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Influence of Arselon Knitted Fabric Structure on its Properties

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Abstract. The paper is devoted to comparison analyzing different kinds of knitted fabrics produced of Arselon yarns for determination of influence of structure of fire-resistant knitted fabrics produced of Arselon yarns on their properties. To selecting the most acceptable option for making helmet liners an assessment of the effect of knitted fabrics structure on their following air and vapor permeability, breaking force, extensibilityremaining strain after singe-cycle and multi-cycle testswas carried out. It was found that the knitted interlock fabric has thebest combination of hygienic and mechanical properties for its end use.

INTRODUCTION

Protective textiles are one of the main varieties of technical materials the development of the range of which is one of the promising directions for the textile industry in the world. Flame retardant and flame resistance textiles play an important role in many industries [1, 2] but the most important thing is the correct choice of fire-resistant materials in the manufacturing firefighter's clothing.

For the protective clothing production the following types of fabrics are used:

- fabrics made of high-performance flame resistant fibers, for example, Kevlar, Nomex, Kermel, PBI, PBO, etc. [3, 4]. Clothing made of such fabrics has constant fire protection during operation, good resistance to various chemical reagents, long service life which in turn affects the cost of the material;
- flame retardant impregnated or modified fabrics made of inflammable textile fibers (cotton, polyester) and their blends [5, 6];
- fabrics made of flame resistant and inflammable fibers blends with flame retardant impregnation or without it.

A lot of research on the development of protective textiles is devoted to the analyzing of woven fabrics structure and properties. Most of the publications are devoted to the research the fabrics flammability, but there are also papers focused on the properties affecting the clothes comfort [7].

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In addition, there are publications devoted to investigation of yarns of different structures obtained of fire-resistant fibers, as well as the effect of the composition and structure of the yarns on woven fabrics properties [8, 9].

Namely woven fabrics are the main type of materials for the firefighters' clothing production. The high bending rigidity of the woven fabrics allows them to be used when creating protective clothing with a free silhouette. At the same time, the clothes keep their shape better and do not interfere with wearing. The resulting air gap between the outer layer of clothing and the body acts as an additional means of protection against heat flow in extreme conditions.

However, it is also of interest to create new types of knitted fabrics which can be used, for example, for the helmet liner manufacturing for firefighters and rescuers.

Unlike other garments, means for head and hand protection is worn directly over the body. The air gap between the helmetliner and the human body causes discomfort and inconvenience during operation. So, to achieve wearing comfort it is necessary to use a knitted fabric. When worn directly on the body, the positive features of the knitted material are its low rigidity, increased extensibility and softness.

The stretchability of the structure of the material allows the garment to fit the body without folds, even in places with a complex geometric shape. This eliminates the need to install additional fasteners of various designs on the equipment. Thus, the ease of removing and putting on the helmet liner is ensured and its design is simplified. Depending on the requirements for the mechanical properties of the fabric, by selecting the appropriate knit structure, it is possible to achieve significant changes in the material's bending stiffness, extensibility in the required directions and other physical mechanical characteristics of the fabric, as well as to affect some hygienic indicators.

It is particularly important to determine the extent to which the fiberand fabric structure affects the final burning behavior of the product. This will allow manufacturers to produce final products with suitable physical and burningproperties for end use [10].

For textile enterprises of Belarus, it is of interest to develop a technology for the production of protective materials based on domestic raw materials. The only type of flame retardant fiber produced in Belarus is Arselon. In this regard, the goal the objective of presented research is determination of the dependencies of Arselon fabrics properties on their structures for selecting the knit for manufacturing of helmet liners for firefighters.

MATERIALS AND METHOD

Arselon is a polyoxadiazole heat-resistant fiber produced at JSC "SvetlogorskKhimvolokno" (Belarus). As the production process was designed alternatively to meta-aramid fibers, thus by its properties Arselon is very similar to various meta-aramid fibers. The staple fiber Arselon is a basis for spun yarns and felts which further can be processed into many kinds of materials for thermal application. The manufacturer indicates the following main features of Arselon:

- oxygen index (LOI) is 30%;
- no melting;
- temperature of use is 250 °C;
- heat shock temperature is 400° C;
- flexible at high low temperatures;
- low thermal expansion coefficient;
- friction coefficient (metal surface) is 0,2;
- good adhesion to rubber;
- moisture level is 10-12% (similar to cotton);
- high electrical insulation properties.

Properties of used Arselon yarn are presented in the Table 1.

TABLE 1. Properties of Arselon yarn

Property	Value
Linear density, tex	22,2 × 2
Breaking tenacity, cN/tex	21,48
Coefficient of variation of breaking tenacity, %	8,03
Elongation, %	18,12
Evenness CVm, %	11,32
Thin places (-50%), 1/km	2,0

TABLE 1. Continued

Property	Value
Thick places (+50%), 1/km	11,0
Neps (+200%), 1/km	8,0
Hairiness	5,6

Despite the fact that Arselon belongs to fire-resistant fibers, it is inferior to high-performance fibers in terms of tensile properties and flammability and other properties. In this regard, it is necessary to pay more attention to the choice of the structure of the fabric which ensures the achievement of the values of the indicators required for the manufacture of elements of firefighters' clothing.

Five knitted fabric samples of various structures were produced (Table 2).

TABLE 2. Characteristics of knitted fabrics samples

Sample	Knitted structure	Surface density, g/m^2	Course density, cm^{-1}	Wale density, cm^{-1}
1	jersey	239,7	6,5	6,0
2	1×1 rib	443,6	7,0	11,0
3	two-layered knit (1×1 rib + tubular smooth surface)	491,4	6,6	11,0
4	two-layered knit (1×1 rib + jersey)	438,2	8,5	12.5
5	interlock	379,0	12,0	12,0

For the samples producing the Arselon yarn 22 tex×2 was used [11]. In the inner layer of sample 4 cotton yarn 11.8 tex×2 was also used in order to assess the natural fibers influence on the hygienic properties of the fabrics.

The choice of structure options was based on the hypothesis that the heat-insulating properties of knitted fabrics largely depend on their thickness, and two-layer fabrics provide greater protection against heat flow compared to single-layer fabrics.

To determine the most acceptable option for making helmet liners the assessment of the effect of the knitted fabric structure on their following properties was carried out:

- air permeability,
- water vapor permeability,
- breaking force along in the wale and course directions,
- extensibility under load less than breaking force;
- remaining strain after singe-cycle and multi-cycle tests.

Fabrics for helmet liners manufacturing must have high hygienic characteristics, well conduct moisture and air from the underwear space. Air permeability was determined according to standard GOST 12088-77 on the instrument VPTM-2.

Water vapor permeability is the most important property, as it helps to remove moisture from the underwear layer. The moisture conductivity of the material significantly depends on the sorption properties of the fibers and yarns and the porosity of the structure fabric.To determine the water vapor permeability of fabrics for a fireman's helmet liners instrument Radwag MAX50 was used.

In addition to hygienic properties, the material for the helmet liner manufacturing must have high strength characteristics and retain its original dimensions after long-term use. Therefore, the investigated fabrics were tested to determine their tensile characteristics and multi-cycle tensile deformation characteristics.

Extensibility of the fabrics ensures comfortable dressing of the helmet liner and a low percentage of remaining strain provides of shape stability.When firefighter puts the liner on his head it stretches and then remains in this state during the task completion. After that, he takes off the liner which must take its original shapeafter a certain period of time. This type of deformation perfectly simulates by the single-cycle test for determining extensibility and remaining strain under loading 600 cN. For such tests tensile tester WDW500 was used.

During operation, the liner undergoes repeated stretching, which causes a change in the structure of the material and leads to a deterioration in its properties. For the investigated knitted fabrics also multi-cycle tests using pulsator were carried out to determine the remaining strain after 10000 cycles under loading 0,1 % of breaking force and relaxation during 30 minutes.

For breaking tenacity determining tensile machine RT-250 was chosen because this type of instrument is provided by the technical conditions for tested type of knitted fabrics. It can be noted that the tests of fabrics using tensile tester WDW500 shows significantly lower breaking load in comparison to values obtained on machine RT-250.

The limiting oxygen index of knitted fabrics was not determined since they are made of fire-resistant fibers. Additional tests carried out for the resistance of materials to heat flowof 5.0 kW/m^2 using a specially designed testing device.

RESULTS AND DISCUSSION

All obtained samples are characterized by sufficient resistance to heat flow rate 5,0 kW/m^2.Results of the tests are presented in the Table 3. During the test destruction of fabrics on all samples is not occurred.

To assess the effect of the fabric thickness on the obtained results a correlation analysis was carried out. It was found that the temperature on the fabric back side correlates with the heat flow value measured on this side. However, the influence of thethickness on the values of the obtained indicators significantly depends on the fabric composition. So, if the analysis uses the data for all tested samples the correlation is not found (r = 0,191). But if we exclude from consideration sample 4 one of the layers of which is made of cotton yarn then the correlation coefficient between the thickness of the fabric and the temperature on its back side when exposed to a heat flux of 5,0 kW/m^2 becomes r = -0,834. Thus, the following conclusions can be drawn:

- with an increase in the thickness of the Arselon knitted fabric its thermal insulation properties also rise;
- cotton yarn into the structure of the fabric reduces its thermal insulation properties even with an increase of its thickness.

TABLE 3. Results of testing materials for resistance to heat flow 5.0 kW / m^2

Sample	Thickness, mm	Heat flow on the fabric back side, kW / m^2	Temperature on the fabric back side, ° C
1	1,07	2,6	54
2	1,80	2,5	53
3	1,88	2,3	52
4	1,81	2,7	55
5	1,27	2,5	53

All samples showed high resistance of a material to an open flame during surface ignition. The time of residual smoldering and burning was 0 s. In addition, Arselon knitted fabrics have low thermal conductivity. With superficial ignition, the temperature on the back of the fabric does not reach values that lead to charring of the cotton yarn in sample 4.

As mentioned earlier, the comfort of any garment, including protective clothing, is largely provided by the air and water vapor permeability of the fabrics used for its manufacture.Information about tested samples permeability is shown in the Table 4.

TABLE 4. Permeability of knitted fabrics samples

Sample	Water vapor permeability, %	Air permeability, dm^3/(m^2·s)
1	73,33	1495
2	74,17	820
3	71,30	985
4	65,28	920
5	72,96	650

Water vapor permeability of all investigated samples of the knitted fabrics except sample 4 exceeds 70 % which ensures a comfortable state of the person. Sample 4 has lower vapor permeability since the process of vapor passage through the material is slowed down due to the simultaneous moisture sorption by cotton yarn on the inner fabric layer.

Tables 4 shows that sample 1 has high air permeability since it exceeds 1000 dm^3/(m^2·s). The rest samples have medium air permeability which is a positive fact for the following reasons. With multiple use of the helmet liner it stretches which leads to an increase in its porosity. The knitted fabric porosity is one of the characteristics that have the greatest impact on its air permeability. In this regard, it is of interest to assess the dependence of air permeability on the deformation of the fabric. Studies have shown that when the fabric is biaxially stretched by 20%, its air permeability increases by approximately 30-50% for the tested samples. On the other hand, rise of the air permeability not only increases the comfort of liner using by improvement of the hygienic properties but also reduces its fire resistance. In [10] it was experimentally proven that an increase in air permeability of knits from Nomex Delta TA 18 tex×2 yarns from 500 to 2000 $dm^3/(m^2\ s)$ leads to a reduction in the burning time by more than 2 times. This effect is quite expected for flame retardant knitted fabrics made from other types of fibers.Thus, sample 5 is the most acceptable from the point of view of hygienic propertiestaking into account the assumption of an increase in the air permeability of the knitted fabric during its subsequent use.

Because influence knitted fabric deformation on its flammability it is very important to determine extensibilityand remaining strain of tested samples. The results of determining the knitted fabrics mechanical propertiesobtained by single-cycle and multi-cycle tests are shown in Table 5.

TABLE5. Mechanical properties of knitted fabrics samples

Sample	Breaking force, N		Knitted fabrics extensibility, %		Remaining strain (single-cycle test), %		Remaining strain (multi-cycle test), %	
	Wale direction	Course direction	Wale direction	Course direction	Wale direction	Course direction	Wale direction	Course direction
1	419	422	12	94	1	3	1	2
2	1170	480	18	199	1	10	5	11
3	1090	649	19	56	2	3	3	2
4	691	593	14	46	2	4	1	2
5	967	435	17	44	3	6	1	3

In accordance with the requirements for knitted fabrics for the manufacture of a fireman's helmet liner their breaking load must be at least 500 N in the wale direction and at least 400 Nin the course direction. Table 5 shows that all samples except sample 1 meet strength requirements.

It can be seen that sample 1 has high extensibility in the course directionwith a low percentage of irreversible deformation. Tests showed even greater tensile strength of sample 2 but with high remaining strain in the course direction. Samples 3 and 4, 5, 6 showed relatively low extensibility in the course direction. But obtained values are enough for these fabrics taking into account their area of application.

Sample 3 meets all the requirements but it is characterized by an increased surface density which increases the material consumption of the product.

As a result of the samples properties analysis it was found that of interlock knitted fabric with a surface density 379 g/m^2 (sample 5) is the most preferable one for firefighters clothes elements manufacturing, for example, for helmet liners.

CONCLUSIONS

The structure of the knitted fabric has a significant impact on its tensile, hygienic and thermal insulation properties. It has been established that an increase in the thickness of the Arselon fabric leads to a decrease in temperature on its back side when exposed to a heat flow. The introduction of cotton yarn reduces both thermal insulation properties and water vapor permeability. Given this negative effect, it is not recommended to combine Arselon and cotton yarn in the structure of the fabric for the manufacture of firefighter's helmet liners.

When choosing the optimal structure of the knits, it is necessary to take into account the increase in its air permeability due to deformation, as well as the fact that the increase in the permeability of the fabrics accompanied by a decrease in its burning time.

The knitted fabrics of all investigated structures except rip are characterized by low remaining strain determined at single-cycle and multi-cycle tests with sufficient extensibility which will ensure the manufacturing clothes from them with good dimensional stability.

All obtained samples are characterized by sufficient resistance to heat flow rate 5.0 kW/m^2. During the test destruction of fabrics on all samples is not occurred.

Interlock knitted fabric with a surface density 379 g/m^2 is selected as the most preferable knit for firefighters clothes elements manufacturing, for example, for helmet liners. This surface density provides an average material consumption of products with high water vapor permeability and tensile properties, as well as acceptable extensibility and air permeability.

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