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Construction and Technology of Sports Clothing from Membrane Materials and High-Stretch Fabric

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Abstract. The article deals of the development of sportswear for children involved in biathlon. Were solved: the analysis of the training activity of young biathletes was carried out; selected materials for the product; a model and rational design of a tracksuit for girls has been developed; the study of the properties and the choice of the sewing mode was carried out. In this work, to study the properties of materials, method of microscopy, methods of studying strength, thermal conductivity, permeability and toxicity of textile materials were used; for the development of a rational design - a computational-graphic method; to optimize the modes of seams - the method of mathematical modeling. As a result, the main recommendations were formulated for the design and processing technology of sportswear for children, made using composite membrane materials on a knitted basis. The area of use of the results is the clothing industry.

INTRODUCTION

Nowadays there is a state program to support physical activity and sports in the Republic of Belarus. The program targets students in 5-7 grades and aims to provide them high-quality sportswear. To do this, you need to develop recommendations for the choice of materials, modes of their processing and design of the sportswear.

Biathlon requires special equipment. Biathletes train at air temperatures from + 9 °C to - 15 °C. During training activities, biathletes sweat, and exposed to low temperatures, snow, and wind. Therefore, clothes for a biathlete should provide the least wind protection at high speeds, precent the snow getting under the cloths in case of possible falls, reduce muscle fatigue, be flexible, prevent over cooling, collection of moisture, and overall create a comfortable microclimate under the clothes.

The main requirement for children's sportswear is to ensure the prevention of morbidity and sports injuries, since in the process of training, children are prone to falls and hypothermia. Compared to adults, their body is more fragile, less trained, its thermoregulation is not entirely fine-tuned, and the level of the child's sportsmanship is low. In this regard, to protect the chest, knee and elbow joints from adverse effects in sportswear, waterproof, windproof, but breathable and comfortable materials are needed, and to provide the necessary freedom of movement, highly stretchable knitted fabrics. The combination of such materials, differing in structure and properties, in one product requires optimization of design methods and study of technological processing modes.

The goal of this work is to define a rational choice of materials, modes of their processing and an engineering solution for a biathlete's apparel.

The materials of the biathlete's outfit must provide freedom of movement, protection from wind, snow, water, be breathable and warm. Composite membrane textiles on a knitted basis meet the listed requirements. They have a high level of breathability and water resistance, wind protection, strength, significant thermal resistance. However, their natural flexibility may not be enough to ensure required freedom of movement. Therefore, it is necessary to design the usage of the materials with various flexibility across the construction. To achieve the goal of the work, the research of the properties of the selected materials were carried out to confirm their compliance with the defined requirements.

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The optimal modes of joining the materials were determined, and a effective ergonomic design of the sportwear was developed.

MATERIALS AND METHODS

When choosing materials, we used the method of engineering assembly described in the source [1, 2, 3]. We selected various materials for different sections of the structure. A composite layered membrane material on a knitted basis (sample #1) and bi-elastic knitted fabric (sample #2) have been selected for the top of the suite. A unique design allowed to compose various materials to provide excellent protection from severe weather conditions, freedom of movement and a snug fit. A thin stretchable two-layer membrane composite material (sample #3) was used as a wind and moisture protective pad on the back of the jacket. We have chosen a fleece-type knitted fabric (sample #4) for the lining of the jacket

The study of the properties of materials according to the indicators presented in Table 1 was carried out in an accredited laboratory of Vitebsk State Technological University (VSTU) using both common standards and proprietary methods. The structure of the membrane material was studied by microscopy using a VEGA II LSH scanning electron microscope.

We used the method of optimizing the types of thread connections for sample #1 only. Since it is the membrane three-layer materials that are least of all covered with scientific research in this area. The optimization of parts from sample No. 1 was done based on the parameters of strength and wear resistance. A full factorial experiment was performed. The following sewing parameters were varied: sewing needle diameter, linear density of sewing threads, sewing frequency.

The tensile load of the seam was taken as a strength criterion. The tensile load of the seam after multi-cycle stretching and bending was taken as a wear resistance criterion. We used the method of modeling operational loads on the device designed and built in VSTU. The device makes it possible to put material samples into to cyclic bending and tension at a certain frequency at different preset strain values. Based on the available data, various test modes were established. When simulating the operation, the tension was set to 10% of the initial sample length and the number of loading cycles was 15 000 [4, 5, 6]. Generic test samples were cut out in a rectangular shape so that the seam follows the same direction as a buttonhole column of the fabric. The size of the sample with the seam was 200 mm × 50 mm. Samples of two types were prepared - to study the strength and wear resistance of the seam when stretched along and across the seam. Thus, we figured out types of the main seams in the product under tension and bending deformation: side seams, step seams, sleeve seams. Samples with seams were prepared on a Jack-F4 universal industrial sewing machine equipped with a differential fabric motor and a Teflon foot. To connect the parts, a shuttle stitch machine, sewing needles with a sharpened point of the KN type and reinforced threads were used. The samples were put together without bartacks, at a speed of rotation of the main shaft of the machine at about 2000 rpm. For each combination of controlled conditions, 5 generic samples with seams were prepared. Before and after the modeling of operational wear, a research of the breaking load of the seams was carried out on a tension testing machine RT-250 according to GOST 28073-89 "Sewing products. Methods for determining breaking load, lengthening of thread seams, stretching of fabric threads in the seams." The design was developed using the computational and graphic method.

RESULTS AND DISCUSSION

The research results of the properties of the selected materials are presented in Table 1. Designation in the table are: PE – Polyester; PU – Polyurethane; PA – Polyamide.

The normalized value of property indicators was established according to Technical Regulations of the Customs Union (TR CU) 007/2011 "Safety of products intended for children and teenagers" and according to the analysis of the information source [6, 7, 8, 9].

A diagram of the structure of composite membrane materials #1 and #3 is shown in Figure 1. The research of the structure of the material showed that the outer layer of the membrane material (sample #1) is made of knitted fabric of a single cross-linked weave with a thickness of 0.24 mm. The seamy side is made of 0.21 mm thick double weave fabric. Between the canvases, there is a thin sheet membrane 0.02 mm thick, connected to the textile layers pointwise along the supporting surfaces of the hinges (Fig. 1 (b)). Sample #2 – bielastic knitted fabric with crochet stitch weave. Sample #3 is a two-layer tensile composite laminate. Its front side is a sheet monolithic non-porous membrane with a thickness of about 0.25 mm. The seamy side is a polyester knitted fabric with a crochet stitch weave. The fastening of the textile fabric to the membrane is pointwise along the supporting surfaces of the hinges (Fig. 1 (a)).

Sample #4 – knitted fabric of the fleece type, 0.7 mm thick, plush weave with continuous double-sided pile.

The properties of the selected materials meet the stated requirements, the material of the top (sample #1) is durable, stretchable, non-toxic, non-electrifying, has a color resistant to physical and mechanical impact, windproof and has a high level of water resistance. This material will provide the required level of protection in the details of the front of the jacket and the front of the pants. The moisture wicking and stretchability properties of sample No. 1 is not too high, but to ensure freedom of movement and the moisture wicking the sportwear has other parts made from a more breathable and stretchable material (sample #2). It is rational to place the elastic material on the back, upper part of the jacket sleeves and on the back of the pants. To ensure the stretchability and waterproofing of the back and upper parts of the sleeves, it is necessary to provide a waterproof and windproof pad made of material of sample #3. The stretchability of samples #2 and #3 is similar. The required thermal insulation of the jacket will be provided by a fleece lining (sample #4). All samples in terms of properties comply with the requirements of TR CU 007/2011, which allows them to be used for commercial use in the production of children's clothing.

TABLE 1. The results of the materials properties research

Indicator name, units of measurement	Test method	Values for samples			
		#1	#2	#3	#4
Composition of textile layers, %	manufacturer's data	PE 100	PU 20, PA 80	PE 100	PE 100
Number of stitch rows in 100 mm	GOST 8846	260 (outer layer) 210 (inner layer)	346	280	198
Number of hinge posts per 100 mm	GOST 8846	240 (outer layer) 180 (inner layer)	410	280	176
Membrane layer composition, %	manufacturer's data	PU 100	-	PU 100	-
Surface density, g / m^2	GOST 8845	274	162	98	202
Stretch at a load of 6 N across*	GOST 8847	9	54	40	38
Stretch at a load of 6 N along*%	GOST 8847	6	42	34	22
Moisture wicking, g / (m^2 24 h)	GOST 22900	1468	4780	1685	4100
Waterproofness, MPa	GOST 413, not less than 0.07	0.22	-	0.42	-
Breathability, dm^3 / (m^2 s)	GOST 12088	0	68	0	80
Toxicity index, %	GOST 32075, from 70 to 120	90	82	77	110
Breaking load along *, H	GOST 8847	770	340	276	-
Breaking load across *, N		530	298	245	-
Stretch at break along *, %		102	228	210	-
Stretch at break across *, %		180	290	256	-
Thermal resistance, ($m^2 \cdot$ ℃) / W	[5], not less than 0.5	1.27	0.23	0.41	0.9
Color loss resistance to, points:	GOST 9733, not less than 3				
washing		4	5	-	4
sweat		5	5	-	5
wet friction		4	5	-	5
Electrostatic field intensity level, kV / m:	SanPiN9-29.7-96, no more than 15				
at rest		0.4	0.7	0.3	2.4
after rubbing		5.1	6.8	4.1	11.2
Free formaldehyde content, mkg / g	GOST 25617, no more than 75	18	9	3	2

* along the canvas, across the canvas

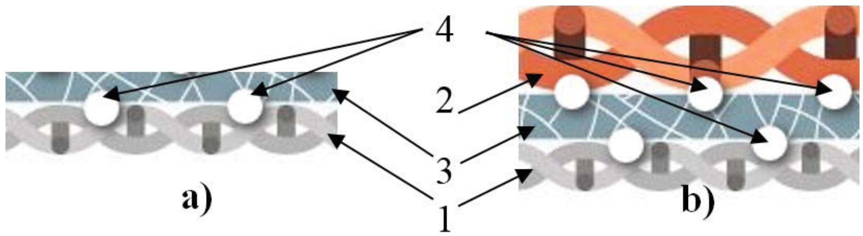

FIGURE 1. Scheme of the structure of sample #3 (a) and sample #1 (b):1 – fabric on the inner side, 2 – fabric on the outer side, 3 – polymer membrane, 4 – gluing points

The technology for making garments from membrane materials on a knitted basis does not fundamentally differ from the traditional technology of knot processing, but it has significant features in terms of choosing the modes of thread connections. When sewing products from materials such as samples #1 and #3, problems may arise, since the stitching occurs under conditions of increased resistance to puncture with a needle and intense friction of the sewing thread on the layers of material during the stitch formation process. The threads of the knitted layers, fixed in the structure of the composite with glue, are hardly moving under needle impact and have an increased tendency to be cut with the needle. The polymer membrane film can be damaged along the stitching line. During the subsequent usage of the seams, due to rubbing of the seam threads with the edge of the polymer film and binder, a significant decrease in their strength is possible. As a result, the following disadvantages are possible: explicit and hidden cutting, a significant decrease in the strength of the thread connection during the usage of the products. To reduce the cutting of materials, it is recommended to use the sharpening of sewing needles of the KN type. The choice of connecting modes for parts made of supplex (sample #2) was carried out considering the data of the information source [10, 11, 12].

The characteristics of the researched variants of reinforced sewing threads are presented in Table 2. The range and intervals of variation of the controlled factors were determined based on the results of the preliminary research.

TABLE 2. Characteristics of sewing threads for joining parts

Trade number	Composition	Linear density, tex	Breaking load, H	Stretch at break, %
140	PE 100%, Saba	22	8.5	11,6
120	PE 100%, Saba	27.5	12.4	11,8
100	PE 100%, Saba	33	16.2	14,2

Controllable factors and levels of their variation are presented in Table 3. Optimization criteria: strength across the seam (Y1) – breaking load of the seam immediately after manufacturing the seam, across the seam (H); wear resistance across the seam (Y2) – breaking load after 15 000 bending and stretching cycles of the seam by 10% of its original length, across the seam (H); strength along the seam (Y3) – breaking load of the seam immediately after manufacturing the seam, along the seam (H); wear resistance along the seam (Y4) – breaking load after 15 000 bending and stretching cycles of the seam by 10% of its original length, along the seam (H).

TABLE 3. Controllable factors and levels of their variation

Designation and naming of factors	Levels of variation			Interval
	-1	0	+1	
X_1 – number of stitches per 5 cm	18	22	26	4 st/5cm
X_2 – needle diameter	70	75	80	5 mm^{-2}
X_3 – linear density of threads	22	27.5	33	5.5 tex

Mathematical models of changes in optimization criteria look like (1, 2, 3, 4):

$$Y1 = 8.9X_1 - 2.34X_2 - 7.05X_3 + 0.17X_2X_3 \quad (1)$$
$$Y2 = -1.23X_2 + 7.19X_3 + 0.1X_1 X_2 - 0.07X_2X_3 \quad (2)$$
$$Y3 = 2048.3 - 68.6X_1 - 26.9X_2 + 0.93X_1X_2 - 0.032X_2X_3 \quad (3)$$
$$Y4 = 335.3 - 4.9X_2 + 4.6X_3 \quad (4)$$

Analysis of the obtained models shows that the number of stitches per 5 cm of a line affects different optimization criteria in different ways. The sewing frequency is insignificant for wear resistance, but very significant for strength. Moreover, when stretching across the seam, the strength decreases with an increase in the sewing frequency, and when stretched along the seam, it increases. The linear density of the sewing thread has the same effect. For all directions of stretching and for all criteria, the diameter of the needle is significant and equally important. The thicker the needle, the lower the level of the optimization criteria.

As a result of optimization of thread connections in terms of strength and wear resistance, it was revealed that to obtain a strong and wear-resistant thread connection of a three-layer membrane material on a knitted basis, it is required to sew with a needle with the smallest core diameter recommended for the corresponding material thickness. To obtain the highest tension strength at high strength in the direction both along and across the line, the thread connection must be done at an average stitch frequency and average linear density of sewing threads from the range of variation established in the experiment: needle number - 70 with KN point sharpening; thread number - 120 (linear density 27.5 tex); sewing frequency - 22 stitches per 5 cm line.

The design of the product was developed using computational and graphic method. The properties of materials were considered when designing different stretchability of the upper materials, their different thicknesses, and densities. A schema of the structure is shown in Figure 2. The parts made of elastic supplex are shown as shaded (sample #2).

FIGURE 2. Jacket construction schema

CONCLUSION

Based on the results of the research, the following conclusions can be made:

-selected as upper materials, membrane composite materials meet the requirements for a biathlete's outfit. They provide protection from wind, snow, and rain. Heat protection, freedom of movement and comfort are achieved due to the use of a stretchable knitted fabric in certain areas of the product;

-recommended modes for joining parts made of membrane materials on a knitted basis with shuttle stitches are the following: needle number – 70 with KN point sharpening; thread number – 120 (linear density 27.5 Tex), sewing frequency – 22 stitches in 5 cm lines;

-when designing an optimal structure, it is recommended to alternate materials that simultaneously provide protection from harsh weather conditions, freedom of movement and a snug fit: flexible materials must be placed in the shoulders, front parts of sleeves, side parts of the jacket. Windproof and waterproof membrane materials should be used on the front, lower back, and elbows of the sleeves.

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