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Performance Evaluation of Newly Designed Disposable Surgical Gowns

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ABSTRACT

Surgical gowns are used as protective clothing in operating room for medical personnel and patients to minimize the transmission of viruses and pathogens, and are designed to serve as a barrier against non-sterile area and to reduce the risk of infections. In this study, since disposable gowns provide better barrier effect compared to reusable ones, surgical gowns designed using nonwoven fabric and membrane-nonwoven combination were investigated in terms of their performance characteristics and thermal comfort properties. Functional properties of produced disposable surgical gowns such as tensile strength, tear strength, resistance to water penetration, air permeability, thermal properties, water vapor permeability and water vapor resistance were tested and statistically evaluated. Results show that SMS fabrics have higher tear strength than that of PP and PE fabrics, and welding method provides higher seam strength than that of ultrasonic one. Membrane reinforcement was found to be required for both PP and SMS fabrics, especially in areas that may be exposed to fluid passage. SMS fabrics have higher air permeability values than that of PP fabrics leading to improved comfort of the wearer. Membrane reinforcement caused an increase in thermal conductivity, thermal resistance, thermal diffusion, thermal absorption and water vapor resistance values. Considering the performance and comfort requirements of the wearer, SMS nonwoven fabric, and membrane reinforcement in areas where there is a possibility of exposure to body fluids was the most suitable model.

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Protective textile, surgical gown, thermal comfort, water vapour permeability

1. INTRODUCTION

Surgical gowns are used in the operating room to prevent transfer of microorganisms and body fluids from medical personnel to patient and also from patient to personnel. These gowns should be impervious to blood, liquids, and other infectious material. Current surgical gowns can be categorized as either reusable or disposable. The disposable surgical gowns are generally produced from nonwoven fabric. They should provide protection against body liquids and microorganisms with adequate level of comfort. Triple layer fabrics are generally used for surgical gown to meet desired requirements. Triple layer covers an outer layer resisting abrasion and tearing, middle layer providing barrier resistance to fluid penetration, soft bottom layer improving comfort. However, surgical gown usually has a chemical finish to further protective properties, and most likely areas to be exposed to body fluids should be reinforced with an extra layer. However, medical personnel feel less comfortable when wearing reinforced gown due to the less heat transfer leading to more sweating [1-6].

Thermal comfort is a critical product requirement, especially for prolonged operations. Thermophysiological comfort is associated with thermal balance of the human body and the body internal temperature must be kept constant at 37 °C. Any minor deficiency of comfort may have an adverse effect on the quality of work and safety. Even 5 °C changes in body temperature may result in fatal consequences such as hypothermia or hyperthermia [7].

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Since thermophysiological comfort is directly related to human physiology, its analysis is of great importance in textile applications, where there is an interaction between the textile material and human body. Therefore, the comfort of the person is a vital factor in evaluating the performance of the garment, as well as its protective performance. Thermophysiological clothing comfort depends on the heat and moisture transport properties of the garment that provide the body's heat balance [8-9]. In the literature, parameters affecting thermophysiological comfort are given as personal features, environmental features and clothing features [10-17]. Major clothing properties affecting thermal comfort include thermal conductivity, water vapor permeability, air permeability and water impermeability [2]. In addition, surgical gowns should allow freedom of movement, be lightweight and have adequate tensile strength.

To date, there is limited number of studies on the thermal comfort properties of nonwoven surgical gowns [18-22]. Pamuk et al. evaluated thermal comfort properties of different disposable surgical gowns (Spunlace normal, Spunlace reinforced and SMS normal) using the thermal manikin [18]. Woo et al. developed a theoretical model that provides thermal conductivity estimation for nonwoven fabrics. They measured the thermal conductivity of various nonwoven barrier fabrics for the designed model [19]. Issa et al. analyzed some of the thermal properties of disposable surgical gowns before and after different sterilization methods by evaluating the effects of sterilization on thermal comfort [20]. They concluded that disposable materials (laminate, nonwoven, PE) used in the hospital are affected by the sterilization process. Bogdan et al. examined the thermal insulation of modern materials used in the production of medical clothing and the thermal comfort properties of surgical clothing [21]. They stated that medical clothes made of modern materials lead to the risk of thermal stress. Aslan et al. investigated the comfort and microbial protection performances of two types of disposable and two types of reusable surgical gowns [22]. They found that the microfiber polyester woven gown has good thermal comfort performance.

The aim of this paper is to present comprehensive research to design a surgical gown considering the constructional and technological requirements of wearer. Three different types of polypropylene-based nonwoven fabric (a spunbond, a spunbond/meltblown/spunbond and a polyethylene coated nonwoven fabric) with different unit weights were used for surgical gown design. Differently from current literature, the regions that may be exposed to fluid passage were determined and their resistance to fluid transmission was improved by membrane integration. Secondly, nonwoven fabrics and nonwoven-membrane combinations were joined using new welding techniques including ultrasonic and hot air welding method. The performance of nonwoven fabrics and nonwoven-membrane combinations were extensively investigated in terms of thermal comfort, water vapor permeability, water permeability resistance, air permeability, and tensile strength. The findings of this study will provide a number of practical implications for designing a surgical gown considering wearer's comfort as well as protection.

2. MATRERIALS AND METHODS

2.1 Material

Since disposable gowns provide better barrier effect compared to reusable gowns, surgical gowns produced using polypropylene-based nonwoven fabrics were investigated. The nonwoven fabrics used in this study were supplied from Mogul Tekstil (Turkey), which is a key supplier of meltblown and meltblown/spunbond fabrics globally. Since fabric unit weight is one of the most important factors determining thermal comfort [23], three different types of polypropylene-based nonwoven fabric with different unit weights were used for surgical gown design. Polyurethane membrane (85 g/m^2) was used as a reinforcement for resistance to fluid transmission and integrated to nonwoven fabrics. The nonwoven fabrics used are as following:

1. 100% polypropylene based spunbond nonwoven fabric (PP)
2. 100% polypropylene based spunbond/meltblown/spunbond nonwoven fabric (SMS)
3. Polyethylene coated 100% polypropylene based spunbond nonwoven fabric (PE-coated nonwoven)

The technical properties of the fabrics were given in Table 1.

2.2 Methods

Production of the samples

Ultrasonic and hot air welding methods were used for the production of surgical gown. High frequency vibrations are used to bond two or more material layers in the ultrasonic welding method by means of a rapid heat increase inside the material. Ultrasonic welding machine parameters have a critical importance on the joint strength of fabric layers. Teksmak ultrasonic welding machine was used at a pressure of 2.2 bar, 2 m/min and 10 mm distance. Pfaff hot air welding sewing machine was used as an alternative method to the ultrasonic one in the regions where liquid impermeability is required and cannot be joined with ultrasonic welding method. Pfaff hot air welding sewing machine parameters are used as 355 °C temperature, 3 m/min velocity and 3.3 bar pressure. The parameters were kept constant for all samples.

Table 1. Properties of nonwoven fabrics used in this study

Sample codes	Mass per unit area (g/cm^2)	Thickness (mm)
SMS 35	35	0.33
SMS 50	50	0.37
SMS 60	60	0.42
SMS 80	80	0.45
SMS 90	90	0.50
PP 30	30	0.28
PP 50	50	0.38
PP 60	60	0.44
PP 70	70	0.48
PP 80	80	0.51
PP105	105	0.61
PP110	110	0.63
PE-coated nonwoven	35	0.15
PE-coated nonwoven	80	0.28
PE-coated nonwoven	100	0.38

In order to improve the resistance to fluid transmission, polyurethane membrane (85 g/m^2) was used as a reinforcement and integrated to nonwoven fabrics. PE-coated nonwoven fabric covers an absorbent inner layer made from spunbond and an outer layer made from a polyethylene material with a barrier effect against bacteria and fluid transmission. Since it is impervious to water, no membrane reinforcement is required for this type of fabrics. For this reason, membrane integration was only applied for PP and SMS fabrics. Two nonwoven fabrics were joined at the side seams using ultrasonic welding while hot air welding was used to join membrane-nonwoven combinations.

Performance evaluation of the samples

All nonwoven samples were tested for tensile and tear strength, water permeability resistance (hydrostatic pressure tester), air permeability tests. Tensile and tear strength tests were carried out using Titan James Heal Universal Strength Tester in accordance with the standard of TS EN ISO 13934-1 and TS EN ISO 13937-2, respectively. The hydrostatic pressure tester (M023B) was used to evaluate the seam's resistance to water penetration and resistance of the samples to water penetration according to TS 257 EN 20811 and ISO 811:2018, respectively. Air permeability test was carried out using Prowhite air permeability tester according to the standards of TS 391 EN ISO 9237. Seam strength of the samples was measured for both ultrasonic and hot air welding techniques using Titan James Heal Universal Strength Tester according to the standard of TS 1619-2 EN ISO 13935-2.

Nonwoven samples (SMS, PP and PE coated fabrics) and nonwoven samples reinforced with membrane (SMS + Membrane and PP + Membrane fabric) were evaluated in terms of thermal comfort properties, water vapor permeability and water vapor resistance. Thermal properties of the samples including thermal conductivity (λ), thermal absorptivity (b), thermal diffusion (a), thermal resistance (R) were measured by using Alambeta device according to standard of TS EN ISO 11092. Water vapor permeability and water vapour resistance of the samples were tested using Permetest tester (Skin model) according to TS EN ISO 11092.

Relative thermal comfort index (RTCI) of the samples was calculated to evaluate their capability to ensure comfort for winter clothing using the following formula [24]:

$$RTCI = \sum_{i=1}^{n}\left(a_{xi} * \frac{Xi - XiminIG}{Xi}\right) + \sum_{j=1}^{m}\left(a_{zj} * \frac{Zjmax - Zj}{ZjmaxIG}\right)$$

RTCI – Relative thermal comfort index

Xi – The value of ith parameter, which results in an improvement of thermal comfort when increased, where i = 1, 2, …, n,

ximinIG – minimum value of ith parameter needed to ensure thermal comfort,

zj – the value of jth parameter, which results in a deterioration in thermal comfort when increased, where j = 1, 2, …, m,
zjmaxIG – maximum value of jth parameter, which is acceptable from the point of view of thermal comfort

Experimental design for all tests has ben given in Table 2. All tests have been repeated for five times and the average was taken as a result.

Table 2. Experimental design of all tests

Independent variables for all tests			
Tear Strenght	**Seam strength**	**Thermal comfort tests, water vapor permeability**	**Air permeability, Water permeability resistance**
SMS (in all unit weights)	Hot air welding method	SMS (in all unit weights) SMS (in all unit weights) + membrane	SMS (in all unit weights)
PP (in all unit weights)	Ultrosonic welding	PP (in all unit weights) PP (in all unit weights) + membrane	PP (in all unit weights)
PE-coated nonwoven (in all unit weights)		PE-coated nonwoven (in all unit weights)	PE-coated nonwoven (in all unit weights)

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of tensile, tear and seam strength

The tensile and tear strength of nonwoven fabrics are presented in Figure 1. It is seen that tensile strength of nonwoven fabrics for both direction was quite high and suitable for use as a surgical grown [25]. Tear strength along warp direction was found to be higher than weft direction. In addition, SMS fabrics were observed to have higher tear strength than polypropylene and PE-coated nonwoven fabrics.

Seam strength of the samples was evaluated for both ultrasonic and hot air welding techniques. Table 3&4 show the seam strength of the samples for ultrasonic and hot air welding method, respectively. From Table 3, it is seen that samples sewed by ultrasonic method exhibited very high seam strength while some of them ruptured without allowing seam to open. Welding method was applied for fusing the membrane and nonwoven samples to each other. Table 4 shows that higher seam strength was obtained for welding method as compared to ultrasonic one.

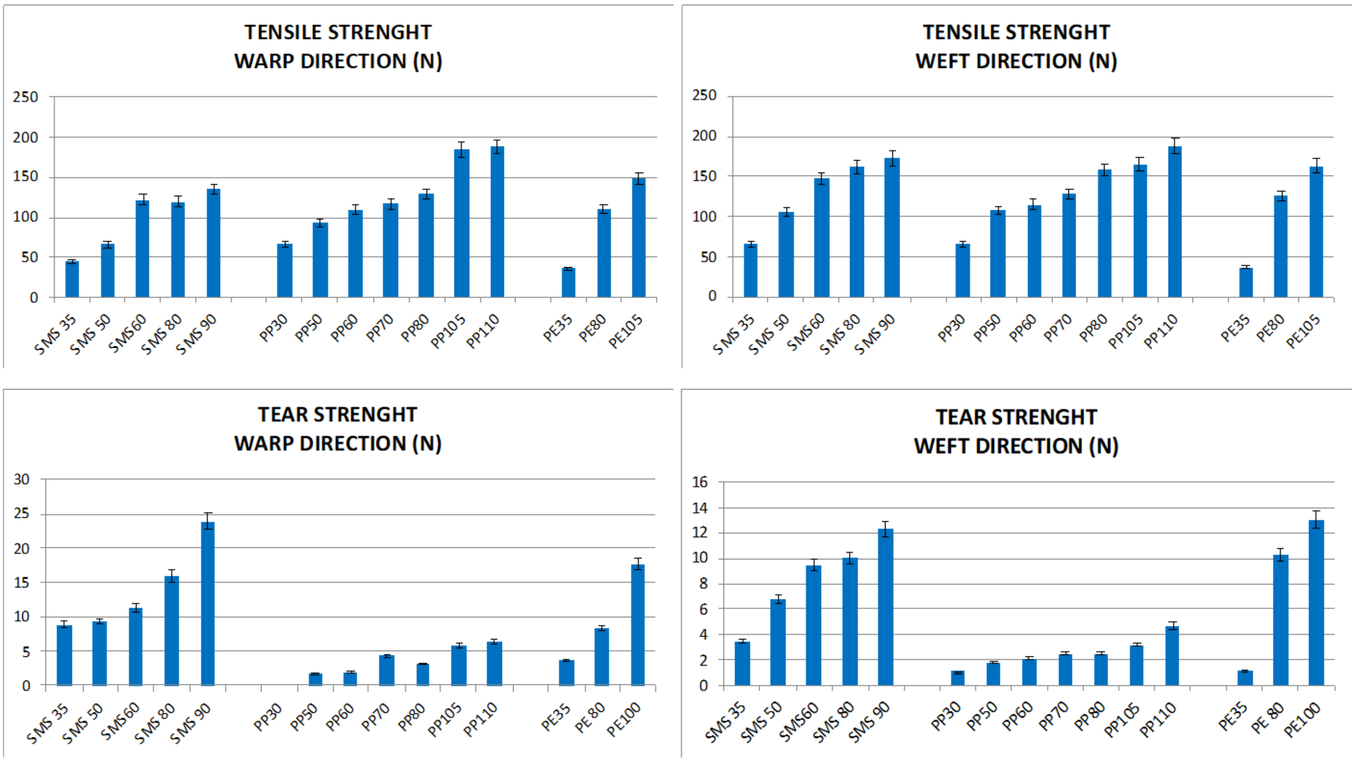

Figure 1. Tensile and tear strength of nonwoven fabrics

3.2 Evaluation of thermal properties

Thermal properties of the nonwoven (SMS, PP, PE-coated nonwoven fabric) and combined membrane-nonwoven samples (SMS+membrane, PP+membrane) were assessed in terms of thermal conductivity, thermal resistance, thermal absorption and thermal diffusion. Thermal results of nonwoven samples were presented in Figure 2, 3, 4 and 5.

Thermal conductivity is an important factor affecting heat transfer from the body to the garment. Thermal conductivity is the amount of heat transferred from the unit thickness of the material to the unit surface area under steady state conditions and when the heat transfer is only dependent on the temperature difference. The higher the thermal conductivity, the faster the heat transfer from the skin to the fabric, resulting in colder feeling [7, 9]. As shown in Figure 2, thermal conductivity of the samples is in the range of 27-43 mW/m.K. Combined membrane-nonwoven samples (SMS+membrane, PP+ membrane) have higher thermal conductivity as compared to SMS and PP samples without membrane. Heat conduction increases with increase in mass per unit area.

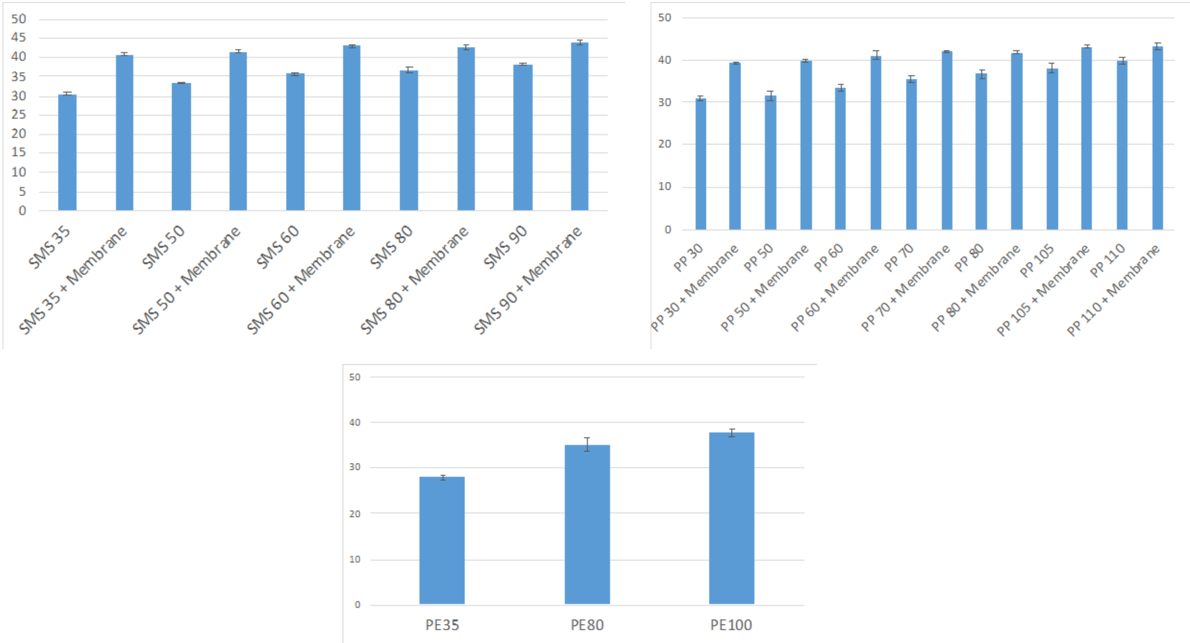

Figure 2. Thermal conductivity of the samples in (mW/m.K)

Table 3. Seam strength for ultrasonic welding method

	WARP		**WEFT**			
Sample	**FORCE AT SEAM OPENING OF 6 MM**		**UNSEAMED WEFT**		**SEAMED**	
	Mean	**Std deviaton**	**Mean**	**Std deviation**	**Mean**	**Std deviation**
SMS 35	74.87	24.91	105.92	12.74	83.85	18.33
SMS 50	BREAKDOWN		148.91	14.56	66.39	15.75
SMS60	77.5	6.65	>200		98.69	6.76
SMS 80	85.2	2.04	>200		104.3	4.3
SMS 90	105.25	3.64	>200		114.97	3.47
PP30	76.35	3.89	91.58	3.31	81.17	6.14
PP50	87.46	17.56	157.42	12.87	159.06	14.4
PP60	119.5	6.42	169.94	8.25	128.17	10.12
PP70	166.44	18.03	>200		193.63	5.54
PP80	157.9	14.57	>200		>200	
PP105	BREAKDOWN		>200		145.83	27.3
PP110	BREAKDOWN		>200		145.34	32.37
PE 35	100.53	22	>200		116.82	17.51
PE100	154.43	18.33	>200		116.84	25.98
PE105	BREAKDOWN		>200		175.21	10.06

Table 4. Seam strength for hot air welding method

Sample	FORCE AT SEAM OPENING OF 6 MM		UNSEAMED WEFT		SEAMED	
	Mean	Std deviaton	Mean	Std deviation	Mean	Std deviation
SMS 35	BREAKDOWN	NA	140.04	10.39	>200	
SMS 50	142.2	BREAKDOWN	162.33	18.37	184.92	19.34
SMS60	169.65	33.87	>200		>200	
SMS 80	>200		>200		>200	
SMS 90	>200		>200		>200	
PP30	>200		>200		>200	
PP50	>200		>200		>200	
PP60	>200		>200		>200	
PP70	>200		>200		>200	
PP80	>200		>200		>200	
PP105	>200		>200		>200	
PP110	>200		>200		>200	

Thermal comfort is greatly dependent on the insulating properties of clothing. Thermal resistance determines thermal insulation property of a textile material. Since the thermal insulation is to insulate the body against the heat loss by trapping the heat into the air spaces inside the garment, an increase in thermal insulation reduces the comfort of medical clothes. Thermal resistance is related to thickness and thermal conductivity coefficient. By adding a membrane to the garment, the thickness of the fabric increases leading to an increase in the thermal insulation/resistance properties of the fabrics. Thermal resistance is observed to increase with increase in mass per unit area, which could be due to the increased quantity of enclosed air. The minimum thermal insulation values were obtained as 9.80, 10.98, 7.38 $W^{-1}.K.\ m^2 \times 10^{-3}$ for SMS 35, PP 30 and PE 35, respectively (Figure 3). It is thought that with the increase in thermal resistance value, the feeling of comfort is adversely affected.

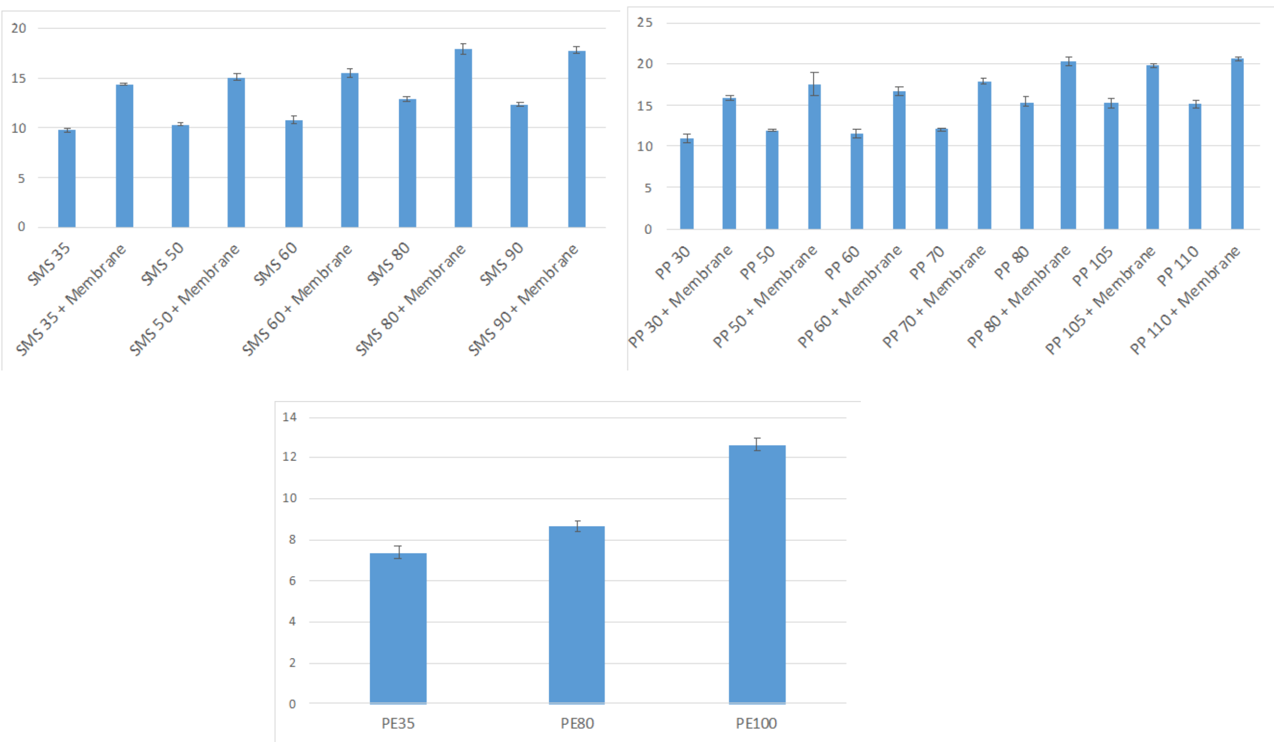

Figure 3. Thermal resistance of the samples ($W^{-1}.K.\ m^2 \times 10^{-3}$)

Thermal diffusivity is the rate of the heat transfer of a material. The higher the thermal diffusivity, the faster the heat dissipation [7, 9]. It is seen from Figure 4 that membrane caused an increase in thermal diffusion of fabrics. The higher thermal diffusion is mainly related to bulky structure of the fabric due to air entrapped inside its structure. The thermal diffusion value of the fabrics increases up to a certain mass per unit area, and then it begins to decrease. This could be attributed to the formation of very tight structure with reduced air gap inside the fabric due to the increased mass per unit area. For polypropylene fabrics, thermal diffusion of nonwoven fabrics with a unit weight higher than 80 gr/m^2 and membrane reinforced ones with a unit weight higher than 70 gr/m^2 are observed to decrease. This leads to increased thermal stress of the body of wearer and uncomfortable microclimate. For SMS nonwoven fabrics, thermal diffusion showed a reduction in fabrics with a unit weight greater than 50 g/m^2, while no significant changes were observed in membrane-integrated ones with a unit weight above 50 g/m.

Thermal absorptivity can be defined as the sensation of warmth and coolness during wearing and depends on the skin contact area of the fabric surface. If the contact area between the fabric and the skin is increased, the thermal absorbance value increases, leading to cooler feeling. Fabrics with low thermal absorptivity give a warm feeling while those with high thermal absorptivity give a cold feeling. As shown in Figure 5, polypropylene fabrics with a unit weight of 70 g/m^2 and higher have higher thermal absorptivity as compared to other PP fabrics. In PP fabrics with a unit weight of 60 g/m^2 and higher, membrane integration caused to decrease thermal absorptivity. In SMS fabrics, thermal absorptivity was not significantly affected by unit weight and membrane reinforcement. SMS 80 has a maximum thermal absorptivity value of 204.04 $W.s^{1/2}/m^2.K$. In PE-coated fabrics, the increase in unit weight from 80 to 100 g/m^2 caused a decrase in thermal absorptivity value. Fabrics such as PE 80, PP 105, PP 110, SMS 80, SMS 60 and SMS 90 have higher thermal absorptivity (150 $W.s^{1/2}/m^2.K$ and higher), giving a more comfortable feeling to wearer. It is seen that thermal absorption values did not change proportionally to weight or thickness of the nonwoven samples, which may be caused by the large variation/non-uniformity in the surface smoothness/roughness of the fabrics. Because the surface property of a fabric (roughness/smoothness) greatly affects this sensation (thermal absorptivity), which is related to the contact area between the fabric and the skin [26-28]. Nonwoven fabrics have non-homogeneous structure because they have uneven thickness caused by the uneven spread of fiber. In order to alleviate this constraint, all the tests have been repeated for five times from different areas of the nonwoven samples.

3.3 Water vapour permeability results

Water vapour permeability, one of the most important factors determining wearer comfort, is the ability of a fabric to allow moisture vapor to pass through it. Lower water vapour permeability values reduce the moisture transport through the fabric, resulted in increased vapour resistance. The higher the water vapour resistance, the lower the 'breathability' of the fabric.

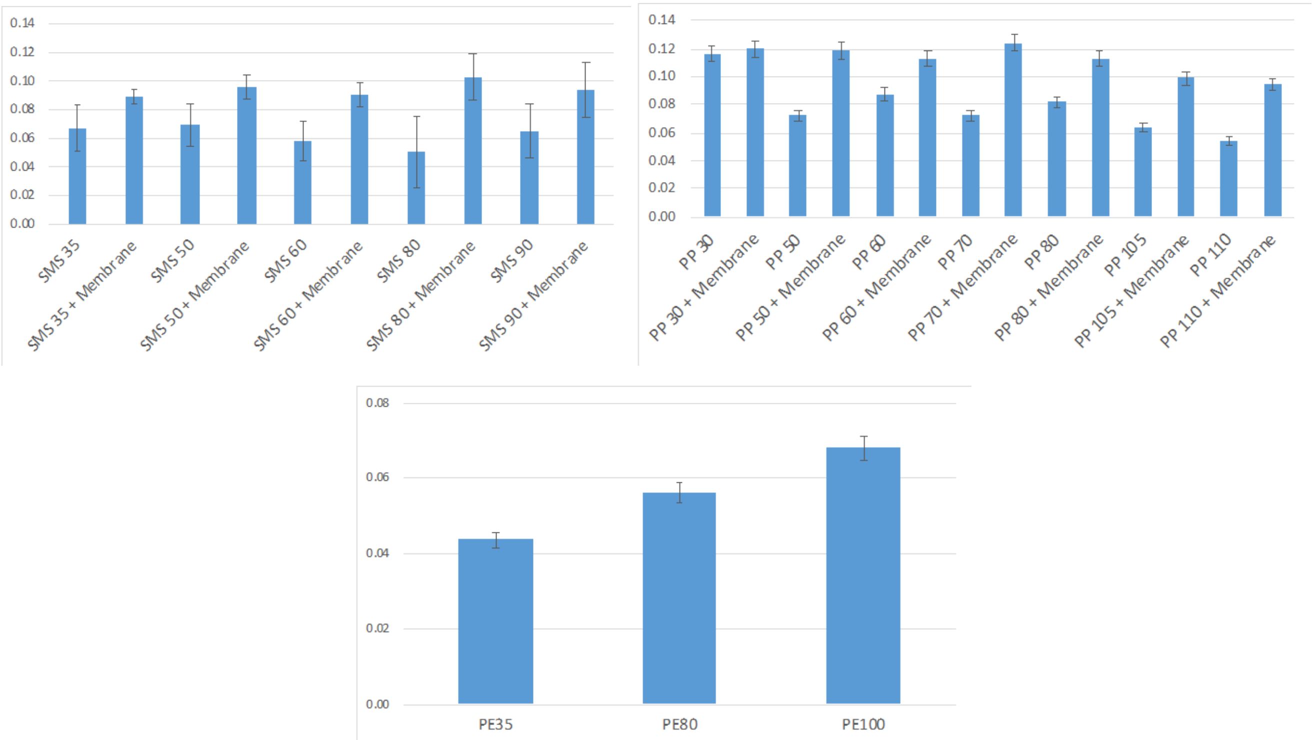

Figure 4. Thermal diffusivity of the samples (mm^2/s)

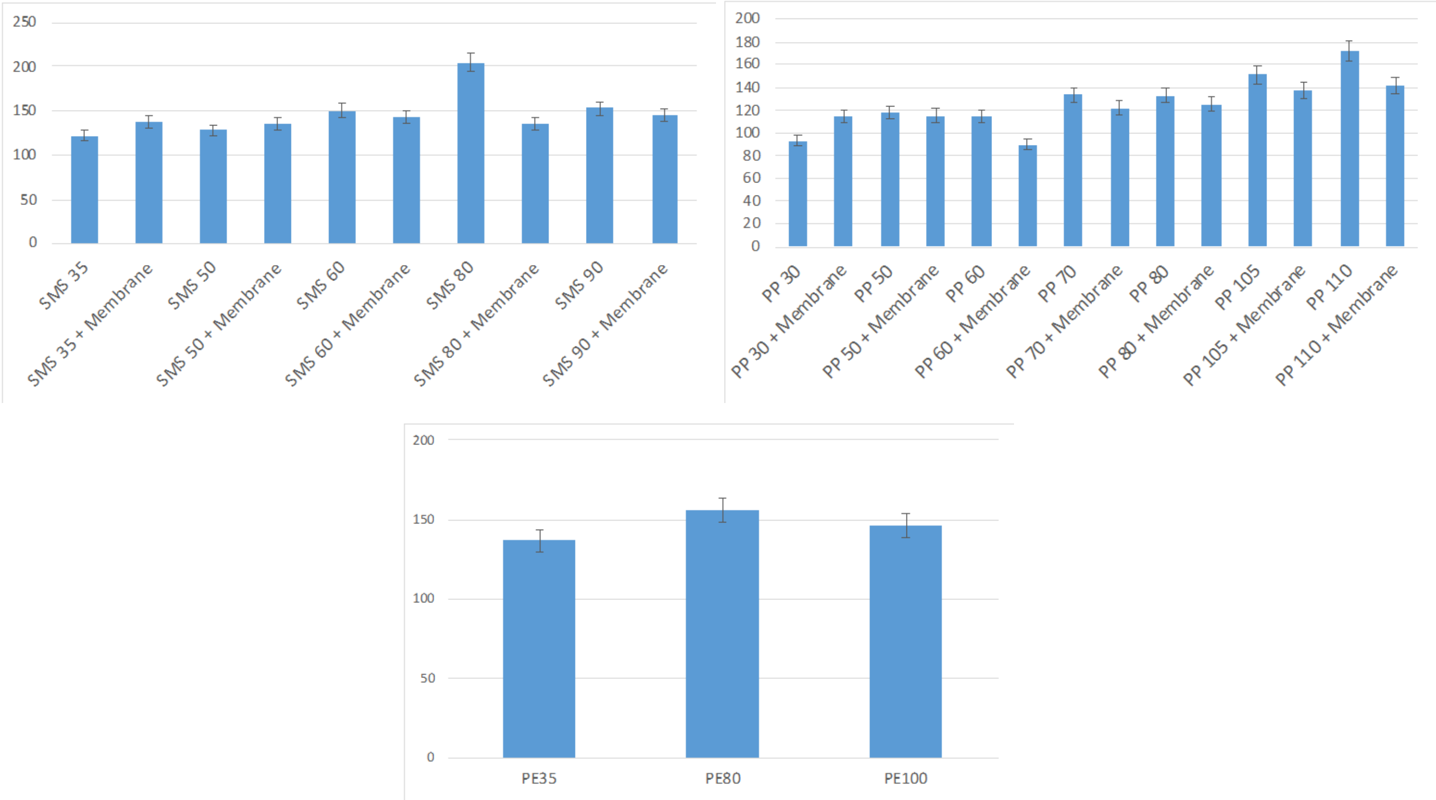

Figure 5. Thermal absorption of the samples (W.s $^{1/2}$/m^2.K**)**

Water vapor resistance also affects the comfort feeling in determining the comfort level of a fabric. High water vapor resistance reduces the excretion of sweat in the body, which causes moisture to accumulate on the skin, creating an uncomfortable feeling. Figure 6 and 7 show the RET values (water vapour resistance) and relative water vapour permeability of nonwoven and combined membrane-nonwoven fabrics, respectively. SMS 90, PP 105 and PP 110 fabrics were found to have higher Ret values among non-membrane fabrics. Increase in Ret value, which means high resistance to moisture transfer, reduced water vapour permeability and impaired comfort, was clearly observed with the addition of membrane. All SMS and PP samples have a RET valaue lower than 6.0 Pa. m^2/ W, indicating that they are extremely breathable and comfortable at higher activity rate [2]. Results revealed that SMS 35, 50, 60, 80, 90 and PP 30, 50, 60, 70, 80, 105 fabrics have a water vapour permeability value higher than 70% and greater comfort for wearers. No meaningful result was obtained for PE-coated samples, which could be attributed to the high water vapour resistance owing to the coated structure.

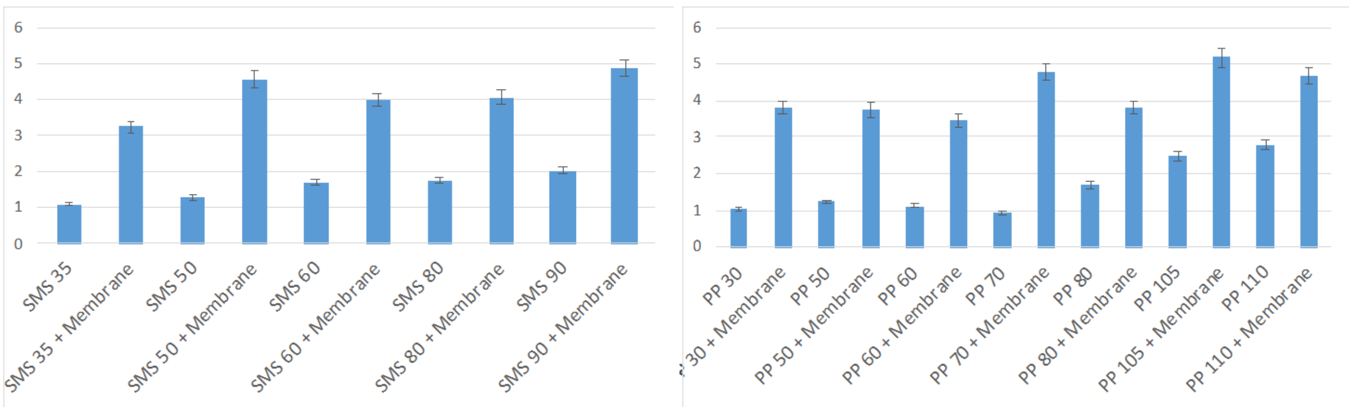

Figure 6. Water vapour resistance (RET) of the samples (Pa. m^2/ W)

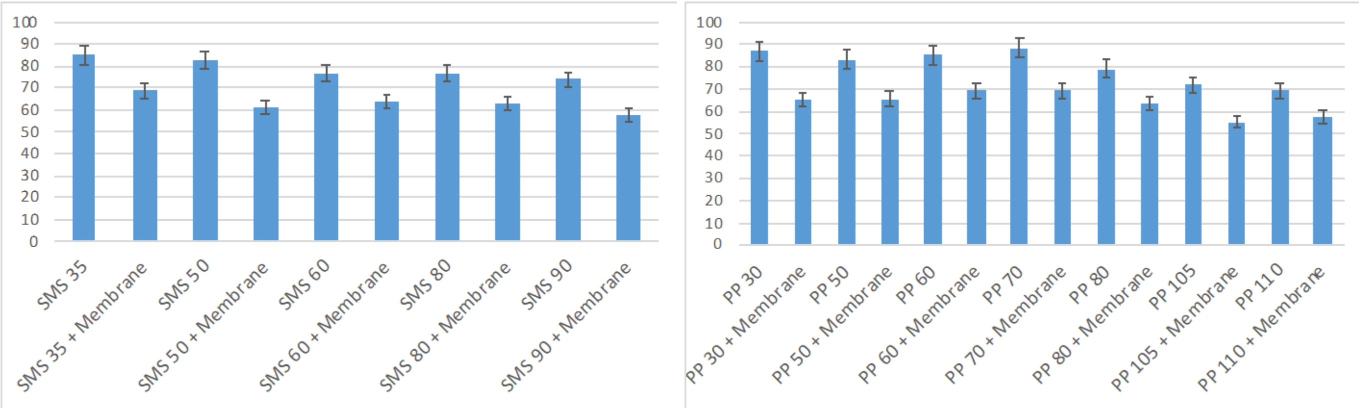

Figure 7. Relative water vapour permeability of the samples (%)

3.4 Air permeability results

Air permeability is a feature that increases the comfort properties of garments in terms of breathability of fabrics. Figure 8 shows the air permeability of non-membrane fabrics since the membrane-integrated ones have an air permeability of zero. It is observed that SMS 35, 50 and PP 105 samples are found to have higher air permeability than others. Since SMS spunbond consists of two layers of spunbond, which sandwich a layer of meltblown, its air permeability decreased with an increase in mass per unit area. However, in polypropylene samples, air permeability increased with increasing mass per unit area due to the increased surface porosity. The air permeability of PE-coated fabrics was found to be zero due to the PE coating, leading to uncomfortable feeling for the wearer.

3.5 Water permeability resistance (hyrostatic pressure test)

Resistance of samples against water penetration was measured from both their back and front side under hydrostatic pressure. The mean of the pressures recorded for the specimens are shown in Figure 9 and 10. Water permeability resistance of the front and back sides of the fabrics is found to be very low in polypropylene fabrics. This indicates that SMS fabrics would be a better choice for protection as compared to polypropylene fabrics.

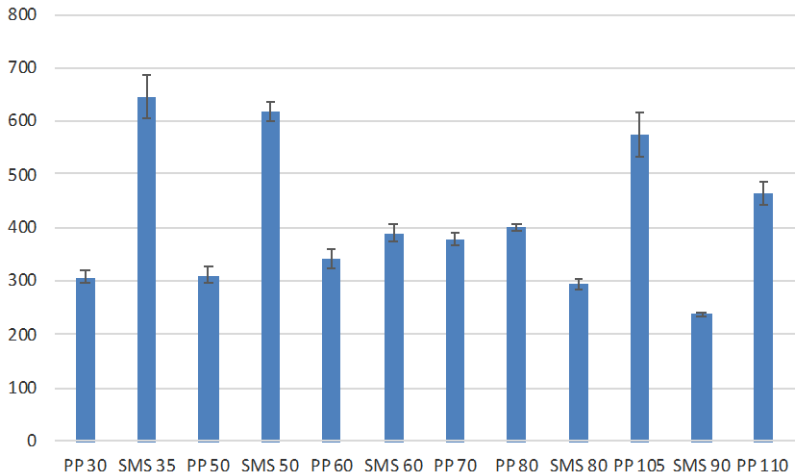

Figure 8. Air permeability test results (L/m^2/sec)

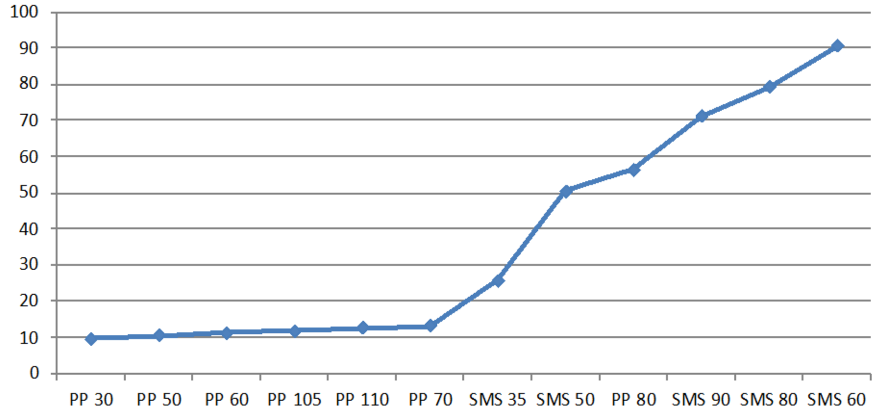

Figure 9. Water penetration resistance results for front side of SMS and PP samples (Pa)

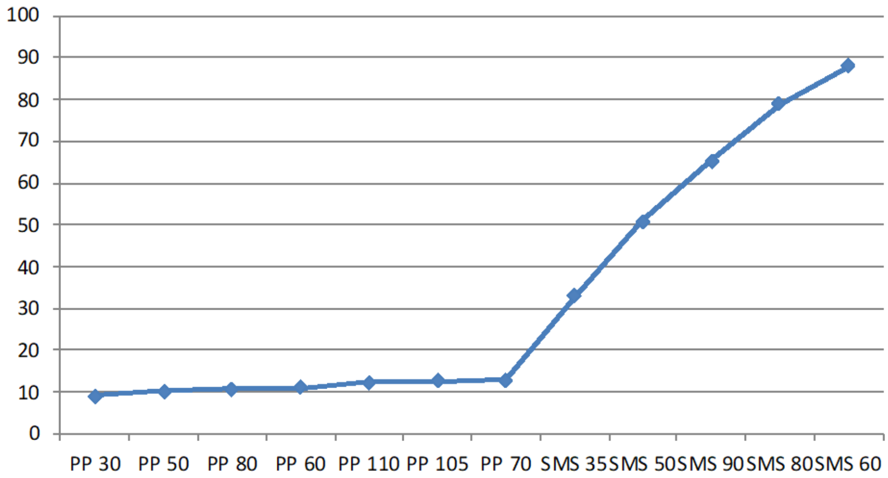

Figure 10. Water penetration resistance results for back side of SMS and PP samples (Pa)

Figure 11 shows the water permeability resistance of the front and back sides of PE-coated fabrics. As can be seen from Figure 11, both front and back sides of PE fabrics have very high water pressure, providing high protection against water penetration.

3.6 Statistical analysis

The relationship between variables was tested using IBM SPSS 25 statistics program. As can be seen from Table 5, water vapor permeability and air permeability values are directly related to fabric thickness and fabric unit weight.

As can be seen from one-way anova test results presented in Table 6, there is a significant relationship between fabric type (PP, SMS, PE) on fabric thermal conductivity, thermal resistance, thermal diffusion, thermal absorption, water vapor resistance, water vapor permeability and air permeability.

Paired Sample T-test was used to evaluate whether there is a significant relationship between membrane reinforcement and fabric thermal and water vapour properties. Table 7 indicates that there is a significant relationship between membrane integration and functional properties of fabric.

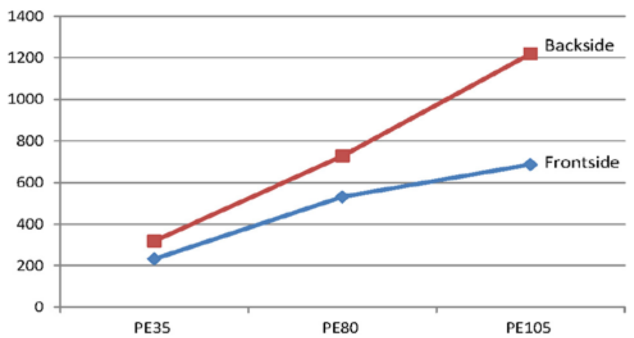

Figure 11. Water penetration resistance results for PE-coated sample

Table 5. Correlation values

Variables	N	Pearson Correlation	Sig. (2-tailed)
Fabric unit weight & water vapor permeability	27	0.881	0.000
Fabric unit weight & air permeability	27	-0.650	0.000
Fabric thickness& water vapor permeability	27	0.893	0.000
Fabric thickness& air permeability	27	-0.499	0.008
Fabric thickness & termal absorption	27	0.402	0.038

Table 6. One way ANOVA test results

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Thermal conductivity	Between Groups	8693.692	2	4346.846	387.899	.000
	Within Groups	268.947	24	11.206		
	Total	8962.639	26			
Thermal resistance	Between Groups	.037	2	.018	52.605	.000
	Within Groups	.008	24	.000		
	Total	.045	26			
Thermal diffusion	Between Groups	86833.933	2	43416.967	159.576	.000
	Within Groups	6529.852	24	272.077		
	Total	93363.785	26			
Thermal absorption	Between Groups	1413.843	2	706.922	108.414	.000
	Within Groups	156.495	24	6.521		
	Total	1570.338	26			
Water vapor resistance	Between Groups	22.251	2	11.125	5.607	.010
	Within Groups	47.616	24	1.984		
	Total	69.867	26			
Water vapor permeability	Between Groups	13681.575	2	6840.787	70.682	.000
	Within Groups	2322.777	24	96.782		
	Total	16004.352	26			
Air permeability	Between Groups	116740.859	2	58370.430	1.143	.336
	Within Groups	1225446.690	24	51060.279		
	Total	1342187.550	26			

Table 7. Paired sample t-test results

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	Thermal conductivity without membrane & Thermal conductivity with membrane	12	.996	.000
Pair 2	Thermal resistance without membrane & Thermal resistance with membrane	12	.913	.000
Pair 3	Thermal diffusion without membrane & Thermal diffusion with membrane	12	.979	.000
Pair 4	Thermal absorption without membrane & Thermal absorption with membrane	12	.997	.000
Pair 5	Water vapour resistance without membrane & Water vapour resistance with membrane	12	.583	.047
Pair 6	Water vapour permeability without membrane & Water vapour permeability with membrane	12	.877	.000

The relative thermal comfort index (RTCI) of the samples were calculated using related formula and given in Table 8 and 9. Based on the RTCI results, it was found that the most comfortable fabrics were 35, 80 and 90 for SMS fabrics whereas 70, 60 and 30 for PP fabrics. It is seen from the results that integration of membrane to the fabrics reduces the comfort properties of the fabric.

Table 8. RTCI indexes of SMS fabrics

Samples	RTCI
SMS 35	0.676
SMS 80	0.675
SMS 90	0.652
SMS 50	0.554
SMS 60	0.526
SMS 35 + Membrane	0.457
SMS 90 + Membrane	0.426
SMS 60 + Membrane	0.396
SMS 80 + Membrane	0.336
SMS 50 + Membrane	0.284

Table 9. RTCI indexes of PP fabrics

Samples	RTCI
PP 70	0.474
PP 60	0.452
PP 30	0.433
PP 50	0.422
PP 80	0.392
PP 105	0.348
PP 110	0.336
PP 30 + Membrane	0.257
PP 60 + Membrane	0.248
PP 50 + Membrane	0.244
PP 80 + Membrane	0.218
PP 70 + Membrane	0.187
PP 110 + Membrane	0.169
PP 105 + Membrane	0.146

4. CONCLUSION

In this study, it is aimed to investigate the comfort and protection properties of three different nonwoven fabrics, SMS, PP and PE-coated, and membrane-nonwoven combinations for the production of newly designed functional disposable surgical gown.

Results revealed that tear strength of the SMS fabrics is higher than that of PP and PE fabrics. Tensile strength of the all fabrics along both directions was found to be very close to each other. Samples joined by welding method have higher seam strength than that of ultrasonic one. Hydrostatic pressure test results indicated that water pressure at which the water penetrates into the fabric is higher in SMS fabric than PP fabrics. However, since water penetration is observed over a certain pressure for both fabric types, membrane reinforcement is required for both PP and SMS fabrics, especially in areas that may be exposed to fluid passage. It was found that the air permeability values of SMS fabrics were higher than that of PP fabrics, and the air permeability of PE fabrics was zero due to PE coating. Considering the comfort performance, the lack of air permeability has a negative effect on the comfort of the wearer. Thermal comfort properties of SMS, PP and PE coated fabrics and SMS + membrane and PP + membrane fabrics were examined. Membrane reinforcement caused an increase in thermal conductivity, thermal resistance, thermal diffusion, thermal absorption and water vapor resistance values. All SMS and PP samples have a RET valaue lower than 6.0 Pa. m^2/ W, indicating that they are extremely breathable and providing greater comfort to wearers. Based on the RTCI results for membrane reinforced and non-membrane fabric types, RTCI values of SMS and SMS+membrane fabrics were found to be higher than that of PP fabrics, providing higher comfort feeling. The comfort values of 35, 80 and 90 for SMS fabrics and 70, 60 and 30 fabrics for PP fabrics were found to be higher compared to others.

As a result of the statistical evaluations, it was found that the fabric thickness and unit weight had a great effect especially on the water vapor resistance. SMS nonwoven fabrics consist of three thermally or adhesively bonded layers. The lower and upper layers are made of spunbond and the middle layer is made of meltblown material. PP nonwoven fabrics, on the other hand, are single-layer fabrics produced using spunbond, and their comfort and protection properties are lower compared to SMS fabrics. Although PE coated fabrics have great waterproof and impervious performance, their comfort properties are low due to the lack of water vapor and air permeability.

According to findings obtained in this study, it was concluded that the disposable surgical gown produced from SMS nonwoven fabric, and membrane reinforcement in areas where there is a likelihood of exposure to body fluids was the most suitable model that meets the performance and comfort requirements of the wearer. It is expected that this study will provide a better understanding of the effect of fabric selection, sewing method and membrane integration on the wearer's comfort and tensile properties in surgical gown design and contribute to the current literature on medical textiles.

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Declaration of interest statement

The authors declare that there is no conflict of interest.

REFERENCES

1. McBriarty JP, Henry NW. (1992). Performance of Protective Clothing, Fourth Volume, West Conshohocken, PA: ASTM International, DOI: 10.1520/STP1133-EB.
2. Song G, Cao W. (2011). Handbook of medical textiles, Chapter 8: Medical textiles and thermal comfort, Woodhead Publishing Limited, USA.
3. Eryuruk SH, Kayaoglu BK, Kalaoglu F. (2017). A study on ultrasonic welding of nonwovens used for surgical gowns. International Journal of Clothing Science and Technology, 29(4), pp. 539-552.
4. Zhong W (2013). An introduction to healthcare and medical textiles, DEStech publications, USA.
5. Prabir J. (2011). Assembling technologies for functional garments—An overview. Indian Journal of Fibre & Textile Research 36, pp.380-387.
6. Dammacco G, Turco E, Glogar MI. (2012). Design of Protective Clothing, In S. Bischof Vikusic (Ed.), Functional Protective Textiles, Firenze, Italy: Grado Zero Espace, pp. 1-32.
7. Das A, Alagirusamy R. (2010). Science in Clothing Comfort, Woodhead India, New Delhi, India.
8. Saville BP, Institute T. (1999). Physical Testing of Textiles, Woodhead Publishing, Limited.
9. Huang J. (2006). Thermal parameters for assessing thermal properties of clothing. Journal of Thermal Biology 31(6): pp. 461-466.
10. Li J, Barker RL, Deaton AS. (2007). Evaluating the Effects of Material Component and Design Feature on Heat Transfer in Firefighter Turnout Clothing by a Sweating Manikin. Textile Research Journal 77, pp. 59-66.
11. Onofrei E, Rocha AM, Catarino A. (2012). Investigating the effect of moisture on the thermal comfort properties of functional elastic fabrics. Journal of Industrial Textiles 42 (1), pp. 34-51.
12. Celcar D. (2013). Influence of Phase-Change Materials on Thermo-Physiological Comfort in Warm Environment. Journal of Textiles, Hindawi Publishing Corporation, Article ID 757319, http://dx.doi.org/10.1155/2013/757319.
13. Bartkowiak G, Dabrowska A, Marszałek A. (2013). Analysis of thermoregulation properties of PCM garments on the basis of ergonomic tests. Textile Research Journal 83 (2), pp. 148-159.
14. Hatch KL, Markee NL, Maibach HI, Barker RL, Woo SS, Radhakrishnaiah P. (1990). “In Vivo Cutaneous and Perceived Comfort Response to Fabric Part III: Water Content and Blood Flow in Human Skin Under Garments Worn by Exercising Subjects in a Hot, Humid Environment. Textile Research Journal 60, pp. 510-519.
15. Shi H, Wang J, Chen X, Luo S, Zhang L. (2016). Research on the seam performance of waterproof clothing based on continuous ultrasonic welding technology. International Journal of Clothing Science and Technology 28 (2), pp.171-190.
16. Yoo S, Barker RL. (2005). Comfort Properties of Heat-Resistant Protective Workwear in Varying Conditions of Physical Activity and Environment. Part I: Thermophysical and Sensorial Properties of Fabrics. Textile Research Journal 75 (7), pp. 523-530.
17. Rogale SF, Rogale D, Dragcevic Z, Nikolic G. (2007). Technical systems in intelligent clothing with active thermal protection. International Journal of Clothing Science and Technology 19(3/4), PP. 223-233.
18. Pamuk O, Abreu MJ, Ondogan Z. (2008). An Investigation on The Comfort Properties for Different Disposable Surgical Gowns by Using Thermal Manikin. Tekstil ve Konfeksiyon 3, pp. 236-239
19. Woo SS, Shalev I, Barker RL. (1994). Heat and Moisture Transfer Through Nonwoven Fabrics Part I: Heat Transfer. Textile Research Journal 64 (3), pp 149-162.
20. Issa M, Abreu MJ, Schacher L, Adolphe D, Silva MEC. (2004). The Influence of The Sterilisation Process on Certain Thermal Properties. Eur J Appl Phys. 92, pp. 673–678
21. Bogdan A, Sudoł-Szopińska I, Szopiński T. (2011). Assessment of Textiles for Use in Operating Theatres with Respect to the Thermal Comfort of Surgeons. Fibres & Textiles in Eastern Europe 192 (85), pp 65-69.
22. Aslan S, Kaplan S, Cetin C. (2013). An Investigation About Comfort and Protection Performances of Disposable and Reusable Surgical Gowns By Objective And Subjective Measurements. The Journal of The Textile Institute 104(8), pp. 870–882.
23. Kar J, Fan J, Yu W. (2011). Advances in Knitting Technology. Chapter 10: Women’s apparel: knitted underwear. Woodhead Publishing Series in Textiles, pp 235-261. https://doi.org/10.1533/9780857090621.3.235
24. Matusiak M, Sikorski K. (2011). Relative Thermal Comfort Index as a Measure of the Usefulness of Fabrics for Winter Clothing Manufacturing. Fibres & Textiles In Eastern Europe 89 (6), pp. 94-100.
25. TS EN 13795+A1. (2013). Surgical drapes, gowns and clean air suits, used as medical devices for patients, clinical staff and equipment-General requirements, processors and products, test methods, performance requirements and performance levels.
26. Rubenstein DA, Yin W, Frame MD. (2022). Chapter 4 - Introduction to heat transfer, Editor(s): David A. Rubenstein, Wei Yin, Mary D. Frame, In Biomedical Engineering, Biofluid Mechanics (Third Edition), Academic Press, pp 135-156. https://doi.org/10.1016/B978-0- 12-818034-1.00004-9.
27. Oğlakcıoğlu N, Marmaralı A. (2010). Thermal comfort properties of cotton knitted fabrics in dry and wet states, Tekstil ve Konfeksiyon 3, pp 213-217.
28. Pac MJ, Bueno MA, Renner M. (2001). Warm-Cool Feeling Relative to Tribological Properties of Fabrics”, Textile Research Journal, 71(9), pp 806-812.