The issue of the development of material package for protective cloth designing

La cuestión del desarrollo del paquete de materiales para el diseño de telas protectoras

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ABSTRACT

Introduction: The article presents the characteristics of existing materials of top, heat-insulating and lining materials which are used for the design of protective clothing. A number of comparative analyses of the studied materials for further use them as a package in overalls was carried out. **Materials and Methods**: When writing, various methods were used, such as the comparison method, the historical method, the market analysis method, and others. **Results and Discussion:** We have researched the various fabrics and non-fabrics produced and used in industry that fall under the category of protective fabrics. **Conclusions:** As a result of a comparative, bibliometric analysis, it was revealed that a wide variety of different special-purpose materials is currently on the market.

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INTRODUCTION

Ensuring safe working conditions for a person is one of the most important tasks in the field of socio-economic policy of any state. Overalls are the most common personal protective equipment against the impact of aggressive production factors, among which a special place is occupied by flames and surfaces heated to high temperatures. The range of special clothing is quite wide - from simple and inexpensive traditional products to modern sets for special purposes. For example, the first fire brigades were created back in the 17th century, and later a firefighter uniform appeared, which included a helmet and a thick suit. In Soviet times, the uniform of firefighters consisted of canvas jacket and trousers that got wet, but at the same time protected from fire. Currently, modern technologies are able to create firefighter clothing with protective properties that allow you to stay in the fire for a long time.

It is known that firefighter combat clothing is designed to protect the human body from dangerous and harmful environmental factors that occur when extinguishing fires and carrying out related emergency rescue operations, as well as from adverse climatic influences. The emergence of natural and man-made emergencies poses a real threat to the country's environmental security. The threat consists in causing damage to life, human health and the environment. Analysis and statistics of fires show that the easy flammability of materials and the high speed of flame propagation reduce the time of possible evacuation of people and lead to human casualties. Therefore, timely forecasting and ensuring a delay at the initial stage of fire development, through the use of personal protective equipment made of fire-resistant materials, will increase the time for evacuation and rescue of people.

It is known that the service of firefighters refers to those types of activities, the distinguishing feature of which is the constant encounter with danger. Saving millions of people's lives, under emergency circumstances, fulfilling the state duty to the population, often firefighters, under extreme conditions of their activity, risk getting various bodily injuries in the form of burns. Currently, the overalls used in the fire services of the Republic of Kazakhstan, brought from the countries of near and far abroad, made of expensive materials, are not effective in terms of their operational properties, collapsing after 6 months of operation. The current situation is largely determined by the lack of evidence-based recommendations, which leads the lives of firefighters-rescuers to a dangerous situation.

Relevance of the research topic. A new promising range of materials includes multilayer textile materials, including non-woven, obtained in various ways. These materials are characterized by high physical-mechanical, hygienic properties; however, they have an increased flammability, which hinders their use in the production of overalls and other household and technical products. In this regard, conducting comprehensive research aimed at developing the production of new nonwoven materials and packages in general, as well as tools and methods for studying thermophysical properties that improve the assessment of material properties when exposed to high-temperature heat flux, is an urgent problem. When developing a new package, it is necessary to have not only experimental data, but also additional information about the specifics of the operation of workwear. Known studies of packages of thermal protective clothing are limited to the determination of the total thermal resistance.

Therefore, a comprehensive study of traditional clothing packages and the development on this basis of a fundamentally new package that meets the requirements of the consumer remains relevant. Protective clothing for firefighters and rescuers must protect against exposure to high temperatures, flames, which places high demands on the operational reliability of the materials used. At the same time, it is promising to use fabrics from a mixture of natural and chemical fibers, which make it possible to improve the hygienic and operational properties of materials and clothing. Therefore, the problem of obtaining heat and fire-retardant materials from a mixture of fibers is of particular importance.

Thus, a fundamental approach to the creation of new materials for the manufacture of special clothing for firefighters acquires extremely important scientific and practical significance. The solution of the above problems contributes to the development of scientific foundations in the field of fire retardant properties and is an actual direction in the development of special clothing for firefighters of the Republic of Kazakhstan. The purpose of this work is to study existing materials used in combat clothing for firefighters of the 1st level

MATERIALS AND METHOD

Currently, flame retardant materials are presented in a wide range, ranging from temperature stability (heat resistance) and strength to cost characteristics and environmental friendliness in use. In Kazakhstan, the fire retardant materials market is represented by foreign manufacturers: Klopman [1](Italy), Westex (USA), Carrington [2] (Great Britain), Finlayson Forssa (Finland), TinCate (Holland) [3], Trade House Tchaikovsky Textile (Russia)), the company "Rodniki-Textile", the company "Soltek", IP "Alfaenergo", the company "Spetszashchita", CJSC "Eliot" [4], LLC "Tosno-Teks",

CJSC "ASO" and others (2022) [5]. Carrington [2] uses the highest quality raw materials (long-staple cotton) and Swiss-made vat dyes, quickly responds to market changes and not only continuously monitors fashion trends, but also constantly develops and implements the latest technological innovations.

OJSC Tchaikovsky Textile uses Pyrovatex® in the production of fire-resistant fabrics Premier FR 350A. The material does not burn or melt, retains flexibility and original dimensions. Fire-resistant fabric "Flame FortW280" made of aramid fibers is designed for sewing special clothing that protects against small splashes of molten metal, metal scale, and short-term contact with a flame [6]. To do this, a silicone coating is applied to its surface. In the manufacture of overalls, the Flame FortW 280 fabric is used as the main fabric or as an additional overlay to the suit. The Soltek company produces fire-resistant fabrics "Termolin", based on the polyoxadiazole fiber "Arselon-S". The operating temperature range is 250-3000C. The material does not burn through in contact with metal particles with a temperature of 700-800 0C and withstands contact with solid surfaces heated to 400 0C for 100 seconds. Special impregnations make it possible to give the fabric resistance to the action of organic solvents, acids, petroleum products, and oils [7].

Fire-retardant fabrics of the Norwegian company "Dale As" are represented by several groups of materials, the Rig Chief group contains 100% cotton and blended materials with the addition of antistatic thread, surface density from 300 to 360 g/m2. The El-safe group combines materials with different percentages of cotton and polyester fibers, with the addition of antistatic thread, with a density of 290 to 300 g/m2. The Dale Antiflame Triple group includes three-layer flame retardant fabrics with a density from 270 to 370 g/m2. All Dale As fabrics are treated with Pyrovatex flame retardant impregnation. Klopman [1] flame retardant fabrics are lightweight from 145 to 460 g/m2, yet offer complete protection against flames and molten metal spatter. The fabrics are produced in blends with a content of 25% polyester and pure cotton. Fire-retardant properties are achieved by using the PROBAN technology.

The Westex [1] concern produces fire-retardant fabrics of the INDURA and INDURA Ultra Soft series, which are produced with PROBAN impregnation. INDURA fabrics are produced from cotton fibers with a density of 240 g/m2 to 472 g/m2. In the production of fabrics of the INDURA Ultra Soft series, a small amount (12%) of polyamide (nylon) fibers is added to the bulk of cotton fibers (88%), with a density of 190 g/m2 to 405 g/m2. The addition of nylon increases the durability of the garment by more than 50% and increases the protective properties of the fabric. Fabrics protect against the effects of an electric arc, open flame, splashes of molten metal and are intended for workers in the oil and gas industry, power engineers, welders, metallurgists and others. The company offers additional fabric treatment with oil- and water-repellent impregnations.

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Flax catonized fiber (up to 50%) was used in the samples of heaters Arktik (CJSC Legpromkom). The cloth has fire-resistant furnish - impregnation by preparations on the basis of flame retardants. It does not burn at 300°C. CJSC "Eliot" produces materials Siloteks97 art.0/8RZh, Siloteks98, TSTPV. These materials are made from aramid yarn, polyaramid fibers of different colors with a polymer coating inside. The materials are intended for fire-resistant sets of firefighters, oil workers, welders, metallurgists and other fire-resistant overalls used at elevated temperatures and contacts with an open flame.

The production company Tosno-tex LLC, established in 1996, specializes in the manufacture of special-purpose fabric-based polymer coatings for the Ministry of Defense of the Russian Federation, the Ministry of Emergency Situations, for workers in the oil and gas industries. LLC "Tosno-Teks" is developing new materials according to the technical specifications of customers interested in various composite materials with a specific set of properties. The development is based on the existing fundamental ideas about the properties of polymeric materials, as well as the results of our own research, which allow us to significantly increase the operation of products made from these materials in various extreme conditions - at elevated (lower) temperatures, in aggressive environments. Some types of products: Heat-resistant material with silicone coating "TTC-02", intended for the manufacture of combat clothing for a fireman of the 1st level (TU 8729-008-43473625-03). The material is a textile fabric, made of technical aramid yarns and SVM yarns, with a one-sided two-layer polymer coating that is resistant to water, elevated temperatures, fire, fuels and lubricants, aqueous solutions of foaming agents and weak solutions (up to 20%) of acids and alkalis. The material can

be operated at temperatures from minus 50 ºC to plus 300 ºC; Lining materials - Viniliskin-T signal heat-resistant two types: type 1 (light-accumulative), type 2 (reflective).
CJSC "ASO" was founded in 1993 in St. Petersburg. ASO manufactures Pyrovitex-K material from 100% armide fibers with various finishes. Heat-resistant fabric "Pirovitex-K" meets the requirements of GOST R 53264-2009 "Fire fighting equipment. Special Protective Clothing" and certified for compliance with Federal Law No. 123-FZ of July 22, 2008 "Technical Regulations on Fire Safety Requirements". It is used for the manufacture of: firefighter combat clothing, various heat-protective and heat-resistant suits, hand and head protection, protective covers for breathing apparatus cylinders, hydraulic cushions, as pressure curtains during vacuum formation.
The fabric has an oil-water-repellent impregnation (MVO). The fabric can be used for reinforcing various composite materials, making heat-resistant filters, etc. To date, the above materials only make it possible to limit the spread of flame, without providing reliable protection against fire due to their low density or the presence of a fusible component required in the thermal bonding technology. Therefore, in order to impart fire-retardant properties to the product, it is necessary to include a special fire-retardant pad in the clothing package. The methodology of the study is to conduct a high-quality selection of materials for further research and design of special clothing for firefighters.

RESULTS

Analysis of the above fire-resistant materials showed that they all have disadvantages. For example, overalls made using fire-retardant chemical coatings do not meet the comprehensive protection against harmful production factors. The use of expensive threads made of heat-resistant fibers significantly increases the cost of the finished material. The main disadvantage of fire-resistant materials from a mixture of mineral fibers and thermoplastic organic fibers is rigidity, mineral fibers can migrate into the underwear space, reducing the hygienic and operational properties of the material. The heat-shielding multilayer material is heavy (the total surface density of the package reaches 1 kg/m2 or more). Carbon fiber is a conductive element. There is a risk of equipment fire when the carbon fiber layer is worked out. The fiber in case of migration (through seams, punctures) into the underwear space can cause allergic reactions, provoke electric shock, reduce the hygienic and operational properties of the material.
Increasing demands on the temperature resistance of materials in various industries are opening up new applications for technologies developed by KERMEL®. Especially for technical applications, the unique Kermel®Tech meta-aramid fiber was invented with permanent flame retardant properties, as well as resistance to basic acids, alkalis and solvents. Kermel®Tech's main applications are high quality chemical and fire resistant filter materials for the steel industry, asphalt plants, and power plants. The mechanical characteristics of the fibers make it possible to use such filter materials for a long time under conditions of constant mechanical influences associated with the regeneration of filters (for example, with impulse cleaning of bag filters), without deformation or destruction. This is achieved by high elongation to break and high modulus of elasticity of the fibers. The delivery program includes fire-resistant non-woven filter media sheets or ready-made filter bags according to customer specifications. Materials based on Kermel®Tech are designed for long-term use (several years) in the temperature range from 170°C to 220°C and withstand peak temperatures up to 240°C.
KERMEL offers its customers various solutions - from fire-resistant insulation materials for pipelines or transformer windings to fire-resistant lining fabric for protective workwear. As objects of study, special-purpose materials were selected, which are part of the package of BOP materials in accordance with ST RK 1495, produced and offered for sale and tailoring of overalls for firefighters. The package of materials includes: outer layer (top material with a polymer coating), heat-insulating lining, consisting of a heat-insulating barrier layer and lining material. The characteristics of the studied upper materials are presented in Table 1.

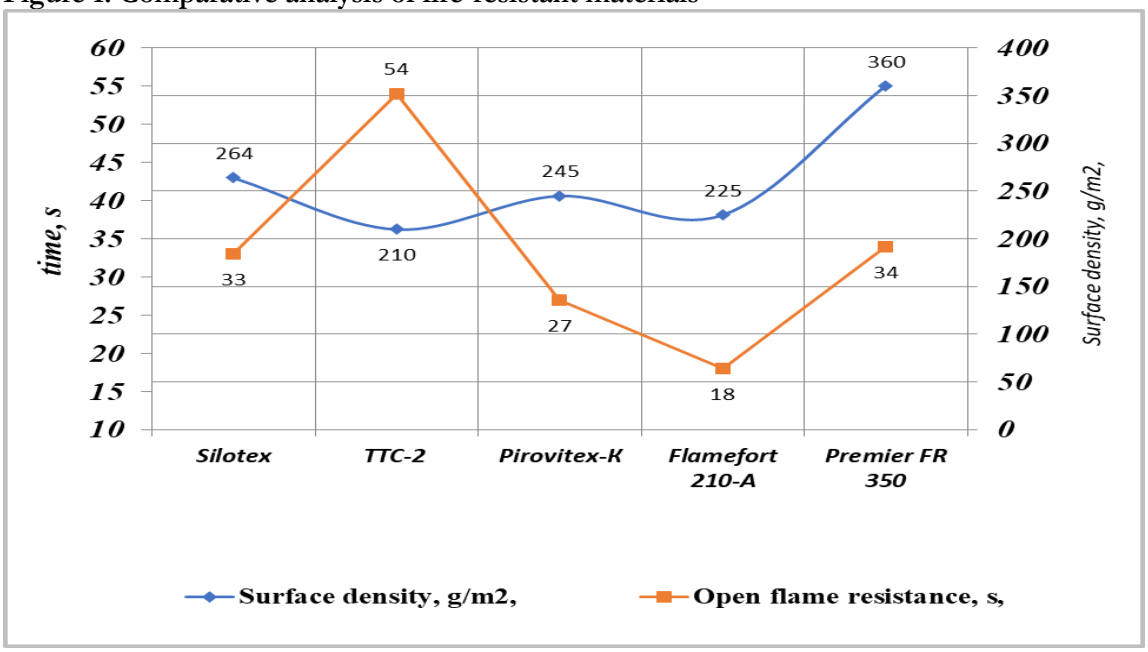
Table 1. Existing fire resistant materials

Textile	Composition width	Finishing	Width, m,	Surface density, g/m2,	Weave Price,	price (tenge)
TTC-02	100% aramid + high modulus threads	SC	1,4	210	twill	6603
Silotex-97	100% Para-aramid	FL	1,4	264	twill	6890
Pirovitex-K	100% Para-aramid	SC	1,4	245	twill	7560
Flamefort 210-A	100 aramid+ antistatic thread	OWRF	1,5	225	twill	4650
Premier FR 350	100%cotton + antistatic thread	FR+ OWRF	1,5	360	satin	2365

SC- siloxane coating
FL- fluoroelastomer
HMT- high modulus threads
FR- Fire retardant impregnation
OWRF- oil water repellent finish

These upper materials comply with ST RK 1495-2006 [10]. To study existing materials, a comparative analysis was carried out with respect to thermophysical indicators[7; 10]. Below are the materials recommended for use as the top of Figure 1.

Figure 1. Comparative analysis of fire-resistant materials



Comparative analysis shows that all materials have sufficiently high protective properties. TTS-2 material is recommended for designing packages of materials, as it has the lowest surface density Ms=210g/m2 and thickness D=0.26 mm and a fairly high resistance to an open flame. To study heat-insulating linings, a comparative analysis for thermal properties was also carried out, presented in table 3 and figure 2.

Figure 2. The dependence of the surface density on the thickness of nonwoven materials

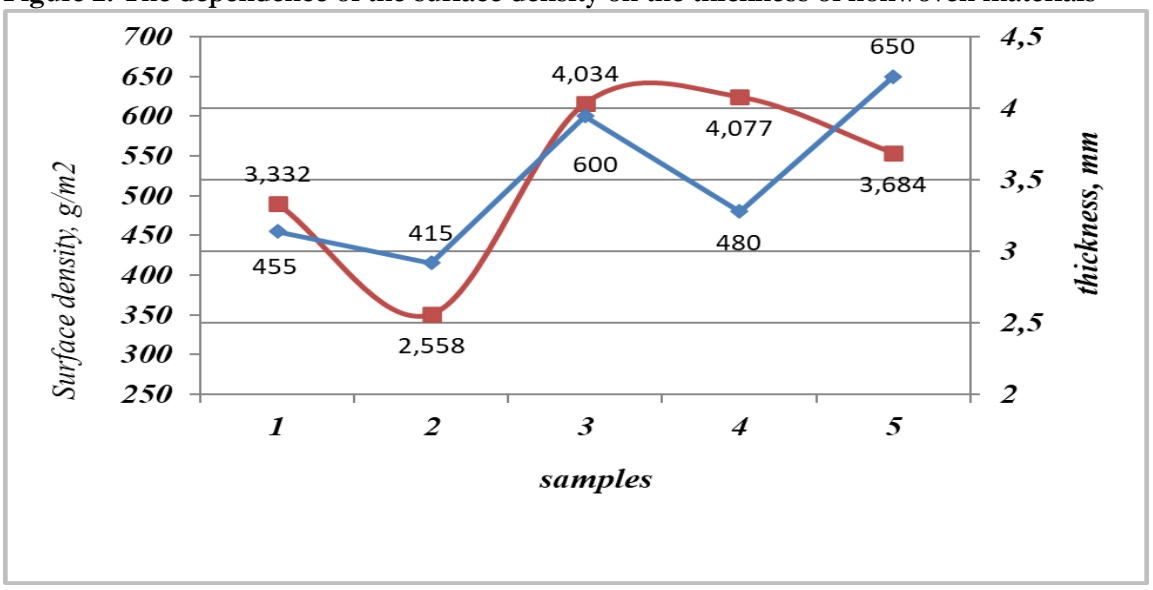
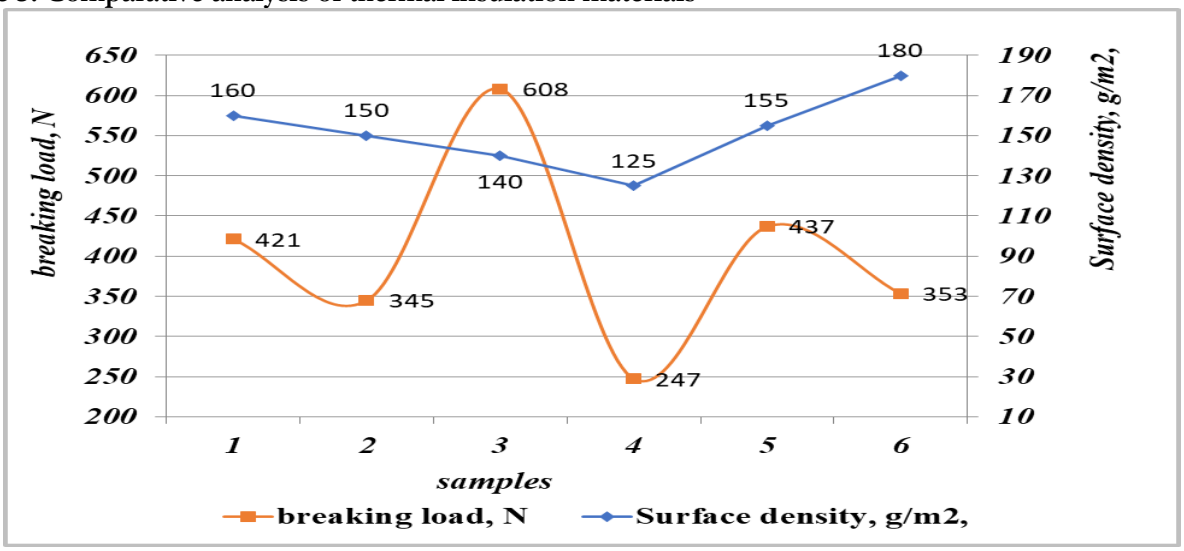


Table 3. Comparative characteristics of heat-insulating materials

No sample	Raw composition	Thickness, Mm	Surface density, g/m2,	Thermal conductivity at temperature 50~150 °C, W/m . °C, no more
1	100% aramid	3,332	455	0,06
2	M-aramid fibers, Waste wool, cotton	2,558	415	0,06
3	polyester fibers, flax waste,	4,034	600	0,06
4	fiberglass	4,077	480	0,06
5	Polyester fibres, cotton waste, wool	3,684	650	0.06

Figure 3. Comparative analysis of thermal insulation materials



From the data presented in table 3 and figure 2, all heat-insulating sheets have increased thermal performance, however, sample 2 has the lowest surface density Ms=415g/m² with a thickness D=2.558mm.

Table 4. Comparative characteristics of existing lining materials.

Name of indicator	Satin	Coarse calico	Lining	Coarse calico	Coarse calico	Coarse calico
№ Sample	1	2	3	4	5	6
Manufacturers	Russia	Russia	South Korea	Uzbekistan	Kazakhstan	Kazakhstan
Price, tg	1000	800	3220	150	450	800
Fiber composition	80% cotton 20% elastane	100% cotton	100% aramid	100% cotton	100% cotton	100% cotton
Color	Dark blue	grey	grey	brown	beige	Dark beige
Fabric thickness, mm	0,38	0,37	0,346	0,268	0,34	0,276
Surface density, g/m2, no more	160	150	140	125	155	180
Breaking load: - on the basis, N,	421353	345	608	247	437	353
- by duck, N,	389	326	763	107	413	346
Base elongation, mm,	16,4	13,4	42,5	11,5	15,8	14,2
by duck, mm,	11,9	12,5	27,16	26	14,8	13,8

It can be seen from the table that, at the price, the most acceptable for further research is the lining material coarse calico. However, sample 3 and sample 5 have increased strength, surface density and thickness, which can be used in combination with a heat-insulating layer in various combinations of a package of materials [11; 12].

DISCUSSION

High-quality selection of materials for the design of special clothing for firefighters requires highly qualified specialists and considerable efforts to study the properties and technical characteristics of various types of fabrics. Only thanks to the combination of "technology-material" it is possible to achieve that overalls provide the greatest safety, comfort in operation at elevated temperatures. TsNIIShP (Russia) is still involved in the development of special clothing. However, in Kazakhstan, until now, unfortunately, there is not a single state-owned enterprise that would be engaged in research and development of new types of firefighters overalls. This is explained by the fact that the light industry is still underdeveloped and has low indicators in terms of volume and output of light industry products.

Improving the process of designing workwear for various working conditions is devoted to a large number of works by scientists and light industry specialists. Scientists have made a huge contribution to solving these problems. In these works, the main tasks of designing workwear were solved from the standpoint of its adaptability to a person, ensuring thermal comfort in the process of production activities with the least stress on the physiological function of thermoregulation [13].

The development of a quality system for the fire safety protection system, the development of highly effective protective materials and fabrics, the creation of new types of protective clothing for firefighters and rescuers are largely determined by achievements in the study of combustion processes and the situation on fires, textile and polymer materials science, and the improvement of theoretical and experimental research models and methods workwear design. The work of I.V. Molkova. V.E. Murashova made a significant contribution to the development of special materials for the SZO of firefighters. Methods for evaluating the design performance of various types of SZO firefighters are reflected in the work of V.I. Loginov. And other authors have contributed to the development of the scientific basis for the design and evaluation of the quality of firefighters overalls.

In the work of Lopatchenko T.P. "Research and development of special heat-protective equipment for rescuers of the Ministry of Emergencies" carried out at the South Russian State University of Economics and Service systematized the factors and criteria that determine the working conditions of rescuers at low temperatures, and developed proposals

to reduce their impact on humans. Various methods for determining the rheological characteristics of modern insulating materials have been developed and investigated. New designs of heat-shielding packages have been created using modern soft insulating materials. A method and a device for measuring the thickness of insulating packages with modern soft insulators with concentrated air gaps have been developed. A set of special heat-protective equipment for rescuers was made, consisting of an insulated jacket and a shortened sleeping bag [14; 15].

Sopelnikova N.G. in the work "Research and development of a protective suit for performing work by industrial mountaineering methods based on human biomechanical characteristics" performed at the South Russian State University of Economics and Service, systematized personal protective equipment against falls from a height used in both sports and industrial mountaineering, in order to identify the relationship between their purpose, design and operating conditions. The design of a protective suit for industrial climbers has been developed and the effectiveness of its use has been determined on a prototype.

At the Saratov State Technical University in the dissertation of Grishina O.A. a technology for modifying polymeric fibrous materials with phosphorus-containing flame retardants has been developed and used in the production of fire-retardant overalls. In the course of the work, the effectiveness of the use of various phosphorus-containing compounds for the modification of polycaproamide, viscose, wool, cotton fibers and their mixtures was determined in order to reduce the combustibility of textile materials. A technology has been developed for modifying polycaproamide, viscose, wool, cotton fibers and their mixtures with phosphorus-containing flame retardants dimethylmethylphosphonate, fosdiol and methylphosphonamide under the influence of induced CO2 laser radiation fluxes. The effect of flame retardants and modification technology on the structure and properties of fibers and physical and chemical processes during pyrolysis and combustion of fire-retardant polymeric fibrous materials has been established. The quality indicators of fire-retardant materials and sewing threads for overalls have been determined.

At the Moscow State Academy of Light Industry Zvyagintsev S.V. in his scientific work on the topic "Development of methods for the integrated design of sets of modified and transformable clothing items" considered the development of a method for designing a mobile assortment of women's clothing based on a comprehensive account of consumer preferences and the use of its modified and transformable elements. To achieve this goal, I solved the following tasks: developed methodological foundations for the integrated design of a mobile assortment of clothing; marketing research of consumer demand was carried out and consumer preferences were identified for designing a mobile assortment of women's youth clothing; the existing method of morphological transformation (MT) has been improved. This method allows you to expand the possibilities of modifying the shape of the elements and creating a variety of clothing sets without a significant increase in the items included in the wardrobe; the main patterns of designing transformable and interchangeable items and parts of clothing were identified and the types of transformable and modified sets of women's youth clothing of the main types were developed; a structural-logical model of the process and the main components of information support for automated integrated design of a mobile assortment of clothing using the principles of modular construction have been developed [9; 16].

CONCLUSIONS

Thus, all the developments listed are unique in their own way regarding the light industry. Technological solutions related to the design of firefighters' overalls, the authors of which are scientists from near and far abroad, have fairly high performance characteristics, but due to the high cost for the Republic of Kazakhstan, they are hardly acceptable. As a result of the comparative, bibliometric analysis, it was revealed that at present there is a wide variety of different special-purpose materials on the market, but at the same time, the following types of materials included in the package are most acceptable for use in the design of special clothing for firefighters: (top material), sample 2 (heat-insulating layer of non-woven material), coarse calico lining. In the future, optimal packages of materials for the manufacture of workwear will be investigated and selected.

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