	**87**

When it comes to the transverse wicking performance of the dyed fabrics, a significant increase in the water absorption time was observed, though the UU sample still had the lowest absorption time (Fig.5). The lower porosity (Table 4) values of the dyed samples implied that the heat-setting and dyeing processes altered pore geometry, volume, and distribution in the relevant layers such that the distance of liquid advancement was limited. These processes may also have lowered the surface tension of the samples as also may be seen from the contact angle measurements. It was also noted that depending on the time, the Umorfil PA6 content in the layers of the dyed samples (e.g. PU, UP) appeared to have a positive impact on the wetted area, in comparison to the PP samples. The relatively finer Umorfil PA6 filaments in the samples may have higher surface tension which facilitates holding the water droplet and transfer it in the lateral direction against gravitational force. These filaments may also have enhanced higher water absorbency as a result of more inter-fibre space helping water better spread laterally. Finally, using the fibers having big differences in moisture affinities (i.e. r-PA 66 and Umorfil PA6) together in the structures appeared to prove as effective means for enhancing the transverse wicking properties of the knitted fabrics because the dyed PU and UP samples consistently gave larger wetting area than UU samples (Fig.6).

Drying Rate

Table 10 shows the drying rates of the samples, and from which it can be seen that the PU, UP, and UU samples absorbed more water that the PP ones, as was expected.

Among all of the fabrics, the PPG sample gave the highest drying rate, whereas the PPD one showed the lowest, which indicated that the samples initially absorbing more water tended to have higher drying rates. Also, thickness is an influential parameter for drying performance of the samples. Moreover, considering the fact that all of the dyed samples dried within 3 hours, the Umorfil contained samples held more water and evaporated faster. This may be due to higher rate of capillary migration in the relevant samples (e.g. UUD, PUD, etc.) (Figure 3-4). As is discussed in the literature, continuous liquid distribution owing to capillary migration is effective in the drying process [35,36,39-41]. According to one way ANOVA analysis, yarn type was found to be a statistically significant factor on drying ability of the samples (Table 11).

4. CONCLUSION

This study mainly focuses on the effect of the yarns from the sustainable fibers, namely Recycled-PA66 and Umorfil Polyamide (i.e. r-PA 66 and Umorfil PA6), and their composition on moisture management and air permeability properties of the spacer knitted structures for sportswear applications. These fabrics were developed such that different yarn compositions on front and back layers (e.g. r-PA 66 on the front and Umorfil PA6 on the back) were employed. Accordingly, the most important results were given as follows:

1. Generally speaking, dyeing and finishing processes did affect the properties of the fabrics.

2. Regarding the air permeability results of both the dyed and greige samples, the ones from Umorfil PA6 allowed slightly higher air permeability than those from r-PA66, which suggests that the Umorfil PA6 containing layer may be employed as the outer layer of the clothing for better air circulation performance.

3. Umorfil PA6 fibers, whether greige or dyed, have proved to be superior in terms of vertical wicking of water due to mostly its inherent properties that would ease the removal and distribute the moisture from the body**.**

4. Since Umorfil PA6 containing layers of the fabrics have the fastest water absorption time, irrespective of the fact that the fabric is greige or dyed, it may be suggested that the water absorption rate of hydrophobic surfaces, as in the case of the fabric layers from r-PA66, can be improved by including Umorfil PA6 based fibers into bilayered structures.

5. It appears that the approach suggested in clause 4 can be an effective way for enhancing the transverse wicking properties of the fabrics which in turn reduces the wetness feeling when r-PA66 has been used for the inner layer of the structures.

6. Giving consideration to the fact that all of the dyed samples dried within three hours, the Umorfil PA6 containing fabrics (e.g. PUD, UUD) hold more water and evaporates the absorbed moisture to the environment well through the outer layers, which makes them favorable alternatives for the intended application area, namely sportswear apparels.

Table 11. One-Way ANOVA results for vertical wicking of the samples

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3407,333	7	486,762	8,891	0,000
Within Groups	876,000	16	54,750		
Total	4283,333	23			

7. The PA6 mono filament spacer yarn, having low affinity to absorb moisture, seems to facilitate rapid transport of moisture in the structures.

The findings of the study indicated that moisture related comfort properties of spacer knitted fabrics for sporting activities can be improved by using r-PA66 and Umorfil PA6 yarns in the inner and outer layers, respectively. However, further research is needed to engineer alternative spacer fabrics from the aforementioned sustainable fibers by focusing on both sports activity and garment types.

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