Analysis of Water Resistance and Mechanical Performance of Microporous Polyurethane Membrane Laminated Waterproof Breathable Fabrics

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ABSTRACT

Composite waterproof breathable textile fabric made with membrane must be characterized by better water resistance and simultaneously good possible permeability of water vapour in order to use as protective clothing or sportswear. This paper describes an experimental analysis on multi-layered textile-polymeric fabrics prepared by microporous polyurethane membrane along with polyester woven and knitted fabrics. Polyurethane membrane was used with three different polyester plain woven fabrics and a one type of single jersey polyester knitted fabric to prepare two-layered and three-layered laminated fabrics. Different properties of these layered fabrics were analyzed on the basis of their different fabric parameters. Water resistance property was measured by SDL ATLAS Hydrostatic Head Tester, whereas water vapour permeability was evaluated by Permetest. Mechanical properties, i.e., bending rigidity and tensile strength which also play vital roles for the comfortability of the users were measured by TH-7 machine and Testometric M350-5CT machine respectively. From the test results and statistical analysis, it has been obvious that there are significant influences of different fabric parameters, i.e., fabric thickness, fabric weight, fabric density along with other fabric composition on their different properties, i.e., water resistance, water vapour permeability, bending rigidity and tensile strength for these two-layered and three-layered fabrics.

Keywords: layered fabric, water resistance, water vapour permeability, bending rigidity, tensile strength.

1 INTRODUCTION

Comfort is an integral part of the human body. Three main types of clothing comfort are tactile comfort, thermal comfort and aesthetic comfort [1]. Water vapour permeability which allows transmission of moisture and heat from the surface of human body into the environment is one of the most important factors for clothing comfort. Because clothing comfort sensation is determined mainly by a balanced process of moisture and heat exchange between human body and environment through clothing system [2].

Again, waterproof breathable fabrics are significantly used in the fields of protective clothing, sportswear and construction industries [3]. These fabrics transport water vapour effectively from inside to outside atmosphere as well as protect the human body from rain, wind and cold weather to maintain a constantly comfortable clothing microclimate. Waterproof breathable fabrics can be classified mainly into densely woven fabrics, laminated fabrics and coated fabrics. Multi-layered waterproof breathable textile-polymeric fabrics are produced from various types of water-tight and wind-tight polymeric membranes that are permeable to water vapour. These membranes are of two basic types: microporous membranes that are mostly of hydrophobic character and hydrophilic membranes with compact structure [4, 5]. Microporous membrane laminated fabrics have holes that are much smaller than the size of the smallest raindrops, yet are much larger than the size of water vapour molecules [6]. As a result, water droplets cannot penetrate this fabric, but water vapour molecules can penetrate.

However, this research study worked on microporous polyurethane (PU) membrane laminated fabrics that could be used as protective clothing or sports fabrics. For this purpose, firstly, polyurethane membranes were laminated with three different types of polyester plain woven fabrics to produce two-layered fabrics. Here, three different types of two-layered fabrics were prepared. Polyester woven fabrics acted as outer layers and membranes acted as inner layers. And secondly, polyurethane membranes were laminated with those three different types of polyester plain woven fabrics and a single jersy polyester knitted fabric to prepare three-layered fabrics. Here, three different types of three-layered fabrics were prepared. Polyurethane membrane acted as middle layer and knitted fabric acted as inner layer for each of three different types of three-layered fabrics. But, outer layers of three different laminated three-layered sample fabrics were three different polyester woven fabrics. Then all the produced layered six sample fabrics were characterized and analyzed statistically. It has been found from the test results and statistical analysis that there are significant influences of different fabric parameters on their different fabric properties.

2 METHODS

In order to produce two-layered and three-layered laminated fabrics, three different types of polyester plain

woven fabrics with different fabric weights were used as outer layers. One type of single Jersey polyester knitted fabric (K) with 127 GSM (g/m^2) was applied as inner layer for preparation of each three-layered laminated fabric. 20 GSM (g/m^2) microporous polyurethane (PU) membrane was used as inner layer for each two-layered fabric lamination and as middle layer for each three-layered fabric lamination. Particulars of three different types of woven fabrics are given in Table-1.

Fabric code	Type of fabric	Fabric weight (g/m^2)	Warp and weft cover factor of fabric (K_1 & K_2)
F-1	Polyester woven fabric	139	(14 & 12)
F-2	Polyester woven fabric	128	(13 & 10)
F-3	Polyester woven fabric	122	(11 & 10)

Table 1: Particulars of woven fabrics.

Comel PL/T 1250 Heat and Press Machine was used for producing six different types of laminated fabrics. Two-layered three samples were prepared placing one upon another in the order of polyurethane (PU) membrane and each of three different polyester woven fabrics separately. And three-layered three samples were prepared laying one upon another in the order of polyester knitted fabric, PU membrane and each of three different polyester woven fabrics separately. Then fabrics were laminated under heat and pressure treatment of the machine at 160°C temperature with 2 bar pressure for 15 seconds. Characteristics of produced six laminated sample fabrics are shown in Table-2.

Sample fabric code	Outer layer to inner layer	Areal density (g/m^2)	Thickness (mm)	Density (kg/m^3)
FM-1	F-1+PU	158±1.01	0.42±0.01	376±1.16
FM-2	F-2+PU	147±1.29	0.40±0.01	367±1.26
FM-3	F-3+PU	141±1.12	0.39±0.01	361±1.18
FMK-4	F-1+PU+K	283±1.77	0.69±0.01	410±1.55
FMK-5	F-2+PU+K	271±1.42	0.68±0.01	398±1.61
FMK-6	F-3+PU+K	263±1.26	0.67±0.01	392±1.85

Table 2: Characteristics of laminated sample fabrics.

3 RESULTS AND DISCUSSION

Water resistance

Water vapour permeability is meaningless without proper water resistance property. Here, water resistance property is measured by hydrostatic resistance value in the unit of cmH_2O. Hydrostatic resistance values of 500 cmH_2O for high quality products and 130 cmH_2O for lower grade products have been reported [7]. It is evident from Figure-1 and Figure-2 that all the laminated sample fabrics prepared in the experiment show the values more than 500 cmH_2O and these fabrics can be used as outdoor sports clothing. However, P-value from ANOVA for fabric weight and hydrostatic resistance is found less than 0.05 which explains a significant influence of fabric weight on water resistance of the samples. Pearson correlation coefficient (r) for fabric weight and hydrostatic resistance is obtained +0.9743 that represents a strong positive correlation between fabric weight and water resistance of the sample fabrics. Here, coefficient of determination (R^2) value is 0.9493 that denotes good strength linear association between fabric weight and water resistance of different samples. Again, P-value is obtained less than 0.05 from ANOVA for fabric density and hydrostatic resistance that also explains a significant influence of fabric density on water resistance of the samples. Here, r-value and R^2-value are obtained +0.9988 and 0.9976 respectively. This also indicates strong positive relation between fabric density and water resistance.

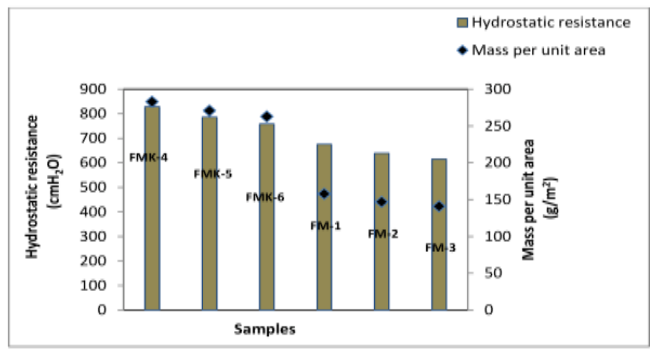

Figure 1: Fabric weight vs. hydrostatic resistance.

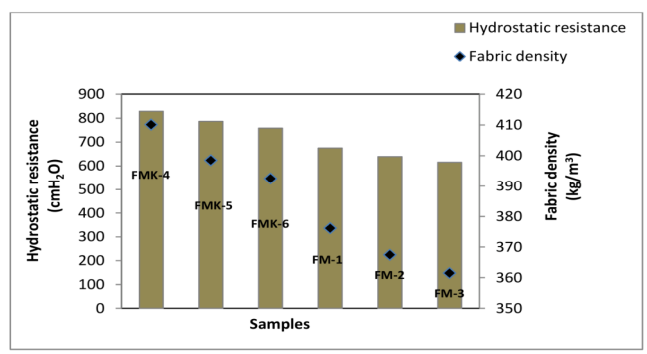

Figure 2: Fabric density vs. hydrostatic resistance.

However, all three-layered samples show better water resistance property than all two-layered samples as there are good increases of water resistance values for all three-layered samples when knitted fabrics are added as inner layers during their lamination process. Among the six samples, highest water resistance property is obtained for FMK-4 sample due to its highest fabric weight and density

and lowest is found for FM-3 sample due to its lowest fabric weight and density. When compared only two-layered three samples to each other, the best water resistance is obtained for FM-1 and when compared only three-layered three samples to each other, highest water resistance is found for FMK-4 sample. The reason is that outer woven layer parts of both of these two samples are prepared by F-1 polyester woven fabric whose cover factor is more than the cover factors of F-2 and F-3 polyester woven fabrics.

Water vapour permeabiity

Water vapour permeability of a fabric is obtained by measuring relative water vapour permeability (RWVP). Increased RWVP determines the higher water vapour transmission of the measuring samples. P-value is less than 0.05 from ANOVA of fabric weight and RWVP. This indicates the significant influence of fabric weight of the sample fabric on their RWVP. But, r-value and R^2-value are -0.9531 and 0.9084 respectively when correlation between fabric weight and RWVP is considered. This represents a negative strong relationship between fabric weight and RWVP as well as denotes a good linear relationship between them. Laminated sample fabric becomes more comfortable when the fabric weight is lower. Because, there is an increase of RWVP with the decrease of fabric weight.

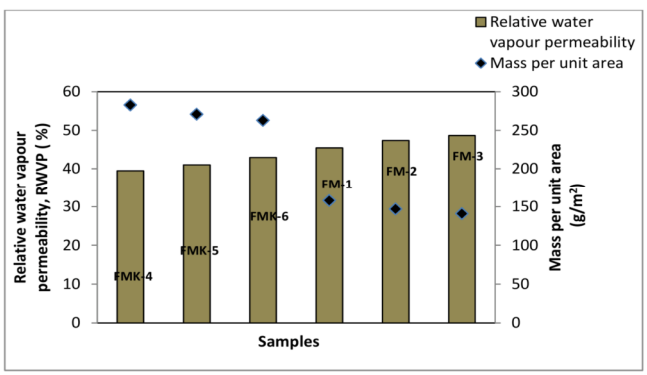

Figure 3: Fabric weight vs. RWVP.

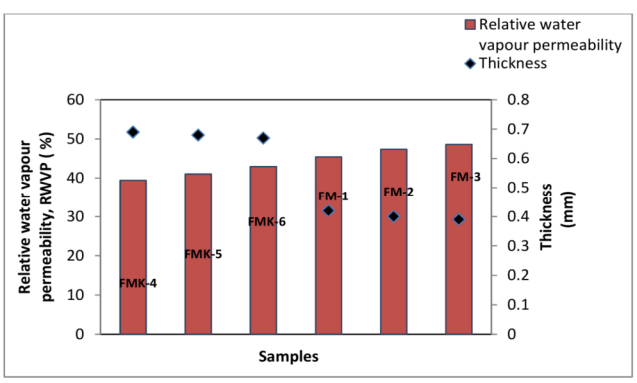

Figure 4: Fabric thickness vs. RWVP.

Again, P-value is obtained less than 0.05 from ANOVA of fabric thickness and RWVP. This also indicates the significant influence of fabric thickness on RWVP. But in this case, r-value and R^2-value are found -0.9373 and 0.8785 respectively and this indicates a good negative relationship between fabric thickness and RWVP. Here also laminated sample fabric becomes more comfortable with the decrease of fabric thickness, as there is an increase of RWVP with the decrease of fabric thickness. However, fabric weight has more influence than fabric thickness on RWVP for the sample fabrics. Because, r-value and R^2-value from correlation between fabric weight with RWVP are more than r-value and R^2-value from correlation between fabric thickness with RWVP.

It is evident from the Figure-3 and Figure-4 that relative water vapour permeability of the two-layered sample fabrics are higher than relative water vapour permeability of the three-layered fabrics. Because, when polyester knitted fabrics are added as inner layers in all three-layered samples, then fabric weight and fabric thickness of these samples are also increased resulting in less relative water vapour permeability. However, among all the samples, highest water vapour permeability is obtained in case of sample FM-3 with lowest fabric weight and thickness. This sample is also prepared with F-3 polyester woven fabric as an outer layer whose fabric weight is also lower than the fabric weights of F-1 and F-2 polyester woven fabrics due to its lower warp and weft cover factor. On the other hand, lowest water vapour permeability is obtained for the sample FMK-4 due to its highest fabric weight and thickness among all fabrics. Moreover, this sample is produced by F-1 polyester woven fabric as an outer layer whose weight is higher than the weights of F-2 and F-3 polyester woven fabrics due to its higher warp and weft cover factor.

Bending rigidity

Bending rigidity represents the fabric stiffness property. Very stiff fabric can be uncomfortable and unfit for use. It is evident from Figure-5 that thickness is the determining factor which influences on bending rigidity of the layered laminated fabric samples. P-value is obtained less than 0.05 from ANOVA of fabric thickness and bending rigidity. Here, pearson correlation coefficient (r) is +0.9999 and coefficient of determination (R^2) is 0.9999. This clearly determines a strong positive significant influence of thickness of the sample fabrics on their bending rigidity.

However, bending rigidity values of two-layered samples are lower than bending rigidity values of three-layered samples due to their lower thickness values than three-layered samples. Among all the samples, highest bending rigidity is obtained in case of sample FMK-4 due to its highest fabric thickness property. And lowest bending rigidity is found for the sample fabric FM-3 due to its lowest thickness property. When only two-layered three samples are compared to each other, higher bending rigidity

is obtained for FM-1 sample due to its higher thickness value than FM-2 and FM-3. Again, when only three-layered three samples are compared to each other, lower bending rigidity is found in case of sample FMK-6 due to its lower thickness value than FMK-4 and FMK-5.

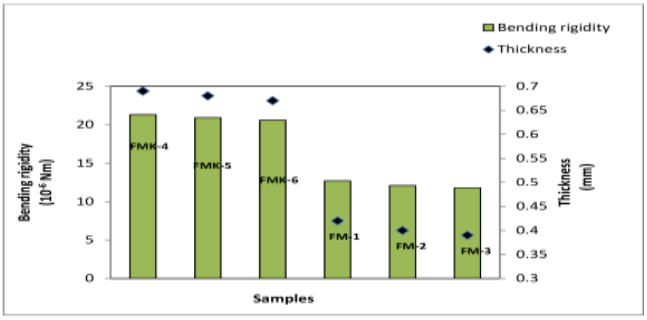

Figure 5: Fabric thickness vs. bending rigidity.

Tensile strength

Breaking force determines the tensile strength property of the sample fabrics. From ANOVA of fabric weight and breaking force, P-value is found less than 0.05 which explains a significant influence of fabric weight on the breaking force of the samples. Pearson correlation coefficient (r) and coefficient of determination (R^2) for fabric weight and breaking force are obtained +0.9523 and 0.9068 respectively. These results represent a strong positive correlation between fabric weight and breaking force of the laminated sample fabrics. Again, P-value is obtained less than 0.05 from ANOVA for fabric density and breaking force that indicates a significant influence of fabric density on breaking force of the samples. Here in this case, r-value and R^2-value are obtained +0.9984 and 0.9969 respectively. This also explains a strong positive linear relationship between fabric density and breaking force. So, it can be said from this statistical analysis that tensile strength of the laminated fabric increases with the increase of fabric weight and density.

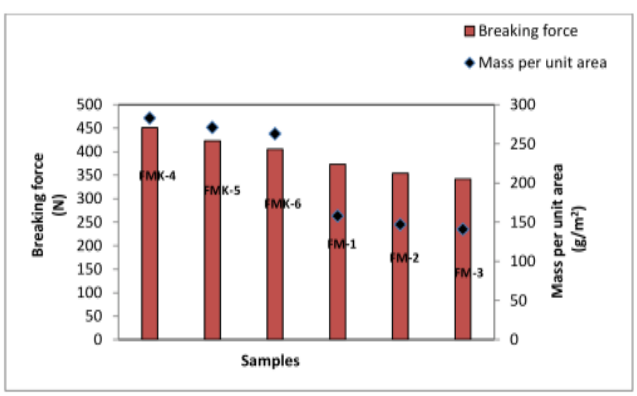

Figure 6: Fabric weight vs. breaking force.

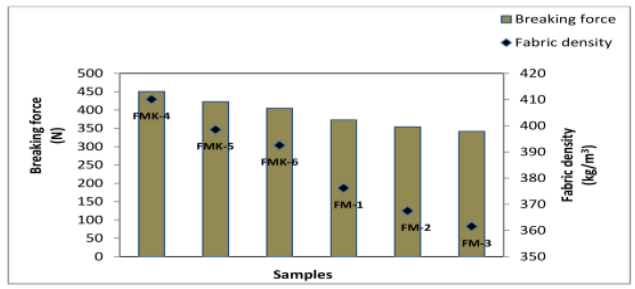

Figure 7: Fabric density vs. breaking force.

It is clear from the Figure-6 and Figure-7 that breaking forces for all three-layered samples are more than breaking forces of all two-layered samples. This is because of increasing fabric weight and fabric density of three-layered three samples after adding polyester knitted fabrics as their inner layers during lamination process.

4 CONCLUSIONS

In the experiment, influences of different characteristic parameters of PU membrane laminated fabrics were analyzed on their different properties. It has been found that hydrostatic resistance is significantly and postively influenced by the fabric weight and density. Water vapour permeability is negatively influenced by fabric weight and thickness. Fabric bending rigidity is positively influenced by fabric thickness, whereas, breaking force is significantly and positively influenced by fabric weight and density. Again, three-layered samples show more hydrostatic resistance property and breaking force than two-layered samples due to their higher fabric weight and density than two-layered samples. But, water vapour permeability of three-layered samples are lower than two-layered samples because of their higher weight and thickness. And bending rigidity is higher for three-layered samples than two-layered samples due to more thickness values. Finally it can be concluded that this analysis of the experiment would be helpful for a designer to make waterproof breathable outdoor sports fabrics.

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