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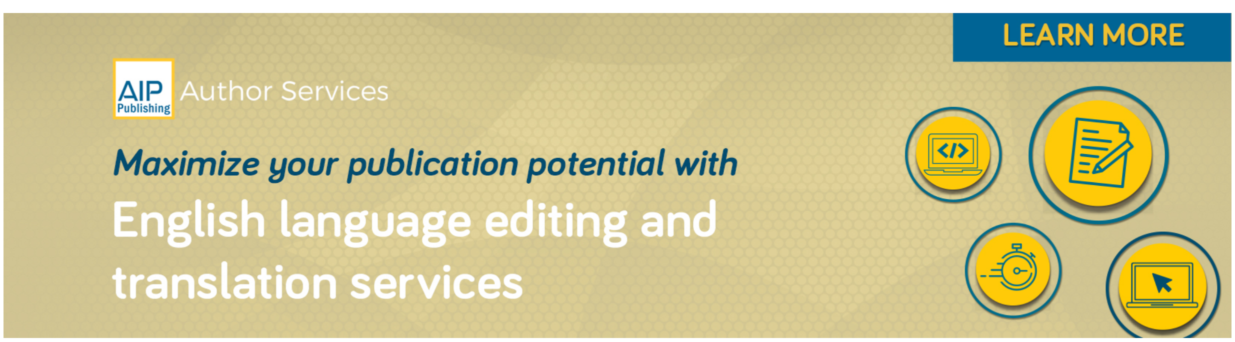

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Properties of Membrane Textile Materials for Apparel in Modeling Exploitation Wear

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Abstract. The aim of the work is to establish the regularity of the effect of low temperatures in combination with mechanical loads on the properties of membrane textile materials of different structures. The following tasks were solved: the study of physical and mechanical properties and the water permeability of membrane textile materials containing membranes different in composition and structure was investigated by simulating operational wear in the temperature range from 0 ℃ to minus 30 ℃ when exposed to 0 to 100 000 cycles of mechanical loads. In this work, the microscopy method, methods of studying the permeability of textile materials to water, water vapor and air, the method of mathematical modeling were used. As a result, the main recommendations for predicting the properties of membrane materials of different structures and their application areas were formulated. The field of application of the results is the textile and clothing industry.

INTRODUCTION

Production of composite materials is the priority direction of development of the textile industry. Therefore, the analysis of the relationship between the structure of composite materials and their properties is the actual scientific task.

The research focuses on waterproof composite textile materials. The materials include textile layers and a polymeric membrane capable of transmitting moisture vapor, but preventing water and airflow penetration. The field of application of the studied materials is the production of household and sports waterproof clothing.

Waterproof composite textile materials with membrane differ in the composition and structure of textile and polymer layers, in the way the layers are bonded together. This makes it possible to obtain the widest range of new materials, which have valuable consumer properties: durability, waterproofness and airtightness, vapor permeability. To ensure high quality garments, this unique set of material properties must be stable over time under operating conditions. To determine the degree of stability of properties during use, materials are subjected to simulated operational stresses, measuring the level of the most important property values before and after exposure.

For waterproof composite materials with membrane (CMM) the main criterion of wear resistance is the reduction of waterproofness during operation. The method of modeling the operational wear of textile materials in laboratory conditions is necessary for predicting the quality of clothing products. Such researches are especially important for new poorly studied materials.

There are still no answers to some questions:

What has the greatest influence on the stability of the level of water resistance of CMM - mechanical factors of wear (stretching, repeated bending, abrasion, etc.) or environmental factors (temperature, humidity) with their simultaneous effect on the material?

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In what range of the number of cycles of exposure there is a significant decrease in the level of water resistance of CMM and what structural features or properties of CMM should be considered when forming a sample of materials for the study of operational wear?

Studies conducted earlier by the authors of the article have shown that the decrease in water resistance after exposure to combined mechanical loads and reduced temperature for woven-based CMM can reach 60% of the initial level for several tens of thousands of cycles. A significant influence on the level of water resistance in the simulation of operating loads has the structure of CMM, the method of their production and the type of membrane [1]. In the sources of literature the issues of wear resistance of waterproof CMM are not widely covered, but their relevance is indisputable: such materials are at the peak of consumer preferences as providing high quality and comfort at extreme level of water protection. Therefore, research and analysis of factors influencing water resistance of CMM of different structures in conditions simulating operational ones is relevant and timely.

METHOD USED

To achieve the goal, multiple bending of materials was simulated while simultaneously exposed to low temperatures. Three-layer composite materials with textile layers of different structures, but of the same fibrous composition, with membrane layers different in composition and structure, were chosen as the objects of research. Samples are used in the garment industry for the manufacture of household and sports windproof waterproof comfortable clothing, operated in a wide temperature range.

To simulate multi-cycle bending under reduced temperature conditions, the setup [2] developed at the Vitebsk State Technological University (VSTU) was used. The unit is a flexometer installed inside a climatic chamber. The test methodology involves simulation of operational mechanical loads in a climatic chamber when materials are exposed to any given number of cycles of bending or stretching in the temperature range from minus 40 °C to plus 150 °C at different humidity in accordance with the purpose of the material [3].

For the test, specimens 50 mm × 90 mm in size were placed in the clamps of the working unit, then the flexometer was switched on and the correctness of fixing of specimens was checked. When the specimen material is properly tucked, it forms a running fold, the clamp ends do not rest on the material, but guide the fold without straining or deforming the specimen.

In the climatic chamber, the temperature and humidity of the test were set according to the experiment plan. When the set parameters were reached, the flexometer was switched on. The test was terminated after the time that provided the specified number of cycles. The exposure rate was set at (120±5) cycles per minute.

The CMM structure was investigated by reflected light microscopy using a BestScope BS 3040 stereomicroscope with a BCL-350 camera plate. The thickness of the samples was determined using a TP-10A thickness gauge with an accuracy of 0.1 mm.

To study the water resistance index, we used a portable hydrostatic device developed at the VSTU [4], which makes it possible to study the waterproofness of materials on small samples (cell size (31±0.5) mm, pressure rise rate 0.002 MPa/min).

The vapor permeability of the materials was investigated by the method of an upright cup using the climatic chamber ”Tuantao” (relative humidity (65±5) %, temperature (20±2) °C, test time 8 hours, thickness of air layer between water surface and bottom surface of the sample (10±1) mm). The stiffness was investigated using a PT-2 device. Air permeability was studied using a VPTM-2 device. Table 1 shows the characteristics of the test methods.

TABLE 1. Test methods.

Name of parameter	Designation	Units of measurement	Test method
Fabric density	Df	number of threads (warp / weft) per 100 mm	GOST 3812-72
Knitting density	Dk	number (buttonhole rows / columns) per 100 mm	GOST 8846-87
Total thickness	h	mm	GOST 12023-93
Surface density	Ms	g/m^2	GOST 8845-87
Waterproofness	Wp	MPa	GOST 413-91 (B)
Water vapour permeability	WVP	g/m^2/24h	ISO 8096:2005
Stiffness	E	μH ·cm^2	GOST 10550-93
Air permeability	Ap	dm^3/(m^2·s)	GOST 12088-77

RESULTS

The results of microscopy of the studied samples are presented in table 2. Designation in the table are: PES – Polyester; PU – Polyurethane.

TABLE 2. The results of microscopy of specimens.

Specimen	Fibrous composition of layer			Type of textile layer*		Thickness of layer, mm		
	outer	membrane	inner	outer	inner	outer	membrane	inner
1	PES	PU hydrofobic	PES	plain jersey fabric	interlock fabric	0.24	0.02	0.38
2	PES	PU hydrofobic	PES	plain jersey fabric	2x2 rib fabric	0.22	0.02	0.28
3	PES	PU hydrofobic	PES	interlock fabric	jersey jacquard	0.37	0.04	0.29
4	PES+ PU	PU hydrofobic	PES	plain weave	single bar cord	0.32	0.05	0.31
5	PES+ PU	PU hydrofobic	PES	plain weave	terry fabric	0.32	0.08	0.65
6	PES+ PU	PU hydrofobic	PES	plain weave	terry fabric	0.35	0.05	0.71
7	PES+ PU	PU hydrofobic	PES	plain weave	terry fabric	0.35	0.06	0.78
8	PES	PU hydrophilic +PU hydrofobic	PES	satin-tricot	single bar cord	0.32	0.07	0.22
9	PES	PU hydrophilic +PU hydrofobic	PES	two-needle atlas	single bar cord	0.41	0.09	0.21
10	PES	PU hydrofobic	PES	plated jersey fabric	terry fabric	0.30	0.03	0.72
11	PES+ PU	PU hydrophilic	PES	plain weave	interlock fabric	0.21	0.04	0.45

* According to ISO 8388:1998 Knitted fabrics — Types — Vocabulary

The characteristics of the samples and the indicators of their physical and mechanical properties are presented in table 3.

TABLE 3. Properties of the studied samples.

Specimen	Textile layer	Dk / Df		h, mm	Ms, g/m^2	E, µH $\cdot sm^2$		WVP, $g/m^2/24h$	Wp, MPa	Ap, $dm^3/(m^2 \cdot s)$
		Along / warp	Across / weft			Along / warp	Across / weft			
1	outer	300	210	0.72	298	3415	620	2726	0.20	0
	inner	230	230							
2	outer	850	730	0.55	270	296	352	2082	0.12	0
	inner	160	120							
3	outer	230	210	0.68	245	310	388	467	0.18	0
	inner	150	140							
4	outer	440	420	0.66	236	4343	440	782	0.16	0
	inner	100	170							
5	outer	440	440	1.30	307	5080	2514	646	0.20	0
	inner	230	230							
6	outer	480	480	1.20	347	2981	3720	717	0.20	0
	inner	210	210							
7	outer	470	430	1.39	295	4771	1983	618	0.40	0
	inner	250	250							
8	outer	210	130	0.57	242	2565	3760	1714	0.38	0
	inner	150	130							

TABLE 3. Continued.

Specimen	Textile layer	Dk / Df	h, mm	Ms, g/m^2	E, µH ·sm^2	WVP,	Wp,	Ap, dm^3/(m^2·s)	Specimen	Textile layer
		Along / warp	Across / weft			Along / warp	Across / weft			
9	outer	150	150	0.55	235	410	389	1866	0.50	0
	inner	130	160							
10	outer	320	530	1.20	270	1738	791	3480	0.20	0
	inner	160	130							
11	outer	490	430	0.68	292	703	389	2004	0.18	0
	inner	190	180							

To assess the degree of the combined effect of repeated bending and reduced air temperature on the stability of the water resistance level of the CMM, a full factorial experiment was performed. The following factors were varied: the temperature in the climate chamber and the number of bending cycles. Before and after the simulation of operational wear, a study of the water resistance of the CMM was carried out. The range of variation of factors was established based on the expected operating conditions of the materials and the analysis of literature sources devoted to CMM research and operation modeling [5 – 10].

The controlled factors and the levels of their variation are presented in table 4. The results of the experiment were processed using the program "Statistica for Windows" according to the method described in the source [11].

During the test, it was found that some samples lost their waterproofness after exposure to 20 000 bending cycles at 0°C.These were the samples under the numbers 3, 4, 5, 6, 7. Almost all of these samples contain a woven front layer of plain weave and a polyurethane hydrophobic membrane.

TABLE 4. The controlled factors and the levels of their variation.

Designation and naming of factors	Variation levels			Interval
	-1	0	+1	
X_1 – bending, cycles	20000	60000	100000	40000
X_2 – temperature in the climate chamber, °C	-30	-15	0	|15|

The experiment planning matrix is shown in table 5.

TABLE 5. The experiment planning matrix.

#	Coded values		Waterproofness, MPa										
	X_1	X_1	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}
1	-1	+1	0.14	0.04	0	0	0	0	0	0.20	0.50	0.18	0.18
2	-1	0	0.14	0.03	0	0	0	0	0	0.18	0.30	0.16	0
3	-1	-1	0.03	0.02	0	0	0	0	0	0.01	0.10	0.08	0
4	0	+1	0.14	0.06	0	0	0	0	0	0.14	0.48	0.08	0
5	0	0	0	0	0	0	0	0	0	0.18	0.25	0.05	0
6	0	-1	0	0	0	0	0	0	0	0	0.04	0	0
7	+1	+1	0	0.02	0	0	0	0	0	0.16	0.08	0.04	0
8	+1	0	0	0	0	0	0	0	0	0.14	0.10	0.01	0
9	+1	-1	0	0	0	0	0	0	0	0	0	0	0

It was not possible to build a mathematical model for all the samples under study. In most cases, this was due to the fact that all dependent variables were zeros.

Regression models of dependence of output parameter on input factors were obtained for samples 2, 8 and 9 after exclusion of insignificant coefficients. Dependences of input factors on the output parameter were described by an incomplete polynomial. Regression coefficients of the obtained models were calculated using the program "Statistica for Windows". Regression equations for samples 2, 8 and 9 looks like (1, 2, 3):

$$Y_2 = 0.036 + 0.001 \cdot X_2 \quad (1)$$

$$Y_8 = 0.194 + 0.005 \cdot X_2 \quad (2)$$

$$Y_9 = 0.359 + 0.010 \cdot X_2 \quad (3)$$

To assess the statistical significance of the developed models, analysis of variance was carried out. For each equation Fisher's criterion was defined, which value for equation 1 – 5.77, for equation 2 – 17.14, for equation 3 – 7.08. At significance level $p<0.05$ Fisher's criterion of all considered models is more than tabulated one, which indicates reliability of developed models.

Based on the analysis of model coefficients, we can conclude that the stability of the level of water resistance of the studied CMM under their repeated bending in conditions of reduced air temperature is most affected by temperature - the lower it is, the lower the value of water resistance of the sample after the combined action.

Correlation analysis of the experimental results showed that the relationship between water resistance and temperature is linear, direct and close. Linear correlation coefficients 0.67, 0.84 and 0.71 were received for samples 2, 8 and 9 correspondingly. Connection with number of loading cycles for the considered samples is linear and inverse - coefficients were: minus 0.47, minus 0.15 and minus 0.55, respectively.

CONCLUSION

As a result of the performed factor analysis, the following conclusions can be made:

- according to the built models, the most significant effect on the level of waterproofness of CMM when they are repeatedly bent in conditions of low air temperature in the range from 0 °C to minus 30 °C has temperature;
- the samples of CMM, containing woven textile webs in the structure, withstand the joint effect of bending and low air temperature worse than the samples in the structure of which textile layers are obtained by knitting. Thus, samples numbered 3, 4, 5, 6, 7, 11 lost their waterproofness already at 0 °C after 20 000 bending cycles. Exactly these samples contain elastane in the woven textile layer. Elastane is known to be unstable to low air temperature [12,13,14]. Probably, the low frost resistance of elastane affects the overall resistance of the composite material to simulation of operating loads at reduced air temperature;
- the analysis of the data of the study of the properties of CMM showed that the stability of the level of waterproofing by simulating operational wear in the temperature range from 0 ℃ to minus 30 ℃ when exposed to 0 to 100 000 cycles of mechanical loads is not affected by the stiffness of the materials. Samples that showed a stable level of water resistance have different stiffness, as well as samples that lost waterproofness very quickly;
- the total thickness of the composite material affects the stability of the waterproofing of three-layer CMM under the combined effect of reduced temperature and multi-cycle bending. The samples with the smallest thickness showed the highest degree of stability of the waterproofing level. Thus, samples numbered 2, 8 and 9 have thicknesses ranging from 0.55 mm to 0.57 mm the most stable water resistance. The remaining samples are characterized by a total thickness of 0.66 mm to 1.39 mm and quickly lose waterproofness when simulating operational loads;
- the analysis of the structure of the studied CMMs showed that the type of interlacing of the textile layers (Table 2) probably influences the stability of the level of waterproofness of the whole composite. In this study, the two samples having textile layers in the structure, worked out with interlacings, which contain long overlaps of threads, showed the best results. In contrast, the samples produced by the weave with the shortest overlap length showed the worst results;
- the type of the membrane layer affects the watertightness of the CMM. Samples numbered 8 and 9 with a combined hydrophilic-hydrophobic membrane turned out to be the most stable in terms of water resistance under the experimental conditions.

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