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Development of a novel fluorocarbon coated acquisition-barrier fabric layer for incontinence application

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Development and characterization of single-faced spun lace polyester-viscose (30:70) fabric as a top layer in incontinence products have been reported. One side of the fabric layer is coated with fluorocarbon using the spray coating process to make it hydrophobic. The coating process parameters, spraying distance (distance between spraying nozzle and fabric), finish concentration, and the partial coating are varied to determine the optimum combination. The effectiveness of the coating process has been assessed by measuring contact angle, moisture management, and rewet tests. The study reveals that the 30 cm spray distance and 5% finish concentration, sprayed following dot/zebra pattern, provides the layer's best liquid moisture transport properties. This process of making the front side hydrophobic and the other side hydrophilic promotes one-way liquid transport and can be very useful for many absorbent medical and hygiene products.

Keywords: Absorbency, Fluorocarbon coated fabric, Hydrophobic, Incontinence application, Nonwoven, One-way liquid transport, Rewet test

1 Introduction

Hygiene and medical textile industries are one of the largest growing industries today. They include surgical masks, incontinence products, gowns, sutures, etc. Incontinence products have a layered architecture consisting of an acquisition layer at the top, followed by distribution, absorbent, and impermeable bottom layers. The top layer remains in direct contact with the skin and needs to be soft, dry in sensation, and antibacterial. Usually, melt-blown, or spun-lace nonwoven polypropylene is used for the top/acquisition layer to provide a dry feel.

Cellulosic fibres, such as cotton and viscose rayon, can be used for incontinence applications as they are soft, biodegradable, skin-friendly and breathable. The cellulosic fibres also exhibit excellent absorption and moisture management properties. However, being hydrophilic, it promotes bacterial growth during prolonged use (8–10 h), which is undesirable in hygiene or medical products. Zimmerer *et al.*[1] and Tüzün *et al.*[2] have reported that with the increased skin wetness, there will be increased abrasion damage due to increased friction against skin, skin permeability, and microbial growth. Hence, there is a demand for self-clean[3] or stain-repellent fabrics for the top layer. Imparting hydrophobicity in cellulosic materials for its use in the top layer can mitigate this problem.

Fluorocarbon has been used in many areas to impart hydrophobicity[4,5]. Typically, C8 fluorocarbons are toxic in nature due to the presence of PFOA (Perfluorooctanoic acid) and PFOS (Perfluorooctane sulphonate). The OEKO-TEX thresholds set for PFOA and its derivatives are < 1μg/m^2, for products which remain in contact with skin[6]. The thermal stability, chemical inertness, dielectric strength, water-repellency, and slipperiness make it valuable for many applications. Lemal[7] has reported application of fluorocarbon in many areas including electrical insulation, carpet finishing, vascular implants in medical science, water repellences in textiles, etc.

Imparting hydrophobicity onto the cellulosic substrate is not a new concept and attempted by many researchers. Zimmermann *et al.*[8] and Wang *et al.*[9] have developed super hydrophobic textile fabrics by coating techniques. Bhushan *et al.*[10] developed the lotus leaf effect by creating micro-, nano-, and hierarchical structures and found increased hydrophobicity with increased side roughness. De Leon and Advincula[11] have developed a temperature-responsive polymer coating material that can switch from hydrophobic to hydrophilic.

Introducing super hydrophobicity on both sides of the top layer fabric may lead to a non-breathable, harsh, and uncomfortable hygiene product for prolong use. Hence, asymmetric finishing is of significant interest in many textile products. The asymmetric or one-way liquid transport can help in self-cleaning, contamination protection, and unidirectional fluid flow.

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One-way liquid transport is highly desirable for the acquisition layer. It will allow the liquid to move towards the absorption layer but resist its return to the skin under external pressure due to body weight or movement.

Surface tension heterogeneity can be the driving force to guide liquid motion on a flat surface. It has been reported that *Stenocara gracilipes* beetle found in the Namibia desert, Africa, has a combination of hydrophilic and hydrophobic areas on their body structures which helps in fog-harvesting[12]. The asymmetric or gradient wet ability concept shown by the beetle can therefore be introduced into a fabric. Such fabrics with unidirectional liquid transport can have excellent potential for moisture management, microfluid systems, desalination, liquid/oil separation, etc.

Various techniques have been used to impart asymmetric or gradient hydrophobicity into the fabric. Tenjimbayashi and Shiratori[13] used a novel spraying method to develop highly durable super hydrophobic coatings by varying the “spray distance between substrate and spray” (SD). Another technique to impart hydrophobicity is foam technique with blade coater[14]. Following this method, the developed single-faced hydrophobic fabric showed high liquid fastness and better moisture transmissibility. Wang *et al.*[15] created unidirectional fluid flow in polyester fabric using the coating technique. The suggested mechanism of unidirectional liquid transport in fabric was, dragging the liquid droplets from the hydrophobic side to the hydrophilic side, then spreading over the hydrophilic side, and simultaneous absorption by the hydrophilic core. Kapoor and Chattopadhyay[16] and Sasaki *et al.*[17] have imparted hydrophobicity by coating fluorocarbon using spraying method. Niles *et al.*[18] developed a two-layer fabric with 100% cotton (hydrophilic) and 100% polyester (hydrophobic) yarn on each side. They found effective moisture transfer from the inner layer to the outer layer of the fabric.

Wang *et al.*[19] has suggested that the wet ability gradient can be produced to have a directional liquid-transport function. The liquid can quickly transfer across the fabric from the super hydrophobic side to the hydrophilic one, but not in the opposite direction unless a sufficient external force was applied. Lao *et al.*[20] have developed a novel skin-like fabric by spatially distributed porous spot channels with gradient wet ability across the thickness of hydrophobic materials. They used a super hydrophobic finishing and selective plasma treatment and found that the liquid transmission rate was 15 times greater than the best available commercial breathable fabrics.

Öner *et al.*[21] have compared the moisture management values of polyester, cotton, and viscose fabrics and found that the higher the value of OMMC (overall moisture management capacity), the better will be the fabric's liquid transport performance. In polyester fabrics, the liquid molecules are not absorbed because of their hydrophobic characteristics. However, they contribute to the wetness comfort by transporting the liquid quickly[21]. Cellulosic fibres (cotton and viscose rayon) absorb liquid readily and keep the liquid within their structure, making it difficult to transport. Das *et al.*[22] studied the polyester and viscose blended fabrics and found that increasing viscose percentage into the blend resulted in better moisture transport and absorption property. Although many researchers have developed single-faced super hydrophobic fabric, but only a few have tried to quantify the finish concentration and its effect on hydrophobicity.

In the present study, polyester-viscose spun lace fabric has been used. The top face of the fabric was spray-coated by a hydrophobic fluorocarbon finish for imparting a unidirectional liquid flow property. The influence of the spraying process parameters, such as spray distance, finish concentration and spray patterns, on the effectiveness of unidirectional liquid flow has been investigated.

2 Materials and Methods

Polyester-viscose blended (30:70) spun-lace fabric (PV) of 30 g/m^2 was procured for use as an acquisition layer. The spray coating setup is shown in Fig. 1. Samples of (20 cm×20 cm) size were cut and fixed on the frame. The fabric samples' front side was spray-coated using fluorocarbon-based eco-friendly[23] liquid-repellent finish AG E061 (Asahi Guard E series) and Meikanate as a cross-linking agent. Asahi Guard AG-E061 doesn't contain any PFOA (at or above detection limit), PFOS, longer-chain PFCAs or their precursors[24].

The process variable chosen were (i) finish concentration (2.5, 5.0 and 7.5 %), (ii) spraying distance (20, 30, 40 and 50 cm), and (ii) spraying pattern (uniform, zebra, and dot). The spraying pressure was kept constant at 10 PSI, and the amount of finish sprayed was 2 mL on the entire side of the fabric samples.

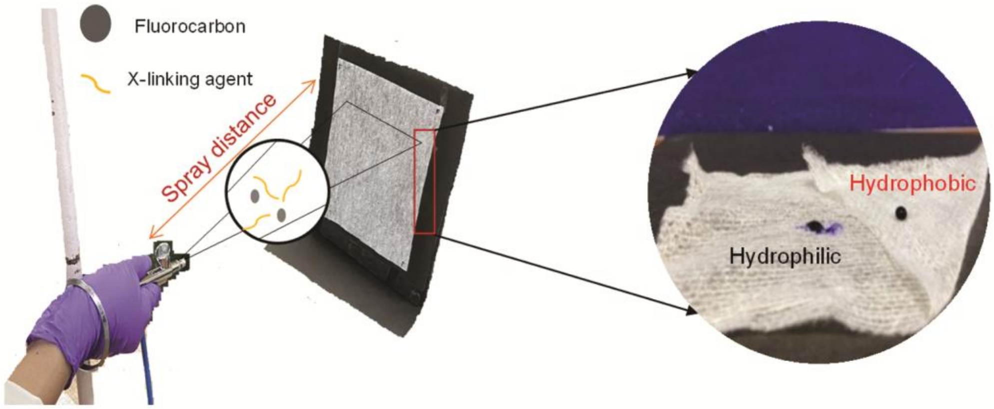


Fig. 1 — Spray coat technique

Three spray patterns were chosen, viz uniform, zebra (stripe) and dot. The zebra pattern had two variations in stripe width (0.5 and 1cm). The dot size was approximately 3.5 mm in diameter in the dot pattern and inter dot distance was around 8 mm (Fig. 2). The idea of using such a pattern is to generate asymmetric/gradient wet ability for the quick spreading of the liquid over the entire fabric surface. The spraying patterns were created by using a suitably designed template so that the finish could reach the designated areas only. After spraying, the samples were dried at 120°C for 180 s and cured at 150°C for 60 s.

2.1 Characterization

Scanning electron microscope images were taken to characterize the side morphologies of the fabrics. Contact angles were estimated with KRUSS made Drop Shape Analyzer equipped with a particular inbuilt optical system and camera. A drop of liquid (6μL) was placed on the fabric, and the image was immediately captured by the camera and then saved for further analysis. The sessile drop method was used to find the angle of contact by liquid. Pictures of both sides of the sample were taken. Standard liquid drop method AATCC 79-2000 was followed for the tests. At least five observations were made for each sample fabric.

2.2 Moisture Management Test

Moisture management test (AATCC Test Method 195-2011) was conducted to determine the liquid moisture spreading properties onto the fabric's top (front) and bottom (back) sides. A sample (8 cm 8 cm) was placed between the two horizontal (top and bottom) electrical sensors. Each sensor has seven concentric pins and 0.22 cc of saline solution was dropped onto the centre of the sample. The liquid solution was free to move in all directions, i.e. radial

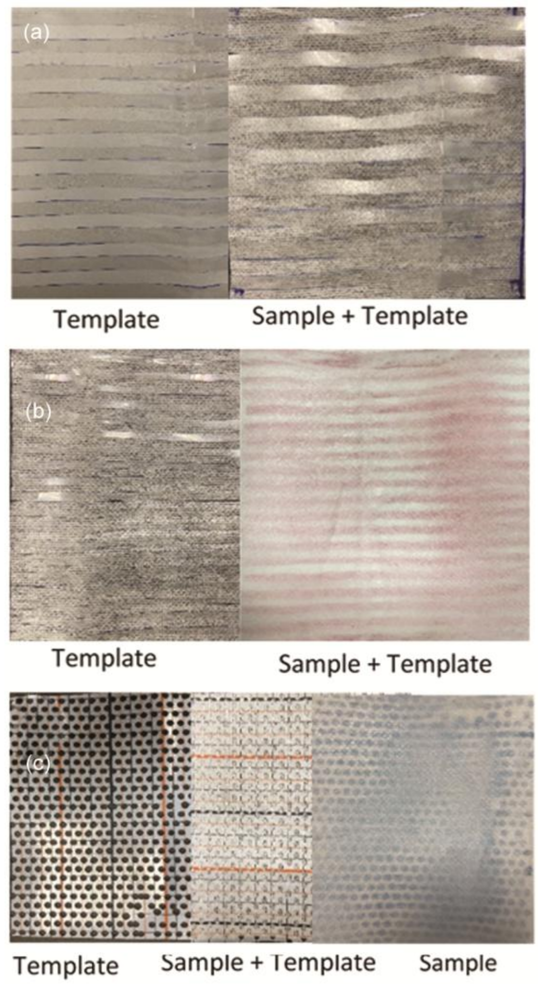


Fig. 2 — Spray pattern/template with stripe width (a) 1 cm, (b) 0.5 cm and (c) dot pattern

spreading on both sides and passage from top to bottom. A change in electric resistance was measured and recorded. The difference in electric resistance was used to calculate the liquid moisture content changes in the sample. Following indices are used to summarise the liquid moisture content in the fabric:

(i) Absorption rate — The change in the average speed of moisture content at the front and back sides.

(ii) One-way liquid transport capability — The difference in the moisture content curves of front and back specimen w.r.t time.

(iii) Maximum wetted radius — The largest ring radius measured at the front and back surface.

(iv) Overall moisture management capabilities — It is defined as an index for the general liquid-vapor moisture transfer of the specimen. It can be calculated by combining three measured attributes, i.e. liquid moisture absorption rate on the back surface, one-way fluid transport capabilities, and spreading speed on the back surface.

(v) Wetting time — Wetting time is defined as the time required in seconds when the front and back sides start wetting just after starting the test procedure.

2.3 Rewet Test

Rewet is the amount of wetness returned to an incontinence product's topside when it is pressed against a wet surface. The rewet test was performed according to the standard NWSP 070.9.R1. A two-layered assembly was made, keeping the treated fabric at the top and the absorbent core at the bottom. Now, 4 mL simulated urine was discharged at the centre of the treated specimen (5 cm diameter) at a 1.5 mL/s rate. The liquid passed through the treated fabric and got absorbed in the absorbent core. Time taken for the liquid to pass through the top layer was noted down.

To know the amount of liquid returning to the top side under external pressure, filter papers (Whatman grade 1) were placed on the top of the treated fabric for absorbing the returned liquid. The weight of the filter papers (w_{df}) was noted down before placement. One psi pressure was applied for 60 s (Fig. 3). The wet filter papers were removed. The weights of the wet filter papers (w_{wf}) and a wet absorbent core (w_{wa}) were measured again. The amount of liquid absorbed by the filter papers was calculated from the difference between the wet and dry weights of the filter papers. The test was repeated five times. The average was used as a measure of rewet (g). The rewet (g/g) was calculated based on the following formula:

$$\text{Rewet (g/g)} = \frac{(w_{wf} - w_{df})}{w_{ca}} \qquad \ldots (1)$$

where w_{ca} is the dry weight of the absorbent core. The % liquid transferred from absorbent core to the filter paper was determined from the following formula.

$$\text{Liquid transferred (\%)} = \frac{(w_{wf} - w_{df})}{(w_{wa} - w_{ca}) + (w_{wf} - w_{df})} \times 100 \qquad \ldots (2)$$

The test configuration includes (i) without top layer and (ii) with top layer [polyester-viscose (PV) non-finished fabric; one side uniformly treated PV fabric; polypropylene (PP); and treated side with two different treatment patterns (zebra and dot)]. In all the cases, the absorbent core was at the bottom (Fig. 4). There were five different combinations

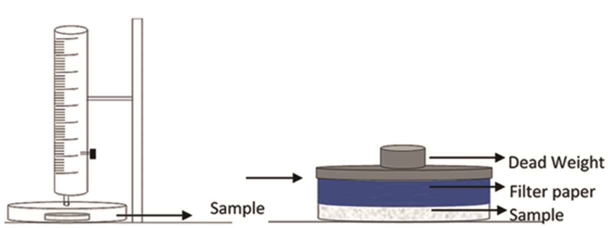


Fig. 3 — Rewet test

3 Results and Discussion

3.1 SEM Study

One typical SEM image (5.00 KX) is shown in Fig. 5. The finish on the treated side of the PV sample is in the form of minute particles, as can be seen in

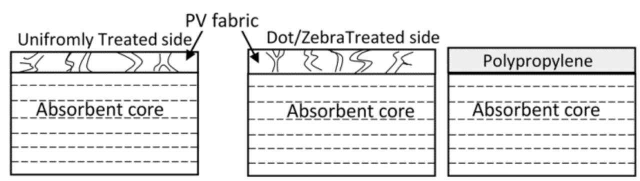


Fig. 4 — Different configuration of the rewet test

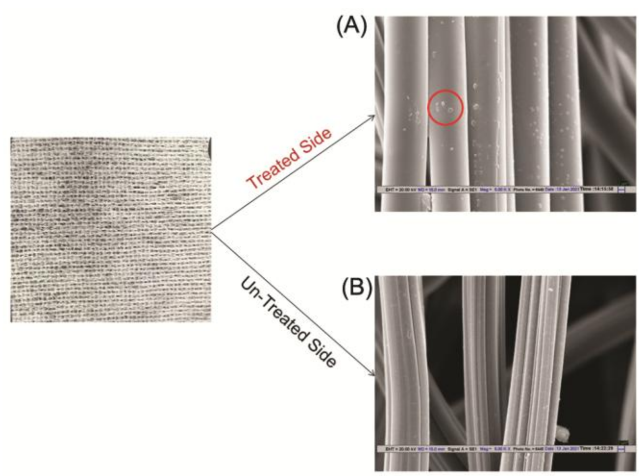


Fig. 5 — SEM image analysis (A) coating (front) side and (B) back side of polyester-viscose spun-lace nonwoven fabric

Fig. 5 (A). Such dots are absent on the un-treated side in Fig. 5 (B).

3.2 Influence of Spraying Parameters

While spraying, there is every possibility for a small finish part to reach the reverse side due to penetration of the finish, either due to the spraying gun being closer or through the wicking phenomenon of the fine finish droplets. Therefore, the influence of spraying distance and finish concentration was evaluated to determine the right combination of the two parameters.

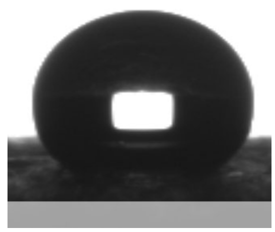
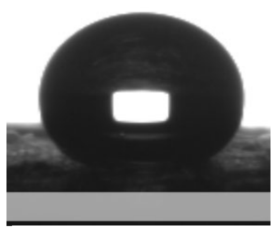
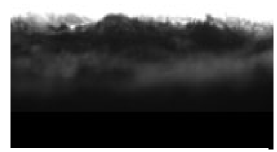
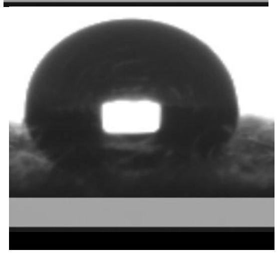
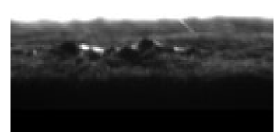
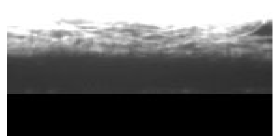
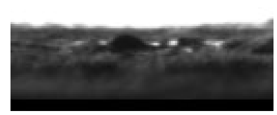
3.2.1 Influence of Spraying Distance

The influence of changing the spraying distance was evaluated by contact angle and moisture management tests (Tables 1 and 2).

The contact angle on the uniformly treated and un-treated sides is 127.5° & 50.74° at 20 cm; 128.9° & 0° at 30 cm; and 121.9°& 0° at 40 cm spraying distances respectively. For the 50 cm spraying distance, the contact angle is found 0° on both sides. Therefore, at a 20 cm spraying distance, the treated side is hydrophobic, and the reverse side also shows some hydrophobicity. At 30 cm and 40 cm spraying distances, only the uniformly treated sides are hydrophobic. At a 50 cm distance, both sides are practically hydrophilic.

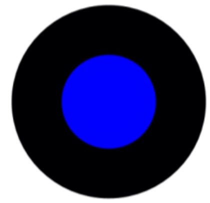
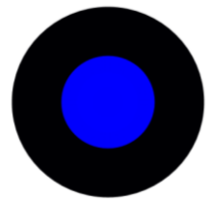
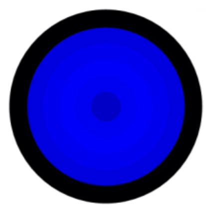
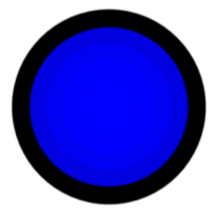
At a short distance (20 cm), the liquid finish penetrates to the backside of the sample, and therefore, the backside shows little hydrophobicity. At higher distances (30 and 40 cm) the sprayed liquid cannot reach the backside, and hence only the front side shows hydrophobicity. With the increase in spraying distance, the spreading area also increases. At 50 cm, the spread area goes beyond the sample area. Therefore, the finish accumulation per unit area of the sample becomes so low that no hydrophobicity is observed even on the treated side. Though, the

Table 1 — Contact angle at two sides of hydrophobic finish coated PV nonwoven

Spraying distance, cm	Spraying side (Front side)	Non-spray side (Back side)
20	 Θ= 127.55°	 Θ= 50.74°
30	 Θ= 128.99°	 Θ= 0°
40	 Θ= 121.96°	 Θ= 0°
50	 Θ= 0°	 Θ= 0°

Θ – Contact angle.

Table 2 — Moisture management test of two sides of hydrophobic finish coated PV nonwoven

Spraying distance, cm	One-way liquid transport capability	Treated face (Front side)	Un-treated face (Back side)
20	2484		
30	2188		
40	1997		
50	1231		

presence of polyester is expected to impart some hydrophobicity in the fabric, however, the predominant presence of 70% viscose fibres, causes the water droplet to easily spread out, showing 0° contact angle.

3.2.1.1 Moisture Management Test (MMT)

Table 2 shows the images of the liquid content of the front and back sides of the samples. The blue part of the image indicates the liquid spread out area, and the black part indicates the non-existence of liquid.

The images show that at 20 cm and 30 cm spraying distances, the treated side is black, indicating the non-existence of liquid. The un-treated side shows little blue patches, indicating the transfer of some liquid from the front and back sides. It means that the front side is entirely hydrophobic, and some liquid has migrated to the backside and spread over a limited area. The one-way liquid transport capability values (2484 for 20 cm and 2188 for 30 cm) are much greater than the rest.

At 40 cm spraying distance, the liquid is present in both front and back sides. Only parts of the sides are devoid of any liquid. It indicates the spreading of liquid on both sides. At 50 cm distance, both sides of the sample are blue, indicating the presence of liquid on both sides. The one-way liquid transport value is, therefore, the lowest (1231).

The above results suggest that a 30 cm spraying distance is most suitable for the parting one-way liquid transfer.

3.2.2 Influence of Finish Concentration

The influence of fluorocarbon finish concentration was evaluated by the moisture management test (Table 3). The one-way liquid transport is maximum for the sample treated with 7.5% finish concentration, and the lowest for 2.5% finish concentration. A comparison of the images of both front and back sides indicates the presence of more liquid on the backside for all the cases as compared to the front sides. The front side of the sample treated with 2.5 % finish concentration shows little traces of liquid.

At 7.5% finish concentration, the blue color is not visible, implying no liquid on the front side. It means the entire liquid got transferred from the front to the backside. Similar observation can be made for the samples treated with a 5% finish concentration. Therefore, one-way liquid transport is practically the same for the samples treated with 5% and 7.5% finish concentration.

3.3 Influence of Spray Pattern

From Table 4, it can be seen that one-way liquid transport capability is maximum (2484) when the finish covers the entire front side of the sample. However, the values are almost identical with patterned finish application except for the zebra pattern with a 0.5cm stripe width. There is no presence of liquid on the front side. The entire liquid goes to the backside.

In the case of zebra pattern, when a small drop of liquid (0.22cc) is poured on the treated part of the fabric, the liquid drop may either (i) pass through the pores of the hydrophobic region (if it is larger than the drop size) (Fig. 6A) or (ii) or partly through the pores of hydrophobic region and the rest through the hydrophilic region, when the size of the hydrophobic region is small (Fig. 6B).

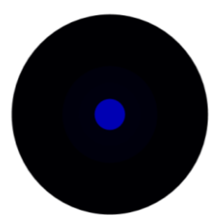
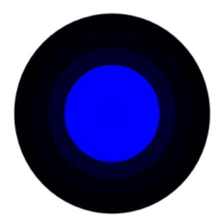
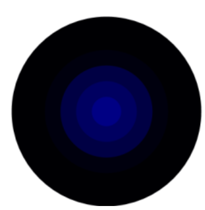
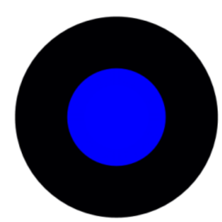
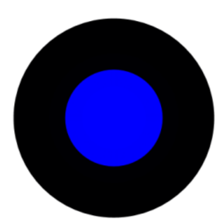
In the second case, part of the liquid is retained by the hydrophilic region. As a result, the liquid is visible on both sides of the sample in the case of small stripes (0.5 cm) but not so in wider ones (1 cm).

In the dot pattern, the treated parts in small circles are very close. The inter dot distances are 8 mm. As the finish is applied, the part of the finish solution may migrate towards the neighboring region due to wicking action, further reducing the hydrophilic region, as shown in Fig. 7. The influence of each circular hydrophobic region becomes larger, and the entire top side of the samples almost behaves as hydrophobic. All the liquid passes through the pores to the other side. Hence, the presence of liquid is seen on the backside only.

3.4 Rewet (%) Test

By rewet test, one can judge the liquid transfer resistance of any fabric through its pores when brought into contact with a wet fabric. The acquisition layer should also act as a barrier to allow minimum liquid transfer from the absorbed core when it

Table 3 — Moisture management test of the treated samples (with varying finish concentration)

Finish concentration, %	One-way liquid transport capability	Treated face (Front side)	Un-treated face (Back side)
2.5	1755		
5.0	2425		
7.5	2474		

experiences pressure due to body movement or a change in body posture. This property is desirable to keep the skin dry.

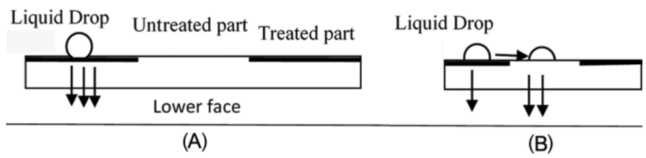


Fig. 6 — Fluid movement across the PV fabric (A) 1 cm stripe width and (B) 0.5 cm stripe width

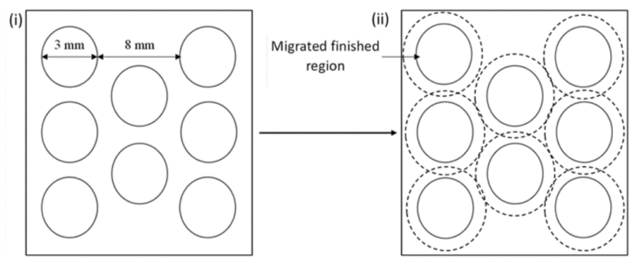


Fig. 7 — Schematic representation of dot pattern (i) before and (ii) after application of finish

The liquid transferred to the filter papers from the absorbent core is found to be around 68% when the top layer is absent (Fig. 8). With the untreated top PV layer, it is hardly changed. The liquid transfer (%) is reduced with uniformly treated PV top layers. The liquid transfer is found 50% and 40% for treated dot

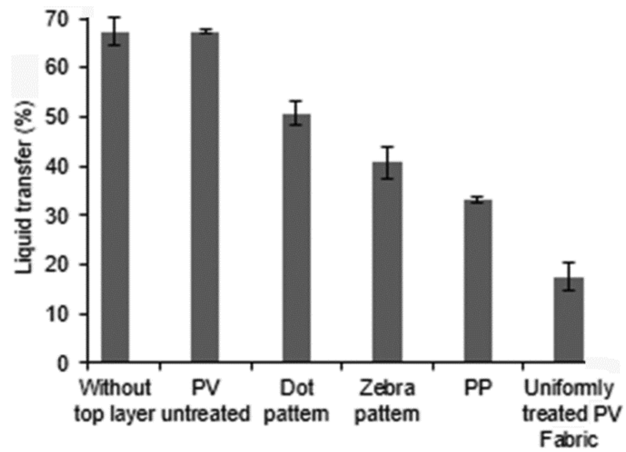
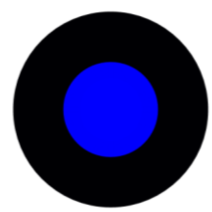
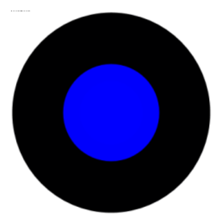
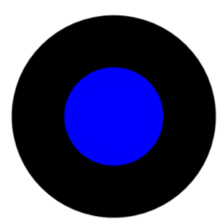
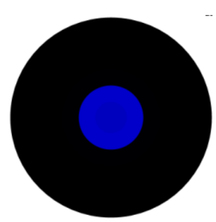
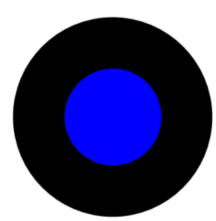


Fig. 8 — Rewet test results

Table 4 — Moisture management test of treated samples (with varying application patterns)

Pattern	Size, cm	One-way liquid transport capability	Treated face (Front side)	Un-treated face (Back side)
Uniformly coated	NA	2484		
Zebra	1	2457		
	0.5	2342		
Dot	NA	2481		

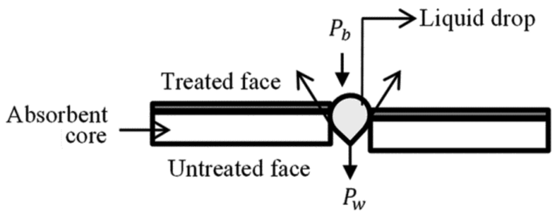


Fig. 9 — Penetration of liquid droplet through PV fabric

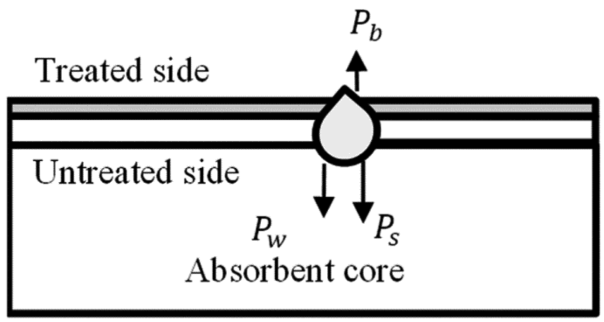


Fig. 10 — Ejection of liquid droplet through uniformly treated PV fabric

and zebra pattern PV fabrics. The % transfer becomes 33% with the PP fabric layer and 18% with uniformly treated PV fabric on the front side. Similar values of rewet (g) have been observed by many researchers[25–28]. To explain the differences in rewet %, we need to understand the fluid movement through the fibrous structure.

3.5 Mechanism of Liquid Movement

According to Chatterjee and Gupta[29], any liquid droplet above a fabric pore (Fig. 9) experiences three types of forces, and as a result, the total downward pressure ΔP acting on it is:

$$\Delta P = P_b(\text{External pressure}) + P_w(\text{Hydrostatic pressure} + P_s(\text{Capillary Pressure}) \quad \ldots (3)$$

$$\Delta P = \Delta P = P_b + \frac{\rho g V}{\pi r^2} + \frac{2\gamma \, Cos\theta}{r} \quad \ldots (4)$$

where ρ is the density of the liquid; v, the volume of the drop; r, the pore radius; γ, the surface tension of the liquid; g, the acceleration due to gravity; and θ, the contact angle.

While the liquid is poured slowly onto the uniformly treated side of the fabric, the external pressure is absent. The treated side being hydrophobic (contact angle θ is >90º) will oppose the penetration of the liquid and allow liquid to accumulate. The hydrostatic pressure gradually increases. Once the hydrostatic pressure (the second term of Eq. 4) due to liquid accumulation overcomes the resistance of the hydrophobic side, the liquid starts penetrating the hydrophobic pore to reach the hydrophilic pores of the untreated hydrophilic side. Both hydrostatic and capillary pressures facilitate quick absorption of the liquid by the entire absorbing core. The amount of liquid build-up required to overcome the initial resistance depends upon the degree of hydrophobicity of the treated surface. Thicker the hydrophobic layer, more liquid must accumulate to overcome the hydrophobic resistance.

During the rewet test, the liquid movement reverses. Under pressure, the absorbed liquid lying within the absorbent core flows towards the hydrophilic lower face of the top layer first and, from there, tries to reach the hydrophobic upper face side. At the interface of the hydrophobic and hydrophilic surfaces, the hydrophobic pores and weight of the liquid resist ($i.e. P_s$ and P_w) upward liquid flow, whereas the external pressure (P_b) favors it (Fig. 10).

The quantity that will finally move out will depend upon the net driving force (ΔP), as shown below:

$$\Delta P = P \qquad - \quad \ldots (5)$$

The net driving force will be minimum for the uniformly treated PV spun lace fabric with the hydrophobic side at the top. The net driving force will be more than the uniformly treated PV fabric for the zebra and dot-treated patterns. Hydrophilic regions on both sides of the fabric act as channels for quick liquid transfer. PP fabric being hydrophobic on both sides will behave similarly to one side uniformly treated PV fabric. One side uniformly treated PV fabric shows minimum value because hydrophobicity of its treated side is greater than that of PP fabric, as evident from the contact angle values stated below:

Polypropylene (PP) fabric – 122.4°
Polyester-viscose (PV) uniformly treated fabric – 129.6°

4 Conclusion

The effectiveness of the spraying hydrophobic finish on the polyester–viscose spun lace fabric was evaluated by SEM images, contact angle, moisture management, and rewet tests. Spraying from 30 cm and 40 cm distance is found to make the front side of the fabric highly hydrophobic without changing the hydrophilicity of the back surface.

The one-way liquid transport is found to be maximum for the sample sprayed with 7.5% finish concentration. Application of finish on the entire surface of the fabric uniformly is found to be the best for one-way liquid transport indicated by moisture management test.

Partially treated sides (dot and wide width zebra pattern) show marginally fewer values in one-way liquid transport than uniformly coated samples. The optimum combination of distance from spraying jet and concentration of liquid-repellent finish (AG E061) is found to be 30 cm and 5% respectively.

The reverse flow of the liquid from the absorbent core to the front face of the top layer under pressure is found to be minimum for the fabric sample, having the front face completely covered by the hydrophobic finish. Partially dot and zebra pattern treated sides (nearly 50%) allow more liquid to appear on the surface of the top layer.

References

1 Zimmerer RE, Lawson KD & Calvert CJ, *Pediatr Dermatol*, 3 (1986) 95.
2 Tüzün Y, Wolf R, Bağlam S & Engin B, *Clin Dermatol*, 33 (2015) 477.
3 Lee HJ, *Improving Superhydrophobic Textile Materials* (Woodhead Publishing Limited), 2011, 339.
4 Goldstein HB, *Text Res J*, 31 (1961) 377.
5 Rahmatinejad J, Khoddami A & Avinc O, *Fibers Polym*, 16 (2015) 2416.
6 De Smet D, Weydts D & Vanneste M, Environmentally Friendly Fabric Finishes, *Sustainable Apparel* (Woodhead Publishing), 2015, 3.
7 Lemal DM, *J Org Chem*, 69 (2004) 1.
8 Zimmermann BJ, Reifler FA, Fortunato G, Gerhardt L & Seeger S, *Adv Funct Mater*, 18 (2008) 3662.
9 Wang H, Fang J, Cheng T, Ding J, Qu L & Dai L, *Chem Comm*, (2008) 877.
10 Bhushan B, Jung YC & Koch K, *Philos Trans A Math Phys Eng Sci*, 367 (2009) 1631.
11 De Leon A & Advincula RC, *ACS Appl Mater Interfaces*, 6 (2014) 22666.
12 White B, Sarkar A & Kietzig AM, *Appl Surf Sci*, 284 (2013) 826.
13 Tenjimbayashi M & Shiratori S, *Int J Appl Phys*, 116 (2014) 114310.
14 Liu Y, Xin JH & Choi C-H, (2012) 17426.
15 Wang H, Ding J, Dai L & Lin T, *J Mater Chem*, 20 (2010) 7938.
16 Kapoor A & Chattopadhyay R, *J Text Apparel Technol Managment*, 11 (2020) 1.
17 Sasaki K, Tenjimbayashi M, Manabe K & Shiratori S, *ACS Appl Mater Interfaces*, 8 (2015) 651.
18 Niles N, Fernando S & Rathnayake N, *Res J Text Apparel*, (2020) 64.
19 Wang H, Wang X & Lin T, *J Nanosci Nanotechnol*, 13 (2013) 839.
20 Lao L, Shou D, Wu YS & Fan JT, *Sci Adv*, 6 (2020) Eaaz0013.
21 Öner E, Atasağun HG, Okur A, Beden AR & Durur G, *J Text Inst*, 104 (2013) 699.
22 Das B, Das A, Kothari VK, Fanguiero R & Araujo MD, *J Eng Fibers Fabric*, 4 (2009) 20.
23 https://www.agcchemicals.com/jp/en/fluorine/products/detail/index.html?pCode=JP-EN-F001 (accessed on December 9, 2021).
24 Park HR & Lee MC, *Text Color Finish*, 24 (2012) 173.
25 Shanmugasundaram OL & Gowda RVM, *Res J Text Apparel*, 15 (2011) 37.
26 Ahmed HAM, Rajendran R, Balakumar C, Jayakumar S & Vaidiki K, *J Text Sci Eng*, 1-8.
27 Easson M, Edwards JV, Mao N, Carr C, Marshall D, Qu J, Graves E, Reynolds M, Villalpando A & Condon B, *Mater*, 11 (2018) 2077.
28 Kathirvel KP & Ramachandran T, *J Nat Fibers*, 11 (2014) 242.
29 Chatterjee PK & Gupta BS, *Absorbent Technology* (Elsevier Ltd), 2002.