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PROPERTIES OF 2-LAYERED AND 3-LAYERED LAMINATED SAILING GARMENTS

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ABSTRACT

Sailing is an active sports type and sailing garments should exhibit several functional and performance properties. Protective sailing garments are expected to protect the wearer against harsh environmental conditions (wind, rain, sea water, sunrays), maintain the comfort and sustain the mobility. To provide all these requirements, sailing garments are manufactured from 2-layered or 3-layered coated or laminated fabrics. After market search, it was inferred that laminated fabrics were preferred more by the sailing garment manufacturers. But there is not enough literature in efficient quality and quantity to understand the properties of commercial sailing garments. Therefore, in this study, commercial sailing garments with polyamide (PA) and polyester (PET) base fabrics and polyurethane (PU) and polytetrafluoroethylene (PTFE) membranes were supplied to create a systematic and their properties were determined. Also 3-layered laminates of PA base fabric, PU membrane and back-linings were tested and compared with 2-layered competitors. According to results, existing sailing garments were in moderate thickness and weight. Most of them provided protection against water and wind to the sailors. Although having different base fabrics, lamination films and fabric structures, their mechanical properties were comparable.

KEYWORDS

Laminated fabrics, Sailing garments, PTFE membrane, PU membrane, Permeability properties, Mechanical properties.

1. INTRODUCTION

Sailors face harsh environmental conditions such as sea water, rain, extreme wind and sunrays. Therefore, sailing garments should maintain the comfort of the sailors while providing protection against water passage, UV damage etc. (Kara and Yeşilpınar, 2017). For this reason, professional sailing garments are mostly produced from coated or laminated fabrics which contain two or three layers. Laminated fabrics are found advantageous in terms of durability and breathability to be used in sailing garment production.

Polyester and polyamide fabrics are the most widely studied base fabrics for laminated fabric researches (Sybilska, Korycki, 2010; Armagan, Karakas, 2008; Doba Kadem, Ergen, 2011a; Doba Kadem, Ergen, 2011b; Huang, Qian, 2008; Gulbiniene et al., 2007; Ren, Ruckman, 2003) and they have a big market share. As for other laminated fabric end-use areas, polyester and polyamide fabrics are the most preferred base fabrics for sportswear, too (Shisho, 2005). They provide advantages such as high tensile strength, high strain, abrasion resistance, crease resistance etc. to the sportswear (Karmakar, 1996; Shisho, 2005).

As sailing is an active sports type, it has many potential research areas in order develop the comfort, safety, mobility etc. of the sailors by using their garments. But, there is not enough information with sufficient quality

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and quantity about sailing garments, in the literature. There are only a few studies to understand the requirements and functionality of sailing garments (Kara, Yesilpınar, 2017; Kara et al., 2017; Jansen et al., 2012, Bye and Hakala, 2005). Because of this, this study is important to understand the properties of existing sailing garments. So that, many improvements may be done in terms of materials, design and functionality of sailing garments.

In this study, commercial laminated sailing garments with polyamide and polyester base fabrics and polyurethane and polytetrafluoroethylene lamination films were supplied to create a systematic. Also 3-layered laminates of PA base fabric, PU membrane and back-linings were tested and compared with 2-layered competitors. Physical, permeability and mechanical properties of samples were determined in order to determine the comfort and protective properties of sailing garments.

2. MATERIALS AND METHODS

2.1 Materials

Materials of this study were commercial sailing garments with PA and PET base fabrics and PU and PTFE (Gore-tex) membranes. Laminated fabric compositions were PA base-PTFE membrane-woven lining, PET base-PTFE membrane, PA base-PU membrane, PET base-PU membrane, PA base-PU membrane-warp knitted lining, PA base-PU membrane-fleece lining. Sample codes, contents and structures are given in Table 1.

Table 1: Materials of the study

Code	**Content**	**Structure**
PET-PTFE	PET base + PTFE film (Gore-tex)	2-layered laminated
PA-PTFE	PA base + PTFE film (Gore-tex)	3-layered laminated
PET-PU	PET base + PU film	2-layered laminated
PA-PU	PA base + PU film	2-layered laminated
PA-PU-C	PA base +PU film+ warp knitted lining	3-layered laminated
PA-PU-P	PA base + PU film + fleece lining	3-layered laminated

2.2 Methods

Physical properties (unit mass, thickness), permeability properties (waterproofness, water vapour permeability and air permeability), mechanical properties (tensile strength, extension, tear strength, bending rigidity and abrasion resistance) and water repellency of samples were determined according to standards (Table 2). Samples were conditioned at standard atmosphere conditions (65 ±2 % relative humidity and 20 ± 2 °C) before all the tests.

In addition, base fabric side and membrane face of samples were evaluated by using Jeol 6060 (Tokyo, Japan) scanning electron microscope (SEM).

For bending rigidity, dimensions of samples were selected as 25 mm x 300 mm. According to measurement results, bending rigidity values in warp and weft directions (B_{warp}, B_{weft}) were calculated according to Formulation 1 (Hu, 2004). Bending length (c), $f_2(\theta)$ and θ was calculated according to Formulation 2, 3 and 4, respectively.

$$\text{Bending rigidity} = B = 0.1 \cdot w \cdot c^3 \text{ [mg.cm]} \quad (1)$$

$$c = 0.1337L \cdot f_2(\theta) \text{ [cm]} \quad (2)$$

$$f_2(\theta) = (\cos\theta / \tan\theta)^{1/3} \quad (3)$$

$$\theta = 32.85 \cdot ((l - 0.1337L)/0.1337L) \text{ [°]} \quad (4)$$

(L is measured length [cm], w is unit mass [g/cm^2], l is loop length [cm]).

Table 2: Test standards

Test	Standard	Details
Unit mass	TS 251	5 repetitions
Thickness	TS 7128 EN ISO 5084	5 repetitions
Air permeability	TS 391 EN ISO 9237	10 repetitions, 100 Pa pressure
Water vapour permeability	BS 3424-Part 34	3 repetitions
Waterproofness	TSE 257 EN 2081	5 repetitions, 60 cm/min test speed
Tensile strength-Extension	TS EN ISO 13934-1	5 repetitions, Strip method
Tear strength	TS EN ISO 13937-2	5 repetitions, Single tear method
Bending rigidity	ASTM D1388	5 repetitions, Heart loop method
Abrasion resistance	TS EN ISO 12947-3	3 repetitions, 9 kPa
Resistance to surface wetting	TS EN ISO 4920	3 repetitions, Spray test
Washing	TS EN ISO 6330-6A	20 cycles, 40˚C

3. RESULTS AND DISCUSSIONS

SEM evaluation results, physical, permeability and mechanical test results of samples are given in the following parts.

3.1 SEM Results

SEM images of samples are given in Figure 1. The membrane face of only PA-PU-P sample was not observed because of the thick fleece lining.

According to SEM images of base fabric sides; it is seen that PET-PTFE, PA-PTFE, PET-PU and PA-PU-P samples had plain weave. PA-PU and PA-PU-C samples had different weave structures. When the membrane faces were observed, it was detected that all the samples had different surface topographies but in general they did not have any porous structure. Normally, PTFE samples have a microporous structure. But for some commercial applications, PTFE membranes are coated with a thin layer of polymer in order to avoid from abrasion and blocking of pores after washing.

3.2 Physical properties

Fabric thickness and unit mass values were determined in order to evaluate the physical properties of commercial sailing garments (Table 3).

Table 3: Physical properties of samples

Sample code	Unit mass (g/m^2) (St. Dev.)	Thickness (mm) (St. Dev.)
PET-PTFE	127 (1.22)	0.24 (0.01)
PA-PTFE	138 (1.32)	0.34 (0.01)
PET-PU	146 (4.34)	0.25 (0.03)
PA-PU	152 (1.13)	0.33 (0.01)
PA-PU-C	141 (4.11)	0.32 (0.01)
PA-PU-P	303 (6.89)	1.52 (0.16)

As seen from Table 3, most of the 2- and 3- layered laminated samples had a unit mass between 125 and 150 g/m^2. These unit mass values can be considered as light-moderate fabric unit mass values. The sample with fleece lining (PA-PU-P) was belong to heavy fabric class with 303 g/m^2 weight. On the other hand, fabric thickness values were between 0.24 and 0.34 mm for most of the samples that can be considered as moderate fabric thickness. The sample with the highest unit mass was also the thickest sample (1.52 mm) because of the thick fleece lining.

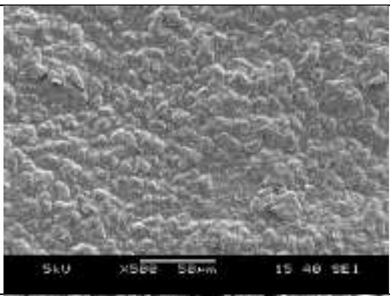
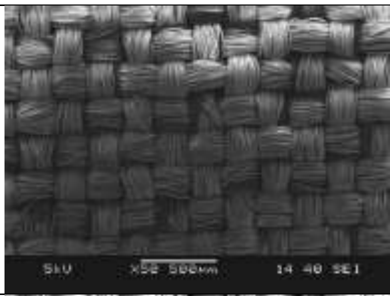
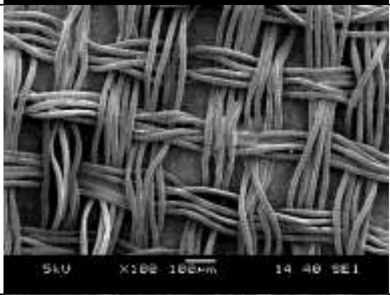
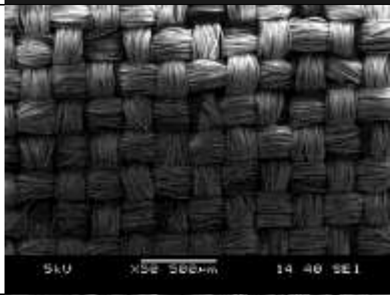
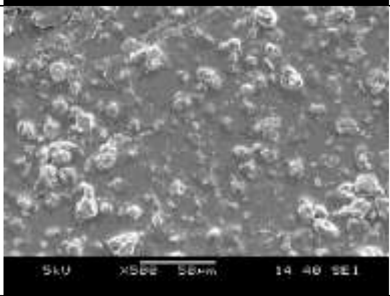
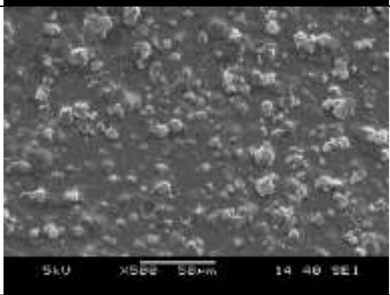
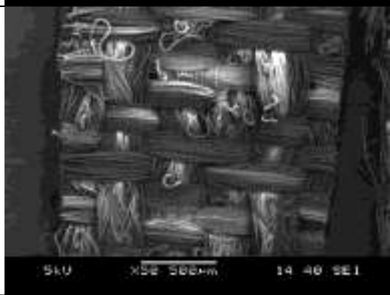
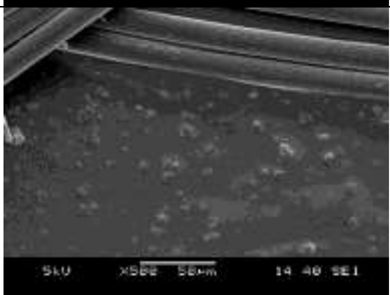
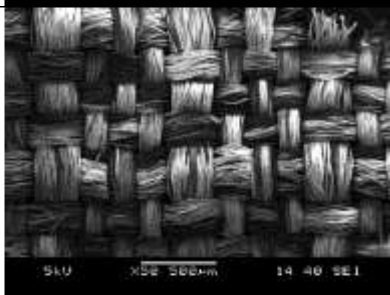
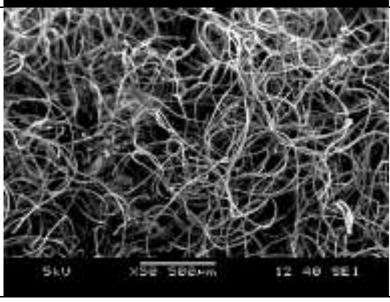
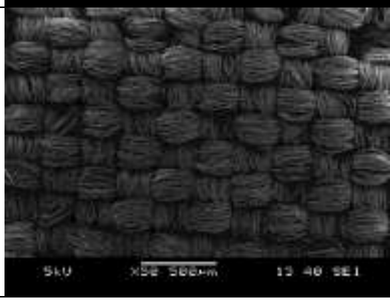
Sample code	**Back face (Membrane or Lining)**	**Outer face (Base Fabric)**
PET-PTFE		
PA-PTFE		
PET-PU		
PA-PU		
PA-PU-C		
PA-PU-P		

Figure 1: SEM images of samples

3.3 Permeability properties

Waterproofness, water vapour permeability and air permeability of samples were determined in order to evaluate the comfort and protection related properties of commercial sailing garments. Also resistances of samples to surface wetting (water repellency) were determined. Permeability properties and resistances to surface wetting of samples are given in Table 4.

Table 4: Permeability properties and resistances to surface wetting of samples

Sample code	Waterproofness (cm w.c.) (St. Dev.)		Water vapour permeability ($g/m^2/24h$) (St. Dev.)	Air perm. (mm/s) (St. Dev.)	Resistance to surface wetting (Mean Rating)
	Before washing	After 20 washing			
PET-PTFE	1100 (0)	681 (42)	699 (22)	8 (0.48)	4
PA-PTFE	1100 (0)	1100 (0)	683 (29)	7 (0.48)	4-5
PET-PU	804 (407)	976 (123)	571 (1)	5 (0.52)	4-5
PA-PU	147 (113)	196 (26)	537 (14)	22 (0.94)	2-3
PA-PU-C	1100 (0)	935 (368)	599 (12)	7 (1.26)	4-5
PA-PU-P	931 (232)	643 (421)	95 (31)	10 (0.97)	2

Waterproofness tests were stopped at 1100 cm water column (cm w. c.) because of the test machine limitations and the average values were calculated. Waterproofness before and after washing are shown in Figure 2, graphically.

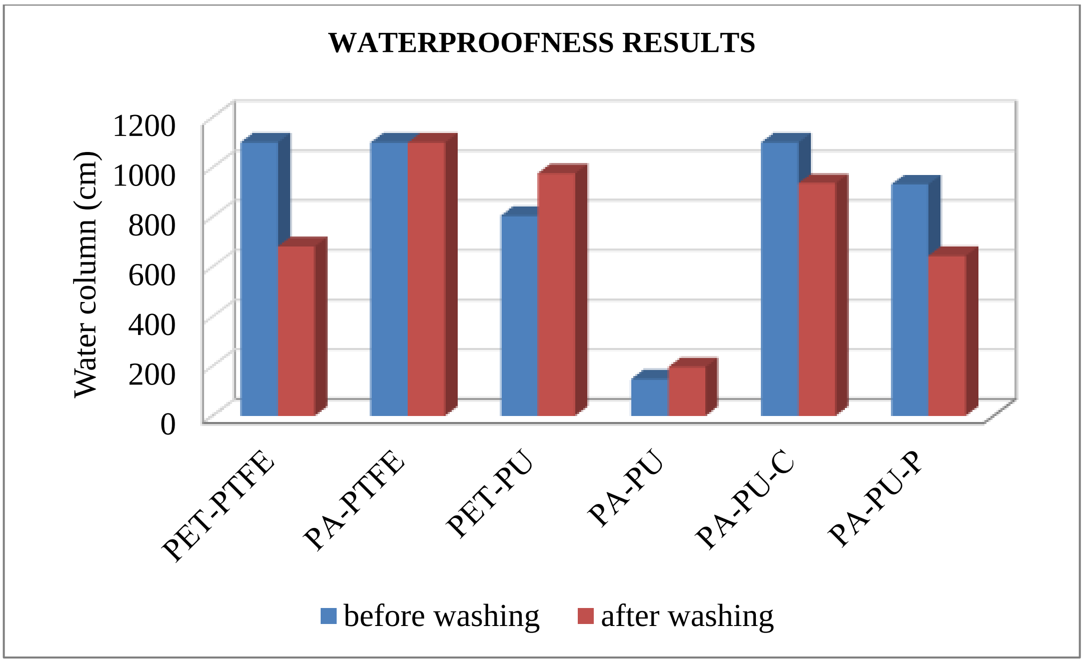


Figure 2: Waterproofness of samples

According to test results PTFE laminated PET-PTFE and PA-PTFE samples and also PU laminated PA-PU-C sample did not permit water passage even at 1100 cm w.c. before washing. Waterproofness of these samples may be higher. Also, PU laminated PET-PU and PA-PU-P samples showed very high waterproofness those were higher than 800 cm w.c. Lowest limit of waterproofness is admitted as 100-130 cm w.c. in the literature (Sen, Damewood, 2001; Fung, 2002). All the samples belonged to waterproof class before washing according to test results.

After 20 times of washing, waterproofness of PTFE laminated PA sample (PA-PTFE) remained at 1100 cm w.c. Waterproofness of PET-PTFE, PA–PU-C and PA-PU-P samples decreased after washing. All the samples remained waterproof after being washed 20 times. Some of the samples showed higher waterproofness after washing and standard deviation values were high. This may be due to non-uniform production of laminated fabrics for commercial sailing garments.

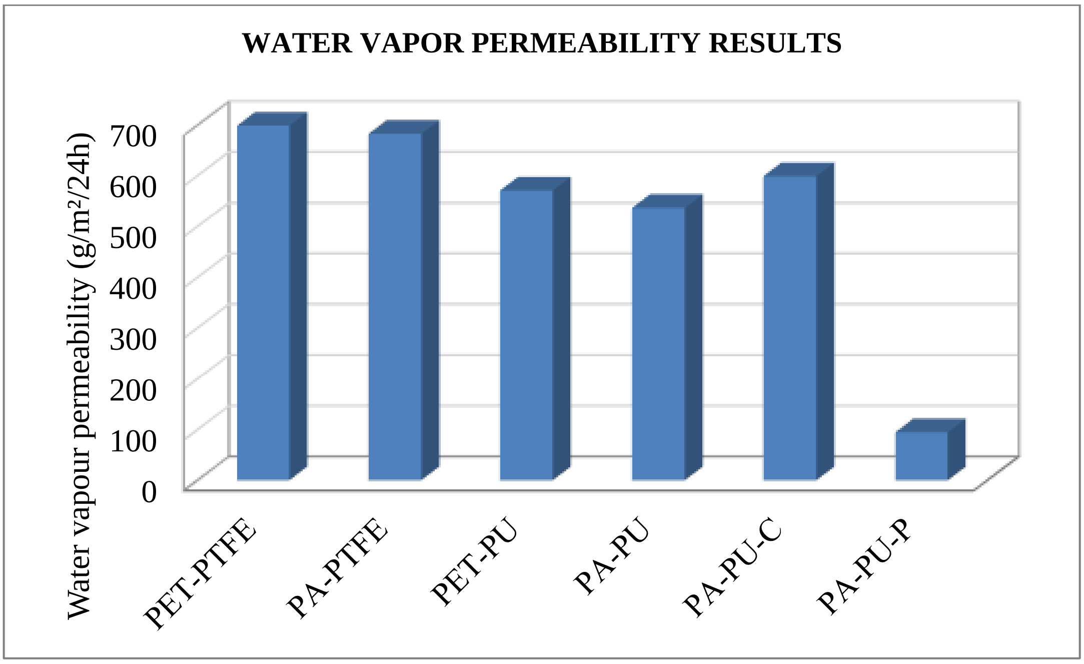


Figure 3: Water vapour permeability of samples

Water vapour permeability of samples were between 95 and 699 $g/m^2/24h$ (Figure 3). PTFE laminated samples had the highest values around 700 $g/m^2/24h$. PU laminated samples showed water vapour permeability between 520-600 $g/m^2/24h$. Lowest water vapour permeability was obtained from the thickest and heaviest 3 layered fabric which was laminated with fleece lining (PA-PU-P). Standard deviations of water vapour permeability results were lower when compared to waterproofness results.

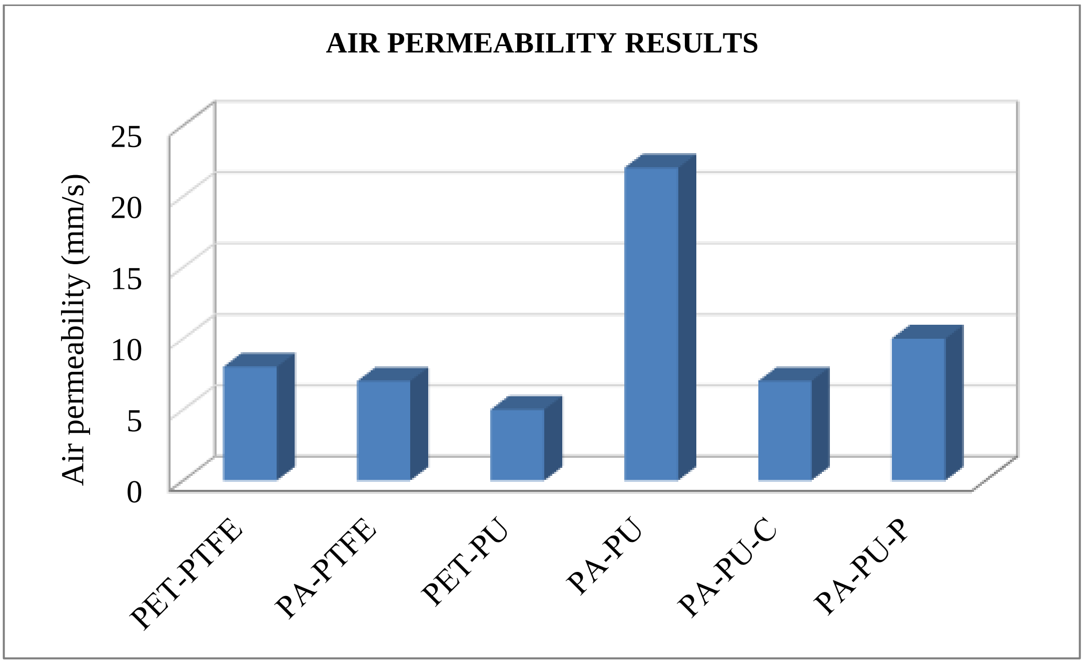


Figure 4: Air permeability of samples

Air permeability of samples were 22 mm/s, maximally (Figure 4). Air permeability values were very low and close to each other for all samples. This result was evaluated as a positive property, as almost all the samples belonged to windproof fabric class (Sen, Damewood, 2001).

Surface wetting properties are given in Table 4. PA-PTFE, PET-PU and PA-PU-C samples had a high water repellency. Similarly, PET-PTFE had a good water repellency. Water repellent finishes may be applied to these samples before or after lamination process.

3.4 Mechanical properties

Mechanical test results of samples are given in Table 5-6 and visualized in Figure 5-8.

Table 5: Mechanical properties of samples

Sample code	Tensile strength (N) (St. Dev.)		Extension (mm) (St. Dev.)		Tear strength (N) (St. Dev.)		Bending rigidity (mg.cm) (St. Dev.)	
	warp	weft	warp	weft	warp	weft	warp	weft
PET-PTFE	816 (11.5)	639 (27.3)	81 (3.1)	62 (3.1)	22 (0.5)	22 (3.2)	130 (21.1)	109 (25.7)
PA-PTFE	831 (49.7)	696 (57.8)	83 (6.6)	77 (5.1)	31 (1.0)	27 (2.4)	110 (17.3)	83 (20.6)
PET-PU	808 (66.0)	964 (64.5)	63 (4.0)	69 (5.1)	16 (1.3)	29 (0.6)	112 (43.1)	133 (18.2)
PA-PU	921 (94.2)	707 (48.3)	97 (9.9)	84 (6.8)	24 (0.6)	23 (1.0)	167 (47.1)	117 (24.0)
PA-PU-C	615 (20.5)	418 (23.8)	65 (3.3)	68 (4.3)	79 (4.3)	24 (4.5)	88 (8.9)	72 (21.3)
PA-PU-P	1046 (67.0)	498 (31.5)	104 (10.9)	102 (3.8)	52 (2.8)	32 (4.9)	494 (207.6)	165 (78.1)

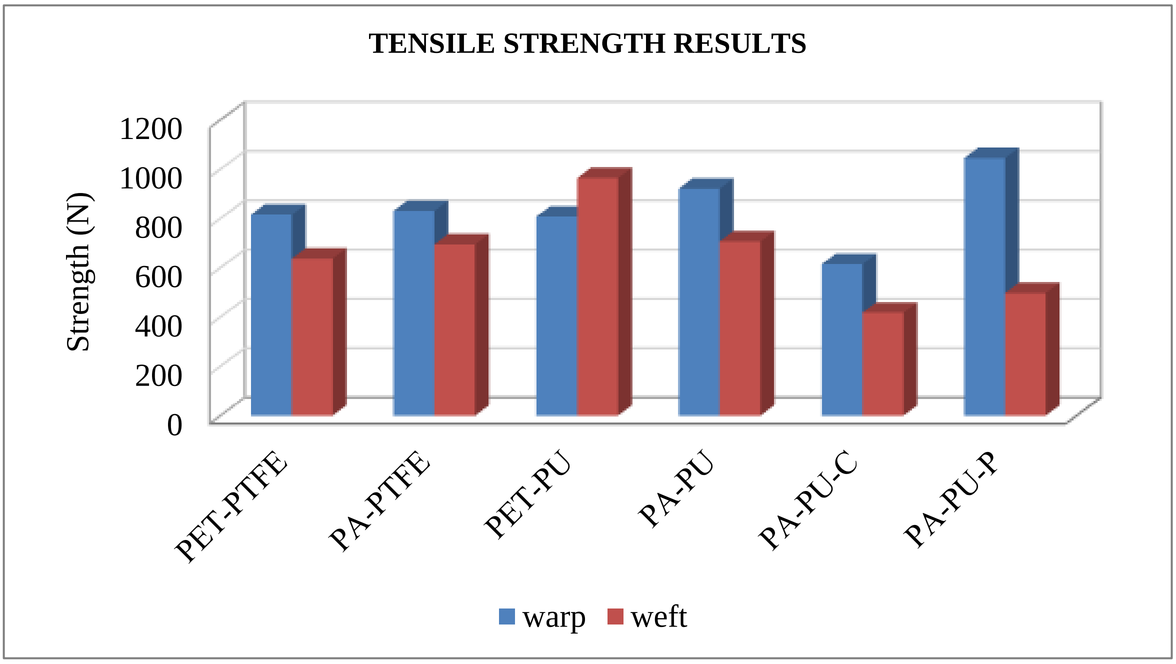


Figure 5: Tensile strength of samples

Tensile strengths in warp and weft directions are shown in Figure 5. Tensile strengths of samples were between 614 and 1046 N in warp direction and 418 and 964 N in weft direction. A systematical change was not detected in tensile strengths of samples with respect to base fabric type and lamination film type. This may be due to different structural parameters of commercial sailing garments. Although being 3-layered, PA-PTFE, PA-PU-C and PA-PU-P samples did not exhibit superior tensile strengths when compared to 2-layered samples.

Extension values of samples were between 62 and 104 mm both in warp and weft directions. When compared to tensile test results, extension values in warp and weft directions were closer to each other for all sample types. 3-layered PA-PU-P sample with the highest tensile strength, also exhibited the highest extension values.

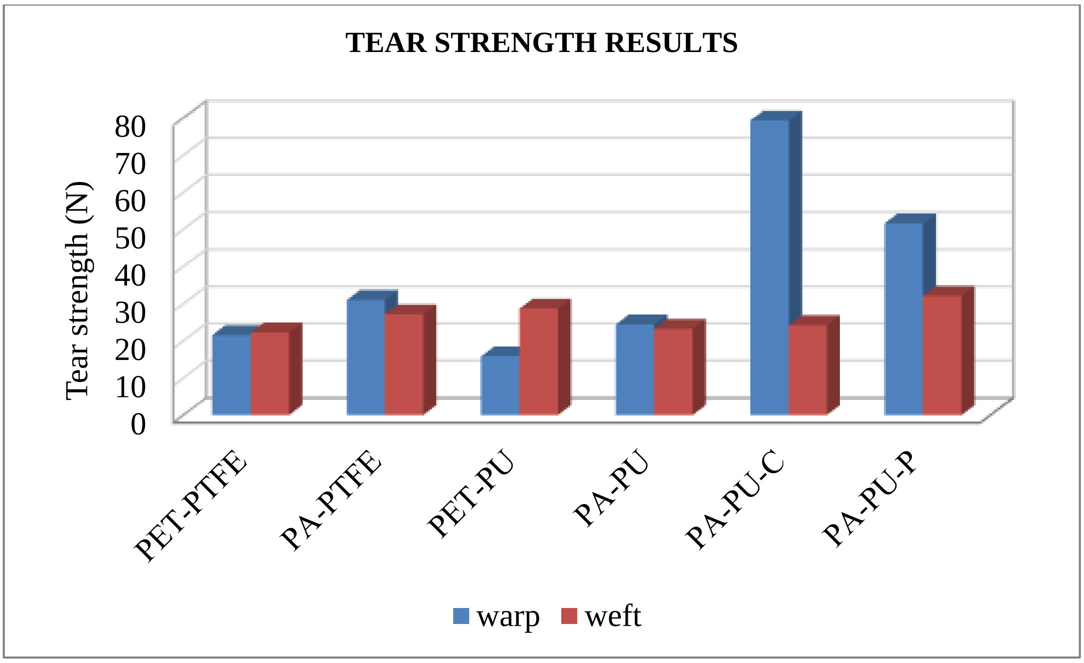


Figure 6: Tear strength of samples

Tear strength results are given in Figure 6. Tear strengths of samples were 16-79 N and 22-32 N in warp and weft directions, respectively. Tear strengths of laminated PA samples in warp direction was obtained higher when compared to laminated PET equivalents. 3-layered PA-PU-C and PA-PU-P samples gave higher tear strength values especially in warp direction. Tear strengths in weft direction were closer to each other when compared to tear strengths in warp direction.

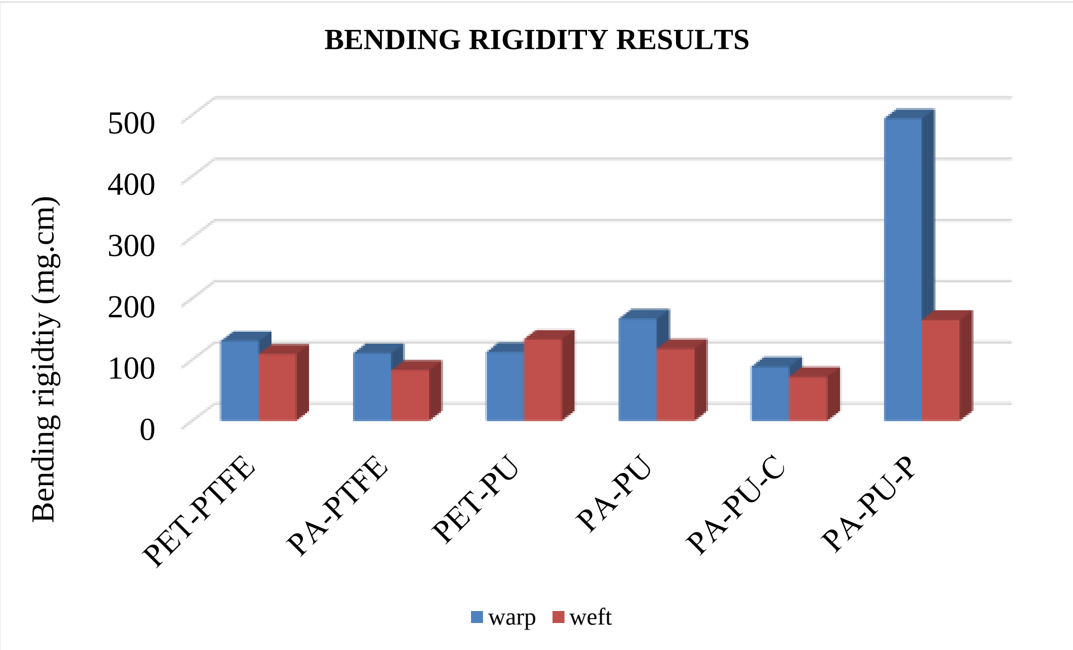


Figure 7: Bending rigidity of samples

Bending rigidity results are given in Figure 7. Bending rigidities of samples in warp direction were 88-494 mg.cm while it was 72-165 mg.cm in weft direction. Bending rigidity of fleece laminated 3 layered PA-PU-P sample was highest in both directions. This may be a result of higher weight and thickness of this sample.

Abrasion resistance of samples are given in Table 6 and Figure 8. Mass changes after certain abrasion cycles are given in grams and in % percentages in Table 6. Abrasion test is applied to base fabric sides of the samples.

Table 6: Abrasion resistance of samples

Sample code	Mass before abrasion (g)	Mass after 5000 cycles (g)	Mass change after 5000 cycles (%)	Mass after 7500 cycles (g)	Mass change after 7500 cycles (%)	Mass after 10000 cycles (g)	Mass change after 10000 cycles (%)	Mass after 15000 cycles (g)	Mass change after 15000 cycles (%)	Mass after 25000 cycles (g)	Mass change after 25000 cycles (%)
PET-PTFE	0.13930	0.13950	0.14	0.13933	0.02	0.13923	-0.05	0.13833	-0.69	0.13670	-1.87
PA-PTFE	0.15230	0.15283	0.35	0.15277	0.31	0.15300	0.46	0.15307	0.50	0.15313	0.55
PET-PU	0.16383	0.16293	-0.55	0.16267	-0.71	0.16240	-0.87	0.16123	-1.59	0.15873	-3.11
PA-PU	0.16540	0.16780	1.47	0.16777	1.45	0.16797	1.58	0.16813	1.68	0.16837	1.82
PA-PU-C	0.15263	0.15300	0.24	0.15290	0.18	0.15317	0.35	0.15340	0.50	0.15353	0.59
PA-PU-P	0.32983	0.33040	0.17	0.33027	0.13	0.33010	0.08	0.32940	-0.13	0.32790	-0.59

Maximum mass loss after abrasion was obtained as 3.11 % for PET-PU sample after 25000 abrasion cycles. In contrary, mass of some samples increased after abrasion. This is due to sticking of fibers of abrasive fabric on the samples. Increase of abrasion cycles did not affect the mass change of samples, importantly.

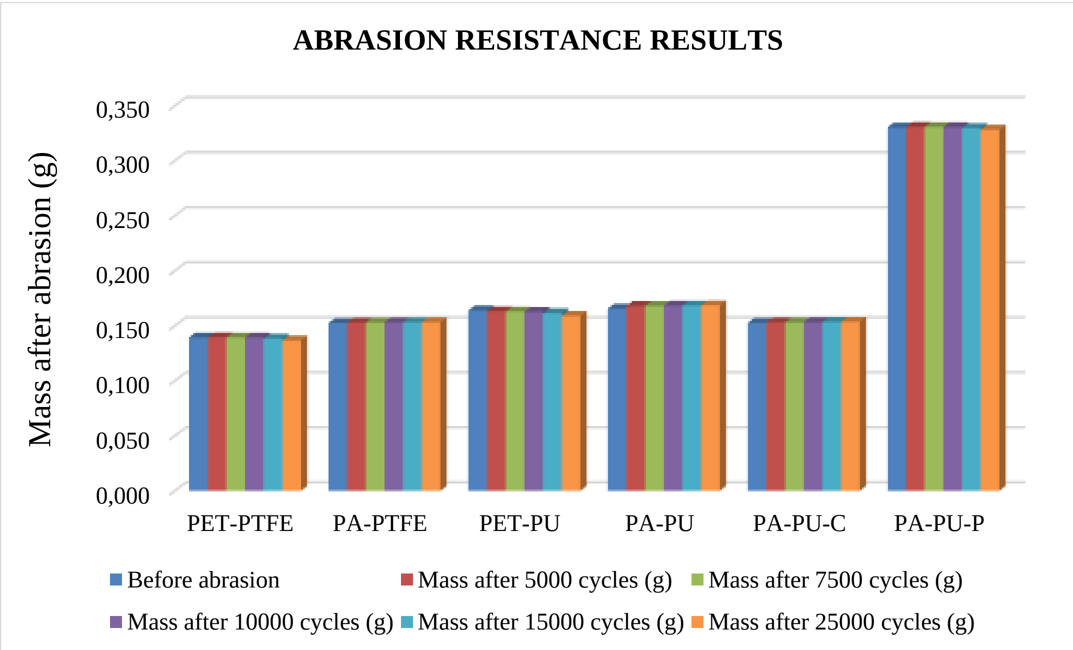


Figure 8: Abrasion resistance of samples

4. CONCLUSION

In this study, 2- and 3- layered laminated sailing garments were supplied and tested for their physical, permeability and mechanical properties. According to test results, most of the samples were in moderate thickness and unit mass values. As thickness and unit mass influences important characteristics such as mobility, heat and mass transfer etc., thinner and lighter fabrics may be improved to be used in sailing garments with acceptable permeability and mechanical properties. It was detected that commercial sailing garments possessed superior waterproofness and windproofness, which provided the sailors a high protection against environmental factors. Also most of the samples possessed a high water repellency that would help to dry fast during sports.

Durability of waterproofness after washing is an important quality factor in order to maintain the protection of garments against sea water and rain. According to test results, commercial sailing garments remained waterproof even after 20 washing cycles. But the waterproofness results had a high standard deviation. This may be overcome by using quality membranes or altering the lamination process.

In this study, a frame for sailing garment mechanical properties was emerged. It was detected that usage of 3 layered samples supported the tensile strength and tear strength results but it resulted with higher bending rigidity for fleece interlined samples. It was found important as bending rigidity affects the formability of fabrics which may be effective on mobility of sailors during sports.

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