Multi-layered Breathable Fabric Structures with Enhanced Water Resistance

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ABSTRACT

This work reports waterproof breathable layered fabrics consisting of simple fabric weave types (plain, twill) and microporous breathable films. The pretreated fabrics were treated with water-repellent finishing chemicals. Afterwards, layered structures were generated by bringing the fabrics and the microporous breathable films together. According to the results of water repellency, hydrostatic pressure (water resistancy) and water vapor permeability tests conducted on the samples with/without microporous film layers, waterproof breathable layered fabrics were able to be generated, which are supposed to be used as construction materials.

INTRODUCTION

Since the mid-1960s, industrial fabrics have made rapid advances [1]. The use of fabrics, knits or nonwovens instead of classic building materials is steadily increasing [2]. Waterproof-breathable fabrics are of significance in the fields of hygenie, agriculture, protective clothing, sportswear, and construction industries [3,4]. They are used as roofing and covering materials in the construction industry. Waterproof breathable fabrics balance two contradicting properties: hey are waterproof and yet water vapor permeable. Hence, producing a material which has both of these properties has proved to be a major challenge for manufacturers of waterproof performance fabrics.

Different types of breathable fabrics can be classified into the following groups [4–9]:
- Cloosely woven fabrics
- Microporous membranes and coatings
- Hydrophilic membranes and coating
- Combination of microporous and hydrophilic membranes and coating
- Retroreflective microbeads
- Smart breathable fabrics
- Fabrics based on biomimetics

One of the most significant developments in breathable waterproof materials was the introduction of the Gore-Tex rainwear fabric in 1976, which is a microporous polymeric film made of polytetrafluoroethylene (PTFE). Numerous product brands have been developed and patents filed since that development inspired further research [10-23]. Nowadays, breathable film fabric laminates have gained increasing acceptance in end uses requiring selectively waterproof but breathable barrier characteristics. All these methods mentioned above are cloosely related to high production costs [4-9].

Before going into detail related to our approach, water repellency and water resistancy will be explained. It is important to distinguish between water-repellent and waterproof fabrics. Water-repellent fabrics have open pores and are permeable to air and water vapor. Water-repellent fabrics will permit the passage of liquid water once hydrostatic pressure is high. Waterproof fabrics are resistant to the penetration of water under much higher hydrostatic pressure than are water-repellent fabrics. These fabrics have fewer open pores and are less permeable to the passage of air and water vapor. The more waterproof a fabric, the less able it is to permit the passage of air or water vapor. Waterproof is an overstatement, a more descriptive term is impermeable to water. A fabric is made water-repellent by depositing a hydrophobic material on the fiber's surface. However, waterproofing requires filling the pores as well [24].

When deciding our approach, we took the known facts into consideration, which are mentioned below:

- Breathability of a material is determined by water vapor permeability [25] and diffusion of water vapor through textiles is the determining factor in breathability. The type of finish applied (i.e. hydrophilic or hydrophobic) to a fabric has no great effect on the diffusion process [26].

- The water vapor transmission through fabrics increases with an increase in the moisture content and in the condensation of water in the fabric [27] meaning that using a hygroscopic fiber enhances the flow of water vapor transfer to the environment comparatively to a fabric which does not absorb and reduces the moisture built up in the microclimate [28-31]. Moisture transmission is also affected by the fabric construction or weave [32,33].

In our study, we tried to make waterproof breathable fabrics consisting of layered structures. In order to produce these fabrics in a cost-effective way, we used a simple but a different approach: We made the fabrics with simple types of weave (plain, twill) water-repellent by applying a conventional flourine-based water-repellent chemical and brought them together with microporous breathable films in different structures. We also changed the fiber type used in weft yarns and evaluated its efficiency in terms of both water repellency and water resistancy. According to concept, this is the first study, in which water-repellent fabrics and microporous breathable films have been used for enhanced water resistancy while keeping the breathability in mind at the same time.

MATERIALS AND METHODS

Materials

Fabrics were kindly provided from Madosa Tekstil Ltd. Şti. and pre-treatment procedure was carried out in Hasözgen Tekstil San. ve Tic. A.Ş. Properties of the fabrics woven and pre-treated are shown in *Table I*. The water-repellent chemical applied was Asahi Guard® AG 7600 (Asahi Glass Company, Japan). Asahi Guard is a fluororesin based on Perfluoroalkylethylacrylate as the main component. Microporous breathable lineer low density polyethylene (LLDPE, T_m: 125 ^oC) films with a 14 gsm (gram square meter) were kindly provided from Pelsan Tekstil Ürünleri San. ve Tic. A.Ş. Ethylene vinyl acetate (EVA) based hot-melt adhesive films (E120, T_m: 75 ^oC) were kindly acquired from ATEG Mühendislik Ltd. Şti.

Methods

Water-Repellent Finishing

Fabrics were impregnated at foulard with the following aqueous compositions for the water-repellent finishing squeezed in the padding mangle to an approximate 55-60% liquor pick-up, dried and baked at 170^{o}C for 1 minute. The amount of the Asahi Guard was 40 g/L.

Lamination Process

EVA-based hot-melt adhesive films were placed after laying each layer and then pressed at 100^{o}C using transfer printing mini press (Okangroup). All results are the average of three measurements.

Spray Test

In order to determine the water-repellent efficiency, spray tests were conducted according to AATCC 22 using Pro-ser Spray Rating Tester. The samples were conditioned for 24 hours at 21^o±1^{o}C at a relative humidity of 65±2% prior to testing. The specimens were stretched on a hoop, which was held at angle of 45^o and 250 mL of water was poured though a spray nozzle. Any wetting or spotted pattern observed was compared with the photographic rating chart. A fabric with complete non-wetting was given a “100” rating, while a fabric with complete wetting was assigned a “0” rating [34,35].

Hydrostatic Pressure Test

Hydrostatic pressure tests were carried out according to AATCC 127 to evaluate the water resistancy of the fabrics to the penetration of water under hydrostatic pressure. Atlas SDL Shirley Hydrostatic Head Tester Model M018 was used as the instrument. The water used was distilled and maintained at 20±2^{o}C; the rate of increase of water pressure was 60±3 cmH_2O/min. The water pressure was recorded at the point at which the water penetrated the fabric at the third place [36]. The unit is expressed as cmH_2O.

TABLE I. Properties of the pre-treated fabrics.

Sample No.	Warp	Warp density (thread/cm)	Weft	Weft density (thread/cm)	Weight (gr/m^2)	Weave
1	20/1 Combed Cotton	51	20/1 Carded Cotton	23.5	227	1/1 plain
2	20/1 Combed Cotton	50	20/1 Carded Cotton	23	222	2/2 twill
3	20/1 Combed Cotton	51	20/1 Carded Polyester	24	231	1/1 plain
4	20/1 Combed Cotton	51	20/1 Carded Polyester	23	231	2/2 twill

Water Vapor Permeability Test

Water vapor permeability (WVP) measurements were done according to the gravimetric cup method (upright cup test) by using Labthink TSY-T3 water vapor permeability tester. The measurements were performed at 23°C with 85% relative humidity (ASTM E96 D) [37]. In the cup method, there is certain pressure difference maintained on two sides of the specimen. Parameters relating water vapor permeability are calculated after testing the water vapor transmission rate of the specimen under specified temperature and relative humidity. The cup method can be operated in two ways based on the same testing principle: desiccant method in which water vapor transmits into the test dish, and water method in which water vapor transmits out of the test dish. We used the water method. In the water method, the dish contains distilled water, and the weighings determine the rate of vapor movement through the specimen from the water to the controlled atmosphere [38]. The unit is expressed as g/m^2/day.

RESULTS AND DISCUSSION

First, the water-repellent characteristics of the treated fabrics were determined. All samples (Sample No 1-4) were given 100 as rating because of non-wetting of the fabrics. Afterwards, the water resistancy of the treated fabrics was tested in the form of single-and two-ply. Also greige fabrics were tested as reference. They exhibited water permability values of 17-18 (single-ply) and 22-24 cmH_2O (two-ply).

Water resistancy test results of the fabrics treated with the Asahi Guard® recipe are given in *Table II*. Generally, densely woven fabrics, namely, plain weave (Sample 1 and 3) exhibited higher water resistancy values in comparison to the loosely woven fabrics, twill weave (Sample 2 and 4). And Co/PES fabrics (Sample 3 and 4) delivered sligthly higher values than Co/Co fabrics (Sample 1 and 2). Two-ply structures almost doubled the water resistancy values. And the best result were been obtained with the Co/PES plain fabric (88.3±0.1 cmH_2O).

It is known that breathability is meaningless without a high standard of waterproofness, and initial hydrostatic head values of 500 cm of water (cmH_2O) for high quality products to 130 cm of water for lower grade products have been reported [39]. According to the water permeability tests performed on the treated fabrics, neither single-ply nor two-ply fabrics pass the test since the results are far below 130 cmH_2O.

TABLE II. Water resistancy of the Asahi Guard® treated fabrics.

Sample No.	Water Resistancy (cmH_2O)	
	Single-ply	Two-ply
1	46.8±2.3	73.7±0.6
2	33.6±1.2	43.4±0.9
3	49.5±3.1	88.3±0.1
4	35.3±0.6	44.0±0.2

Water vapor permeability (WVP) test results of the non-treated and finished fabrics with the water-repellent chemical are given in *Table III*. Desized and scoured fabrics without water-repellent finishing process showed WVP values changing between 2675±8 and 2805±3 g/m^2/day. The same fabrics with two-ply structures delivered lower values. These results are reasonable when considering the fact that the resistance of the fabric to water/moisture vapor transmission increased with increasing fabric's thickness [40-42]. Generally, replacement of the weft yarns with PES fibers (Sample 3 and 4) led to increased vapor resistance resulting in lowered WVP values. In previous studies [27-31,42,43], it was established that using hydrophobic fiber types leads to decreased water vapor transmission through fabrics. And densely woven structures (Sample 1 and 3) exhibited lower WVP values in comparison to the loosely woven fabrics (Sample 2 and 4). These results are in accordance with the literature studies [32,33]. Analysis of the experimental results verified that after hydrophobic treatment, the fabrics did not show any significant change in WVP values when compared to their untreated counterparts. Accordingly, the finishing process applied has a little effect on water vapor permeability of the fabrics, which is in accordance with the study of Wang and Yasuda [26].

TABLE III. Water vapor permeability values of the non-treated and treated fabrics.

Sample No.	Water Vapor Permeability (g/m^2/day)			
	Only Pre-treatment		Asahi Guard®	
	Single-ply	Two-ply	Single-ply	Two-ply
1	2776±4	2714±7	2744±6	2684±5
2	2805±3	2745±3	2801±4	2712±3
3	2687±5	2675±8	2667±2	2642±6
4	2718±3	2701±3	2736±4	2663±4

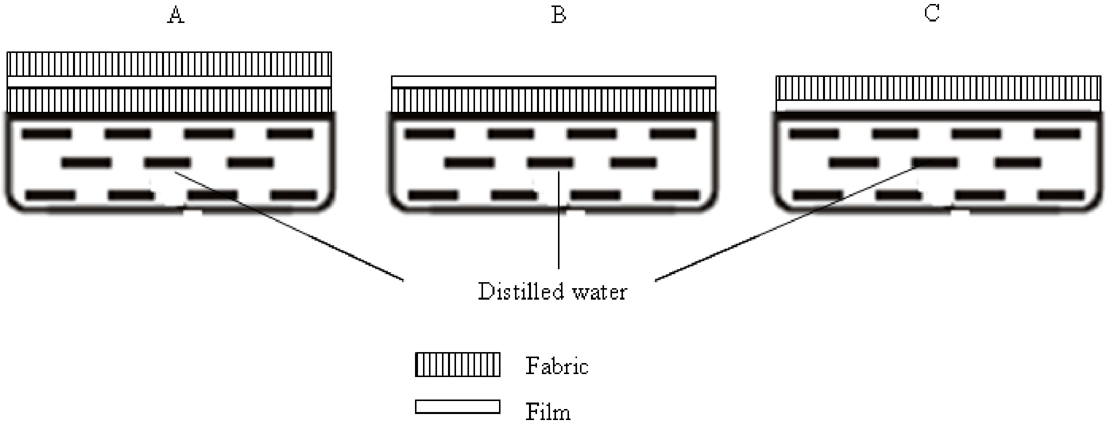

FIGURE 1. The schematic of the structures consisting of microporous films.

Afterwards, the fabrics were tested using microporous breathable films. In order to determine any effect, different structures were generated and tested. The schematic of the structures tested are given in *Figure 1*. Water resistancy and water vapor permeability of the films alone were also tested as reference. They were determined to be 53.7±2.1 cmH_2O and 2110±5 $g/m^2/day$, respectively. The measured values of water resistance and water vapor permeability of the treated fabrics with breathable films have been given in *Table IV* and *V*.

Desized and scoured samples having the A and C structures were not able to be tested in terms of water resistancy since the top-layer is the fabric and, therefore, a whole wetting of the fabric was observed. However, drops have to be observed for evaluation of the water resistancy test. A noticable difference was detected in pre-treated fabrics when the weave type was changed from plain (Sample 1) to twill (Sample 2). The only pre-treated fabric structure B (Sample 1) and microporous film alone have the water resistance values of 94.4±1.2 and 53.7±2.1 cmH_2O, respectively. It is obvious that the plain fabrics (Sample 1 and 3) –though only pre-treated- acted as a barrier for water. Nonetheless, only a slight change has been observed in B structures consisting of loosely woven fabric types (Sample 2 and 4), which is possibly due to the barrier effect of the hot-melt adhesive film. Apart from that, Co/Co and Co/PES fabrics delivered nearly the same water resistance values (*Table IV*). All samples delivered unsatisfactory water resistance values.

The fabrics treated with Asahi Guard® having the A structure consisting of fabric as the inner and outer layers and film as the middle layer exhibited the most striking results when compared with other structures, i.e., B and C. Plain weave type fabrics with the A structure (Sample 1 and 3), delivered the highest water resistancy being 352±1.7 (Sample 1) and 354.4±0.8 cmH_2O (Sample 3). Apparently, the fabric having the PES in weft direction did not influence the waterproofness property. Loosely woven fabrics have lower values, i.e., 248.4±2.4 (Sample 2) and 240±2.7 cmH_2O (Sample 3). Asahi Guard® treated plain fabrics (Sample 1 and 3) with the B structure have values ranging between 113.7±2.6 and 115.4±0.4 cmH_2O. On the other hand, twill fabrics (Sample 2 and 4) showed very low water resistance values (*Table IV*). A difference –though to a small extent- was observed when the structure was changed from B to C. Again, plain fabrics had much higher values than the twill fabrics. According to these results, the weave type used and the structure generated have an enormous effect on achieving materials with enhanced water resistancy. Considering the fact that waterproofing requires filling the pores of the fabric, it is reasonable to have more pronounced waterproofness in densely woven plain fabrics.

These results show that the generation of layered structures by only simple layering is not sufficient for enhanced water resistancy. On the other hand, using densely woven and water-repellent finished fabrics together with microporous breathable films in layered form of type A seems to be satisfactory in terms of waterproofness and breathability. Accordingly, fabrics should have something on them to resist water to some extent. Using tightly woven and water-repellent finished fabrics and using microporous breathable films, increasing number and sequence of layers (fabric-film-fabric) led to unforeseenly more pronounced resistive property of the structures than expected and provided the desired water resistancy. It should be pointed out that the EVA–based adhesive film also has an impact on waterproofness and water vapor permeability to some extent.

TABLE IV. Water resistancy of the non-treated/treated fabrics consisting of microporous films.

Sample No.	Water Resistancy (cmH_2O)					
	Only Pre-treatment			Asahi Guard®		
	A	B	C	A	B	C
1	n.a.	94.4±1.2	n.a.	352±1.7	115.4±0.4	110.8±1.6
2	n.a.	63.3±0.8	n.a.	248.4±2.4	63.5±4.3	64.9±1.9
3	n.a.	87.7±0.9	n.a.	354.4±0.8	113.7±2.6	121.7±2.1
4	n.a.	61.3±3.6	n.a.	240±2.7	62.7±3.1	59.3±1.1

n.a.: not available

Water vapor permeability results are given in *Table V*. Generally, using breathable films decreased the water vapor transmission rate of the laminated structures since WVP values of the pre-treated and finished fabrics are in the order of 2700 to 2800 $g/m^2/day$ and that of the microporous breathable film is 2110 $g/m^2/day$. Nevertheless, laminated structures have WVP values ranging between 1820 to 2060 $g/m^2/day$. Apparently, the number of layers independent of the sequence and adhesive film also lead to decreased WVP values.

Independent upon the structures (A, B, and C) generated, Co/Co fabrics (Sample 1 and 2) exhibited generally higher water vapor permeability values than Co/PES structures (Sample 3 and 4). In all samples only small differences were observed in WVP values, which can be considered negligible. It was noticed that rather than weave type. The fiber type used was the most influential factor affecting water vapor diffusion and hence water vapor permeability.

Moisture regain of the material will be increased causing higher diffusivity with used cotton in weft and warp yarns. In the same way moisture transfer through sorption-desorption process will increase with the hygroscopicity of the material. A hygroscopic fabric absorbs water vapor from the humid air and releases it in dry air. This enhances the flow of water vapor to the environment compared to a fabric which does not absorb and reduces the moisture built up in the microclimate. Whereas fabric with less hygroscopicity will provide higher resistance to the water vapor transfer. In the same way it was seen that vapor resistance of the fabric increases when cotton is used in weft yarns with PES.

TABLE V. Water vapor permeability values of the Asahi Guard® treated fabrics consisting of microporous films.

Sample No.	Water vapor permeability ($g/m^2/day$) Asahi Guard®		
	A	B	C
1	2011±3	2061±4	2044±1
2	2032±5	2085±6	2074±2
3	1836±3	1869±3	1872±4
4	1848±3	1852±2	1891±2

CONCLUSION

In this study, it was revealed that alone water-repellent finished fabrics and alone microporous breathable films couldn not provide waterproofness. Nonetheless, waterproof and yet water vapor permeable structures were obtained with layered structures consisting of water-repellent finished fabrics and microporous films were formed in a reasonable way. We anticipate that structures such as these can find application in the construction industry. To be more spesific, independent of the weave type and fiber type used, all samples treated with the Asahi Guard® and having the type A structure exhibited satisfactory results in terms of waterproofness and breathability. All Asahi Guard® treated fabrics with the B and C structures did not satisfy the waterproofness, since they all have values lower than 130 cmH_2O.

ACKNOWLEDGEMENT

This work was supported by Research Fund of the Erciyes University. Project Number: FBA-10-3015. I would like to thank Madosa Tekstil Ltd. Şti., Hasözgen Tekstil San. ve Tic. A.Ş., Pelsan Tekstil Ürünleri San. ve Tic. A.Ş. and ATEG Mühendislik Ltd. Şti. for providing fabrics and films.

REFERENCES

[1] Rupp, J., "Architectural Textiles: Economical And Ecological Roofing", *Textile World Nonwovens / Technical Textiles*, March/April 2011.

[2] Technical Textiles and Nonwovens: World Market Forecasts to 2010, David Rigby Associates, www.davidrigbyassociates.com, internet access date: 01/06/2011.

[3] Kang, Y.K., Park, C.H., Kim, J, Kang, T.J., 2007, "Application of Electrospun Polyurethane Web to Breathable Water-proof Fabrics", *Fibers and Polymers*, 8/5, 2007, 564-570.

[4] Holms, D.A., 2000, "Waterproof Breathable Fabrics", In: Horrocks, A.R. and Anand S.C. (eds), *Handbook of Technical Textiles*, The Textile Institute, Wood Head Publishing Ltd., Cambridge, England, 2000, 282–315.

[5] Sen, A.K., in "*Coated Textiles: Principles & Applications*", , Technomic Publishing Co. Inc., Lancaster, Basel, 2001, 133–154.

[6] Gretton, J.C., Brook, D.B., Dyson, H.M., Harlock, S.C., "Moisture Vapor Transport through Waterproof Breathable Fabric and Clothing Systems under a Temperature Gradient", *Textile Research Journal*, 68/12, 1998, 936–941.

[7] Yadav, A.K., Kasturiya, N., Mathur, G.N., "Breathablility in Polymeric Coatings", *Man-Made Textiles in India*, 45/2, 2002, 56–60.

[8] Save, N.S., Jassal, M., Agrawal, A.K., "Polyacrylamide based Breathable Coating for Cotton Fabric", *Journal of Industrial Textiles*, 32/2, 2002, 119–138.

[9] White, P.A., Sleeman, M.J., Smith, P.R., "Retroflective Fabrics and Method of Production, Extracts from European Patent Applications,-Part-1B: Primary Industry, Fixed Constructions", *Mining*, 20(14): 1261. 2004, EP 1402107.

[10] Naka, Y., Kawakami, K., USP 4560611: Moisture-Permeable Waterproof Coated Fabric, Shirley Institute. Toray Industries Inc., 1985, December: 8602376.

[11] Sun, K.K., EP 0689500: Flame-retardant Waterproof and Breathable Laminate, EMDOCS. Gore and Associates Inc. WL, 1996, January: 1950617.

[12] Speri, F.S., Guillaume, J.L., USP 4537817: Waterproof Fabric and Fabrication Method thereof, Shirley Institute. 1985, August: 8507877.

[13] Kafchinski, E.R., Chung, T.S., Timmons, W., Gamsan, J., USP 5358780: Breathable Water Resistant Fabrics, 1994, October: 861756.

[14] Tanaka, T., Tanaka, T., Kitamura, M., USP 4695484: Process for Forming Moisture-Permeable Waterproof Coating on Fabrics, Shirley Institute. Dai Ichi Kogyo Seiyaku Co. Ltd, 1987, September: 8707301.

[15] Etzold, S., USP 5855992: Waterproof, Multilayered Nonwoven Fabric of Reduced Weight having Good Vapor Permeability and Method for its Production EMDOCS. Corovin GmbH., 1996, October: 1977082.

[16] Herliky, D.J., EP 0686088: Waterproof Breathable Fabric for Outdoor Athletic Apparel EMDOCS. Aquatic Design Inc., 1995, December: 1949973.

[17] Williams, C., USP 6807683: Waterproof, Breathable Articles of Apparel, 2004, October: 978441.

[18] Morman, M.T., Hwang, P.H., Ono, A.T., Welch, H., Welch, M., Morell, C.J., Conyer, S.P.L., Uitenbroek, D., EP 1240014: Breathable Laminate Review on Designing the Waterproof Breathable Fabrics Permanently Conformable to the Contours of a Wearer Kimberly Clark Worldwide Inc., 1999, December: 2018161.

[19] Dutta, A., Lyon, R., USP 5650225: Three-dimensional, Seamless, Waterproof, Breathable, Flexible Composite Material Gore and Associates, 1997, August: 1962955.

[20] Oken, A., USP 5736467: Waterproof, Vapor-Permeable Fabric and Method for Generating same EMDOCS, 1998, April: 1968274.

[21] Herlihy, D.J., USP 5631074: Waterproof, Breathable Fabric for Outdoor Athletic Apparel EMDOCS, 1997, May: 1961581.

[22] Shimano, Y., Mukai, M., Chatani, H., Takashima, K., Umezawa, Y., Hara, D., USP 5626950: Moisture-Permeable, Waterproof Fabric and its Production Process, Komatsu Seiren Co., 1997, May: 1961216.

[23] Amano, J., Shimada, M., Takano, K. , Tohyama, S., EP 0225060: Waterproof Fabric having High Moisture Permeability and Method of making same, Toray Industries, 1986, May: 8800430.

[24] http://www.anarkimya.com/images/pdf/fluorocarbons.pdf, internet access date: 01/07/2011

[25] Das, B., Das, A., Kothari, V., Fanguiero, R., Araujo, M.D., "Moisture Flow through Blended Fabrics – Effect of Hydrophilicity", *Journal of Engineered Fibers and Fabrics*, 4/4, 2009, 20-28.

[26] Wang, J.-H., Yasuda, H., “Dynamic Water Vapor and Heat Transport Through Layered Fabrics Part I: Effect of Surface Modification”, *Textile Research Journal*, 61/1, 1991, 10-20.

[27] Adler, M.M., Walsh, W. K., “Mechanism of transient moisture transport between fabrics”, *Textile Research Journal*, 5, 1984, 334-343.

[28] Barnes, J.C., Holcombe, B.V., “Moisture sorption and transport in clothing during wear”, *Textile Research Journal*, 66/12, 1996, 777-786.

[29] Hong, K., Hollies, N.R.S., Spivak, S.M., “Dynamic moisture vapor transfer through textiles”, *Textile Research Journal,* 12, 1988, 697-706.

[30] Kim, J.O., “Dynamic moisture vapor transfer through textiles, Part III: Effect of film characteristics on micro climate moisture and temperature”, *Textile Research Journal*, 69 /3, 1999, 193-202.

[31] Suprun, N., “Dynamics of moisture vapor and liquid water transfer through composite textile structures”, *Int. J. Clothing Sci. & Tech.*, 15(3/4), 2003, 218-223.

[32] Adanur, S., Sears, W., in “*Handbook of Industrial Textiles*”, Technomic Publishing Corp. Inc. USA, 1995.

[33] Li, Y., “The Science of Clothing Comfort, Textile Progress”, *The Textile Institute*, 31(1/2), 2001, 1-138.

[34] Özcan, G., “Performance Evaluation of Water-repellent Finishes on Woven Fabric Properties”. *Textile Research Journal*, 77/4, 2007, 265-270.

[35] AATCC 22, Water Repellency: Spray Test, 2002.

[36] AATCC 127, Water Resistance: Hydrostatic Pressure Test, 1989.

[37] ASTM E96. E96M – 10, Standard Test Methods for Water Vapor Transmission of Materials, 1996.

[38] An Outline of Standard ASTM E96 for Cup Method Water Vapor Permeability Testing Labthink Instruments Co.,Ltd., 2009.

[39] Fung, W., in “*Products from Coated and Laminated Fabrics, Coated and Laminated Textiles*”, The Textile Institute, Woodhead Publishing Ltd., Cambridge, England, 2002, 149–249.

[40] Guo, J., “The Effects of Houshold Fabric Softeners on the Thermal Comfort and Flammability of Cotton and Polyester Fabrics”, MSc. Thesis, Virginia Polytechnic Institute and State University, 2003.

[41] Das, B., Das, A., Kothari, V.K., Fanguiero, R., Araújo, M.D., “Moisture Transmission Through Textiles, Part I: Processes involved in moisture transmission and the factors at play”, *AUTEX Research Journal*, 7/2, 2007, 100-110.

[42] Whelan, M.E., MacHattie, L.E., Goodings, A.C., Turl, L.H., “The diffusion of water vapor through laminae with particular reference to textile fabrics”, *Textile Research Journal, 25*/3, 1955, 197-223.

[43] Yoon, H.N., Buckley, A., “Improved comfort polyester. Part I: Transport properties and thermal comfort of polyester/cotton blend fabrics”. *Textile Research Institute, 54*/5, 1984, 289-298.

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