Hydrostatic Resistance and Mechanical Behaviours of Breathable Layered Waterproof Fabrics

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Abstract
Breathable layered waterproof fabrics have good applications in the fields of sportswear, protective clothing and construction industries. The properties of these fabrics in allowing water vapour to pass through while preventing liquid water from entering have made them unique. The mechanical properties of these fabrics are also very important for the satisfaction of the wearers. The layered constructions of these fabrics with different characteristic properties contribute to the influence on their hydrostatic resistance, mechanical properties and water vapour permeability. This study presents an experiment on eight different types of hydrophobic and hydrophilic membrane laminated layered fabrics used as sportswear during hot or cold weather. The hydrostatic resistance, tensile strength, stiffness and water vapour permeability of these fabrics were evaluated by varying different fabric parameters in the experiment. It was found from the test results that the fabric density, thickness and weight as well as types of membranes and layers have a significant effect on those properties of the layered fabrics.

Key words: waterproof fabric, hydrostatic resistance, tensile strength, stiffness, breathability.

Introduction
Breathability and waterproofing are two contradictory properties of fabrics. Breathability allows moisture vapour to flow from one side of a fabric to the other, and is determined by water vapour permeability [1]. Waterproofing resists water molecules from the outside to the inside of a fabric protecting the wearer from being wet under higher hydrostatic pressure. Waterproof fabric has fewer open pores; these are responsible for lower permeability of water vapour [2]. Hence it is a big challenge to maintain these two properties simultaneously in a fabric.

Again, clothing comfort is an integral part of the human body. The three main categories of clothing comfort are tactile comfort, thermal comfort and aesthetic comfort [3]. Besides these, it can be also categorised by mechanical comfort, which can be evaluated by fabric handle, rigidity and tensile properties. For sportswear, it should enable the release of sweat from the surface of skin in hot weather and prevent excessive heat loss in cold weather. Moreover, this fabric should have proper tensile strength and better stiffness for the satisfaction of the wearer.

However, different types of waterproof breathable fabrics can be developed from closely woven fabrics, micro-porous membranes and coating, hydrophilic membranes and coating, a combination of micro-porous and hydrophilic membranes and coating, retroreflective micro-crobeads, smart breathable fabrics and fabrics based on biomimetics [4-6]. Micro-porous membranes have holes that are much smaller than the size of the smallest raindrops, but much larger than the water vapour molecular size. For this reason, water vapor molecules can enter but water cannot penetrate the fabric. On the other hand, nano-porous hydrophilic membranes allow water vapour to pass in a different way. By the chemical adsorption process, water vapour is transmitted here. An amorphous region is developed in the main polymer system of the hydrophilic part. This amorphous region acts as intermolecular pores that allow water vapour molecules to pass, while liquid water penetration is prevented due to the membrane’s solid nature [7-8]. In this research work, different types of layered waterproof breathable polyester (PES) laminated fabrics used as sports clothing were investigated. Two different types of membranes were used to develop these laminated layered fabrics. One was a polytetrafluoroethylene (PTFE) micro-porous hydrophobic membrane and another was a polyurethane (PU) nano-porous hydrophilic membrane. Different characteristic properties of these fabrics were analysed. It was found from the analysis of test results that there are significant influences of fabric density, fabric thickness and fabric weight along with membrane hydrophobic and hydrophilic characteristics and layer types on their different properties, like hydrostatic resistance, mechanical properties and water vapour permeability.

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### Experimental

#### Materials

Eight different types of laminated fabrics with a micro-porous PTFE hydrophobic membrane and nano-porous PU hydrophilic membrane were developed and investigated in the experiment. The first six samples were PTFE membrane laminated and the last two were PU membrane laminated. Among the six PTFE membrane laminated samples, the first four were three-layered fabrics, the fifth and sixth were two-layered fabrics, and the seventh and eighth PU membrane laminated fabrics were two-layered. The outer layers of all eight samples were with PES plain woven structures. PTFE and PU membranes in the fabric samples were after PES plain structures as the middle layers for three-layered fabrics and as the inner layers for two-layered fabrics. Out of the four three-layered PTFE membrane laminated samples, the inner layers of the first two samples were with PES knitted structures, and the inner layers of the third and fourth samples were with PES fleece knitted structures. Cross-sectional images of one three-layered sample and one two-layered sample are shown in **Figure 1**. Characteristics of the samples are shown in **Table 1**.

#### Methods

Different characteristics of the laminated fabric samples, like the cover factor of the outer woven part, stitch density of the inner knitted part and fabric density of the whole laminated fabric sample, as shown in **Table 1**, were established under standard atmospheric conditions.

**Cover factor**

The warp and weft cover factor of the outer woven part layer of the laminated fabric were measured using the Peirce equation [9]:

\[
K_1 = \frac{n_1}{(N_1)^{0.5}} \quad \text{and} \quad K_2 = \frac{n_2}{(N_2)^{0.5}} \quad \text{(1)}
\]

Here, \(K_1\) = warp cover factor, \(K_2\) = weft cover factor, \(n_1\) = warp yarn density/inch, \(n_2\) = weft yarn density/inch, \(N_1\) = English count of warp yarn, and \(N_2\) = English count of weft yarn.

**Stitch density**

The stitch density of the inner knitted layer part of the laminated fabric was calculated by the multiplication of wales/cm and courses/cm with the help of an optical microscope.

**Fabric density**

The fabric density of the whole laminated sample was calculated by the following **Equation (2)** [10]:

\[
\text{Fabric density} = \frac{W}{t} \quad \text{Kg/m}^3 \quad \text{(2)}
\]

Here, ‘W’ is the fabric mass per unit area, which was measured using the electronic weighing scale according to

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**Table 1. Characteristics of laminated fabrics.**

| Fabric sample code | Fabric construction (outer part to inner part) | Warp and weft cover factor of outer woven layer (\(K_1 \& K_2\)) | Stitch density of inner knitted layer, stitches/cm² | Fabric mass per unit area, g/m² | Fabric thickness, mm | Fabric density, Kg/m² |
|--------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------|---------------------|----------------------|
| WMK-1              | PES plain + PTFE + PES Knitting               | (10 & 7)                                        | 273                                             | 89                            | 0.21                | 423.81               |
| WMK-2              | PES plain + PTFE + PES Knitting               | (19 & 14)                                       | 925                                             | 167                           | 0.35                | 477.14               |
| WMF-3              | PES plain + PTFE + PES fleece knitting        | (15 & 12)                                       | 192                                             | 314                           | 1.20                | 261.67               |
| WMF-4              | PES plain + PTFE + PES fleece knitting        | (15 & 13)                                       | 221                                             | 369                           | 1.27                | 306.30               |
| WM-5               | PES plain + PTFE                             | (18 & 12)                                       | –                                               | 86                            | 0.19                | 452.63               |
| WM-6               | PES plain + PTFE                             | (18 & 14)                                       | –                                               | 112                           | 0.24                | 466.67               |
| WM-7               | PES plain + PU                               | (22 & 16)                                       | –                                               | 139                           | 0.26                | 534.62               |
| WM-8               | PES plain + PU                               | (23 & 17)                                       | –                                               | 158                           | 0.29                | 544.83               |

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**Table 2. Different properties of laminated fabrics.**

| Properties                                | WMK-1 | WMK-2 | WMF-3 | WMF-4 | WM-5 | WM-6 | WM-7 | WM-8 |
|-------------------------------------------|-------|-------|-------|-------|------|------|------|------|
| Hydrostatic resistance, cmH₂O             | Mean  | 1464  | 1522  | 1087  | 1114 | 1481 | 1505 | 1578 | 1597 |
| [SD]                                      |       | 6.55  | 6.13  | 4.55  | 4.11 | 6.65 | 4.78 | 5.73 | 4.55 |
| Breaking force, N                         | Mean  | 410   | 478   | 356   | 379  | 428  | 444  | 501  | 513  |
| [SD]                                      |       | 5.50  | 7.69  | 7.94  | 9.44 | 7.86 | 5.99 | 5.78 | 3.50 |
| Bending rigidity, 10⁹ N·mm⁻¹              | Mean  | 7.56  | 13.58 | 27.19 | 28.10 | 6.49 | 8.16 | 10.94 | 12.88 |
| [SD]                                      |       | 0.17  | 0.12  | 0.15  | 0.12 | 0.12 | 0.26 | 0.07  | 0.21 |
| Relative water vapour permeability, RWP, %| Mean  | 47.60 | 42.74 | 33.58 | 30.64 | 48.32 | 45.60 | 40.14 | 38.52 |
| [SD]                                      |       | 0.37  | 0.23  | 0.28  | 0.29 | 0.24 | 0.30 | 0.21  | 0.20 |
| Evaporative resistance, Rₑ, m³Pa/W        | Mean  | 6.44  | 8.42  | 11.64 | 12.76 | 6.16 | 7.86 | 9.44  | 9.92  |
| [SD]                                      |       | 0.21  | 0.27  | 0.22  | 0.21 | 0.10 | 0.19 | 0.24  | 0.12  |
the EN 12127 standard. Fabric thickness ‘t’ was measured according to the EN ISO 5084 standard at a pressure of 100 Pa with a Louis Schopper Automatic Micrometer (Germany).

**Hydrostatic resistance test**
An SDL ATLAS Hydrostatic Head Tester Model MO18 (USA) was used at 20±2 °C for hydrostatic resistance testing according to CSN EN 20811 [11]. The rate of increase in water pressure was 60±3 cmH₂O/min. The maximum compressor pressure of 80 PSI was used. Water pressure was recorded at the point where water penetrated from the outer to inner layer. Here the unit was expressed as cmH₂O; test results are given in Table 2.

**Tensile strength test**
For the tensile strength of the samples, a Testometric M350-5CT machine (UK) was used at room temperature according to the CSN EN ISO 13934-1 standard. The tensile testing speed was 100 mm/min and the specimen size was kept at 20 cm x 5 cm. The result was expressed as the breaking force in Newtons (N). Five sets of experiments were performed, the average results of which with standard deviations are shown in Table 2.

**Measurement of bending rigidity**
The bending force of the fabric was directly measured by a TH-7 instrument (Technical University of Liberec, Czech Republic) [12]. The bending rigidity was calculated by multiplication of the bending force value with a constant value obtained (0.7 x 10⁻⁶), and the unit was expressed as Nm. Test results are given in Table 2.

**Determination of water vapour permeability**
PERMETEST apparatus (Senzora, Czech Republic) was used to determine the water vapour permeability according to the ISO 11092 standard without any destruction of the laminated fabric samples. The sample was placed on a measuring head over a semi-permeable foil and exposed to parallel air flow at a velocity of 1 m/s [13]. The temperature of the measuring head was maintained at room temperature for isothermal conditions. A computer monitor connected to this instrument expressed the relative water vapour permeability (RWVP) in % and evaporative resistance (Rₑ) in m²Pa/W. The results obtained are shown in Table 2.

### Results and discussion

**Comparison of hydrostatic resistance**
Eight different types of fabric samples of various fabric density were examined. From Figure 2, it is found that there is a significant effect of fabric density on the hydrostatic resistance property. Among all the samples, WM-8 and WM-7 have higher hydrostatic resistance than the others due to their higher fabric density. Moreover their PU nano-porous mem-

![Figure 2. Effect of fabric density on hydrostatic resistance.](image1)

![Figure 3. Effect of fabric density on breaking force.](image2)

![Figure 4. Relationship between hydrostatic resistance and breaking force.](image3)

![Figure 5. Effect of fabric thickness on bending rigidity.](image4)
Evaporative resistance (R<sub>et</sub>) and RWVP% indicate the water vapour permeability of the fabric samples. Water vapour permeability is higher when the R<sub>et</sub> value decreases or RWVP% increases. In Figures 6 and 7, the effect of fabric weight (mass per unit area) on water vapour permeability is shown. The R<sub>et</sub> value of the laminated fabric increases with an increase in fabric weight, as shown in Figure 6, and here the correlation coefficient obtained is 0.9296. On the other hand, the RWVP% of the laminated fabric decreases with an increase in fabric weight, as shown in Figure 7, and here the correlation coefficient is – 0.9404.

Among all the samples, WMF-4 and WMF-3 have the lowest water vapour permeability due to their higher fabric weight. Moreover their inner knitted fleece structures and higher thickness properties cause more air entrapment, which lowers the diffusion rate of water vapour. As a result, the release of sweat from the body in the form of water vapour is not easy for these samples. Hence these two types of fabrics are less suitable as sports fabrics, but can still be used as winter sports fabrics. On the other hand, samples WM-5 and WMK-1 show better water vapour permeability than the other

**Comparison of stiffness**

The stiffness test result represents the rigidity of the fabric, determined by the bending rigidity. The bending rigidity of a fabric is an important comfort parameter. Very stiff fabric can be uncomfortable and unfit for use. From Figure 5, it is evident that thickness is the vital determining factor which influences the bending rigidity of the layered laminated fabric samples. Here the correlation coefficient is 0.9807, which determines the positive significant influence of fabric thickness on bending rigidity. However, the thickness of WMF-4 and WMF-3 are higher than for the other six samples. Similarly the bending rigidity of these two samples is also higher than for the rest due to their higher thickness. Among the other six samples, WMK-2, WM-8 and WM-7 have higher rigidity than the other three due to their higher thickness. And the lowest bending rigidity is obtained in the case of sample WM-5 due to its lowest thickness property.

**Figure 6. Effect of fabric weight on R<sub>et</sub> value.**

**Figure 7. Effect of fabric weight on RWVP%**
fabrics due to their lower fabric weight than the others. These fabrics can provide better thermal comfort during sports activities in the summer season, releasing the increased sweating. However, water vapour permeability is lower for samples WM-8 and WM-7 than for WMK-2, although WMK-2 has higher fabric weight than these two samples. The reason is their PU nano-porous membranes reducing the diffusion rate of water vapour, which results in less water vapour permeability.

**Conclusions**

In the experiment, different properties of membrane laminated layered fabrics, like hydrostatic resistance, tensile strength, bending rigidity and water vapour permeability were analyzed. From the test results, it is clear that fabric density and compactness influence the hydrostatic resistance and tensile strength properties significantly. Fabric thickness greatly affects the bending rigidity of the fabrics, whereas water vapour permeability is impacted by the fabric weight as well as fabric compactness and the hydrophobic or hydrophilic nature of the membrane. Moreover there is a positive relationship between the hydrostatic resistance and tensile strength properties.

Laminated layered fabrics with higher hydrostatic resistance and better breathability are considered for outdoor sports clothing. Moreover better tensile strength along with low bending rigidity is preferable for users. Fabrics with better water vapour permeability are suitable for summer sports clothing, whereas those with less water vapour permeability can be used for winter sports clothing. Among all the samples investigated, WM-8 has the highest hydrostatic resistance and tensile strength properties. WM-5 and WMK-1 are more water vapour permeable and also have less bending rigidity; moreover their hydrostatic resistance and tensile strength are also quite satisfactory. As a result, these two types of fabrics should be more preferred by users as summer sports outdoor clothing. WMF-3 and WMF-4 fabric samples are suitable as winter sports clothing due to their lower water vapour permeability. However, two layered fabrics can be used as winter sports clothing, adding sufficient lining materials.

Finally it can be said that during the designing of summer or winter sports waterproof breathable laminated fabrics, hydrostatic resistance, mechanical properties and water vapour permeability should be considered to be of great importance for the comfortability of the wearers.

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**References**

1. Das B, Das A, Kothari V, Fanguiero R, Araujo M D. Moisture flow through blended fabrics - effect of hydrophilicity. J Eng Fib Fab 2009; 4(4): 20-28.
2. Ozen I. Multi-layered breathable fabric structures with enhanced water resistance. J Eng Fib Fab 2012; 7(4): 63-69.
3. Yoon H N, Sawyer L C, Buckley A. Improved comfort polyester – Part II: Mechanical and surface properties. Text Res J 1984; 54: 357-365.
4. Gretton J G, Brook D B, Dyson H M, Harlock S C. Moisture vapor transport through waterproof breathable fabric and clothing systems under a temperature gradient. Text Res J 1998; 68: 936-941.
5. Yadav A K, Kasturiya N, Mathur G N. Breathability in polymeric coatings. MM Text India 2002; 45: 56-60.
6. Save N S, Jassal M, Agrawal A K. Polyacrylamide based breathable coating for cotton fabric. J Ind Text 2002; 32: 119-138.
7. Mukhopadhyay A, Midha V K. A review on designing the waterproof breathable fabrics – Part I: Fundamental principles and designing aspects of breathable fabrics. J Ind Text 2008; 37: 225-262.
8. Mayer W, Moh U, Schriner M. High-tech textiles: Contribution made by finishing in an example of functional sports and leisurewear. Int Text Bull 1989; 53(2): 16-32.
9. www.fibres2fabrics.blogspot.com/2013/03/cover-factor-of-fibre-yarn-and-fabric.html
10. Anumugam V, Mishra R, Militky J, Novak J. Thermo-acoustic behavior of 3D knitted spacer fabrics. Fib Polym 2015; 16: 2467-2476.
11. CSN EN 20811: 1994. Determination of water penetration resistance: Testing with water pressure.
12. Fridrichova L. A new method of measuring the bending rigidity of fabrics and its application to the determination of the their anisotropy. Text Res J 2013; 83: 883-892.
13. Boguslawska-Bączek M, Hes L. Effective water vapour permeability of wet wool fabric and blended fabrics. FIBRES & TEXTILES in Eastern Europe 2013; 21 1(97): 67-71.
14. Fung W. Products from coated and laminated fabrics, coated and laminated textiles. The Textile Institute, Wood Head Publishing Ltd., Cambridge, England, 2002. p.149.