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IDENTIFYING FACTORS AFFECTING COMFORT WORKWEAR FOR MOUNTAIN TOURISM

Saule Nurbay
Corresponding author
PhD Student
International Educational Corporation
Ryskulbekov str., 28,
Almaty, Republic of Kazakhstan, 050043
E-mail: nurbaynurbay.ru@mail.ru
Zhaksybek Usenbekov
Doctor of Technical Sciences, Associate Professor*
Bulat Seitov
Doctor of Technical Sciences, Associate Professor*
Lazzat Sarttarova
PhD, Associate Processor, Dean*
Nazima Seitova
Candidate of Technical Sciences, Head of Department
Department of Technology, Economics
and General Educational Disciplines
«Symbat» Institute of Design and Technology
of the Almaty Humanitarian – Economic University
Kunaev str., 43, Almaty, Republic of Kazakhstan, 050051
*Department of Technology and Design
of Products and Goods
Almaty Technological University
Tole bi str., 100, Almaty, Republic of Kazakhstan, 050012

The quality and comfort of clothing for people engaged in mountain tourism are influenced by the pack of clothing materials, which determine their durability and heat resistance. In practice, wear resistance and thermal insulation of clothing materials are evaluated by standard methods for single-layer materials. To solve the problem of studying the wear resistance and heat resistance of a clothing pack, we developed an experimental setup for studying the wear resistance of the clothing pack under the influence of cyclic loads and an installation for determining the heat-shielding properties of the pack of clothing materials, allowing you to reproduce both the temperature of the underwear space, as well as environmental factors.

By studying the influence of wind flow, humidity and ambient temperature on the heat-shielding ability of packages of various compositions, the most rational package of clothing for mountain tourism was determined. The selected package provides a comfortable state of a person in the absence of air permeability and at a wind speed of 5 m/s; and at wind speeds of 10 m/s and 15 m/s, the temperature of the underwear space decreases. The heat protection of the clothing package is influenced by the breathing of the athlete's body during movements. So, at ambient temperature T_{ok}=20 °C and humidity within 60–70 % when the breathing simulator was turned on in the underwear space, T_{pp}=26 °C, W=62 %, and when it was turned off, T_{pp}=27 °C, and the humidity value did not change.

The developed experimental installations and research methods can be recommended for use at the design stage in the production laboratories of enterprises producing mountain sports clothing

Keywords: mountain tourism, pack of materials, clothes, fatigue wear, wear resistance of clothes, underwear space, heat-shielding functions of clothes

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1. Introduction

Mountain tourism, as a component of a healthy lifestyle, arouses more and more growing interest among people as an extreme sport. This sport is classified as extreme because it combines high physical loads on a person in combination with a number of adverse external and internal factors affecting the body, which often lead to accidents and injuries.

The growing interest in mountain tourism poses the task for light industry workers to purposefully improve the range and quality of clothing, which occupies a special place in the complex of measures to ensure successful and safe trips. A successful outcome of a hiking trip is largely due to the use of clothing with high consumer properties. Distinctive features of specific environmental conditions affect the specifics of the quality indicators of clothing, as well as the choice of techniques performed in mountainous conditions.

An analysis of external and internal factors makes it possible to determine rational ways to reduce the degree of their influence on a person in mountainous conditions, primarily through the implementation of a set of measures to improve the consumer properties of clothing.

Currently, the light industry market offers a wide range of clothing for outdoor activities in a wide price range, which covers almost all categories of consumers. But at the same time, there are practically no high-quality products that correspond to real operating conditions and that take into account the specifics of their use in mountain conditions, and those put up for sale are made of expensive materials and have a rather high cost.

At the same time, according to the results of a consumer survey, it was concluded that the products offered on the market do not adequately meet extreme operating conditions, which can create a situation that reduces the success of mountain tourism.

The design of high-quality clothing for mountain tourism, taking into account high ergonomic indicators, largely depends on a reasonable choice of properties and composition of outer clothing pack material, meeting the needs of consumers.

Therefore, studies devoted to the development of methods for experimental studies of the physical and mechanical properties of a pack of clothing materials, namely, indicators of fatigue wear under cyclic loads, heat-shielding properties depending on environmental factors, are relevant.

2. Literature review and problem statement

Numerical analysis studies are presented, which showed that materials absorb a significant amount of heat from both the human body and the environment [1]. However, issues related to ensuring the moisture exchange of a person with the environment remained unresolved.

The effect of wear and loss of tensile strength of a clothing pack was studied in [2]. However, issues related to fatigue wear resistance of material packages are not considered.

New work clothes for miners were developed that provide protection from cold and ease of movement compared to ordinary work clothes [3]. However, issues related to ensuring the moisture exchange of a person with the environment, which significantly affects the heat-shielding properties of clothing, are not taken into account.

Cooling work clothes were developed using phase change materials in hot underground mines [4]. The required temperature in the layers of the clothing package was determined. But the moisture exchange of a person with the environment, which significantly affects the heat transfer between the layers of the package materials, was not taken into account.

The literature data analyzed the heat-shielding and thermophysiological characteristics and comfort of fire-retardant textile materials [5]. However, no attention was paid to the moisture exchange between the human body and the environment, which significantly affects the comfort of clothing.

The paper [6] emphasizes various methods and techniques for the functionalization of nanomaterials and their integration into textiles with an emphasis on profitability, comfort, wearability, energy conversion efficiency and environmental sustainability. The latest trends in the development of various nanogenerators, supercapacitors and photoelectronic devices on fabric are highlighted, with special emphasis on the efficiency and wear resistance of fabric. But there were unresolved issues related to the determination of fatigue wear resistance of packages of materials.

The vapor permeability and thermal comfort of environmentally friendly woven fabrics with sewn-in fibers were studied in terms of yarn structure and fiber characteristics in accordance with two measurement methods [7]. But the issues related to ensuring the moisture exchange of a person with the environment remained unresolved.

The authors proposed a forced-air warming (FAW) device connected to a thermal suit for hospital patients [8], while not fully taking into account all the factors affecting the heat exchange process.

The authors considered the thermal characteristics of a fire suit [9]. While investigating the intensity of heat exposure, changes in the microclimate in the underwear space and heat-shielding characteristics in each respective phase were not considered.

All this suggests that it is advisable to conduct a study on the wear resistance and heat resistance of clothing packages.

A number of scientists have made a great contribution related to the study of issues of creating comfortable clothing that provides high ergonomic performance [10, 11].

An analysis of a large number of studies devoted to the «man-clothing» system in dynamics shows that the nature of anthropometric contacts of its elements is determined by the laws of functioning of the human musculoskeletal system [10]. In [12, 13], the values of the design parameters of the parts of the product were given depending on changes in the size and shape of the surface of the human body when performing movements. The work [14] presents the results of studies showing that the discrepancy between changes in the surface of clothing parts to the shape and size of the human body in dynamics leads to the appearance of stressed areas in the region of dynamic contacts of the product with the surface of the human body, which is reflected either in significant movements of the product, or in the changing level of deformation in the materials of its parts, or in limiting movements.

In the course of operation, the products wear out. In practice, the study of clothing wear is carried out in the following areas: evaluation of a worn product; holding experimental wear; laboratory testing of a clothing pack. The results of experimental wear allow you to get the most complete picture of the wear resistance of the product. Long-term experimental observations of the wear behavior of products make it possible to: identify the topography of product wear, determine links between visual changes in the surface of materials and the wear time of the product; consider the operating conditions of the product. The disadvantages include the fact that the experimental wear is associated with high costs of both time and money. Moreover, the reliability of the results requires the simultaneous evaluation of a large number of products and is associated with the difficulty of achieving the same wearing conditions. These shortcomings are excluded by laboratory methods for determining the wear resistance of a clothing pack. They allow testing under strictly specified parameters: speed, load, temperature, humidity, etc. The advantage of laboratory methods is: speed and certainty, which are especially important when determining the wear resistance of clothing materials. But at the same time, such a study does not take into account all the real conditions for the wear of a pack of clothing material for people involved in mountain tourism. During hiking trips, in mountainous conditions, tourist clothing experiences heterogeneous effects from both external and internal factors, which leads to alternating volumetric stresses that reduce its strength characteristics.

On hiking trips, people spend a long time in adverse environmental conditions. In this case, the preservation of thermal comfort is provided by clothing. The study of clothing that will protect them from adverse meteorological conditions during hikes is a complex scientific and practical task. Clothing must meet requirements that conflict with each other, and sometimes are not compatible.

During operation, under adverse climatic conditions, clothing is subject to the following requirements: low weight and increased heat-shielding properties; low air permeability and sufficient moisture output, which is necessary to ensure the exchange of moisture between a person and the environment. Therefore, comfortable clothing designed for athletes performing mountain climbing or mountain routes should have such enhanced properties as wear resistance and thermal protection. From the foregoing, it follows that the creation of high-quality clothing associated with such a sport as mountain tourism and mountaineering should be based on the study of clothing pack material for wear resistance under cyclic loads and thermal protection when exposed to adverse environmental conditions.

3. The aim and objectives of the study

The aim of the study is to form rational clothing sets for mountain tourism by testing clothing packages on installations that allow simulating various clothing operating conditions.

To achieve the aim, the following objectives were set:

– to evaluate the heat-shielding properties of the package of products, taking into account the actual operating conditions, on the installation developed for this purpose;

– to evaluate the fatigue wear resistance of the packages on the installation developed for this purpose.

4. Materials and methods

Before proceeding with the development of comfortable, ergonomic clothing that takes into account extreme operating conditions, it is necessary to analyze the factors of preference for sportswear in general or its individual elements by people participating in mountain tourism.

To confirm the objectivity of the analysis, determine consumer preferences and identify possible discrepancies between the sets of clothing used for tourism, the conditions of the environment in which it is used and the needs of people involved in mountain tourism, a questionnaire survey of respondents (potential tourists and climbers) was conducted. The sample size was determined on the basis of statistical analysis, based on certain requirements for the reliability of the results obtained [15].

The authors developed a questionnaire that included 10 questions, each of which offered several answers. 100 people participated in the questionnaire survey. Based on the results of a questionnaire survey of consumers, the authors came to the conclusion that the products offered on the market do not meet the operating conditions, which creates a situation that reduces the success of mountain tourism development. The results of the questionnaire survey showed that: 47 % of respondents are not satisfied with the heat-shielding properties of clothing under various climatic conditions in the mountains, 34 % of respondents noted intensive wear of clothing during the operation of products, and 27 % are not satisfied with the design solutions of clothing. In this regard, it is necessary to conduct a study of wear resistance, heat-shielding properties of the pack of materials, taking into account the actual operating conditions of clothing.

Any garment loses its original appearance during operation, becomes morally obsolete, goes out of fashion. At the same time, any garment must ensure durability, storability, maintainability and reliability properties before failure. And the durability of clothing relies on its wear resistance, i.e. the ability to withstand the action of wearing factors, the result of which is wear. The wear of clothing materials is influenced by many factors and therefore the issue of its study is complex.

The devices used in practice for determining wear intensity in the overwhelming majority take into account changes in the strength of a single-layer material only as a result of abrasion [16]. In this case, the experimental equipment that evaluates the wear intensity is based on the friction of the tested samples and the abrasive [17].

But as practice has shown, the devices for determining the abrasion resistance of textile materials do not allow to fully take into account fatigue wear.

During the operation of products in real conditions, the wear of the pack of clothing materials occurs not only due to abrasion, but also from such loads as stretching, bending and torsion. Moreover, the above loads act cyclically with a time-varying effect. As a result, there is a problem of assessing the fatigue wear resistance of a pack of clothing materials under the action of complex dynamic loads. To solve this problem, it is necessary to develop methods for assessing the wear resistance of not only a single-layer material, but also a pack of clothing materials, since the effectiveness of clothing in extreme conditions depends on the correctly selected pack of materials.

Tests of physical and mechanical, physical and chemical and performance properties of a pack of materials are performed by standard methods [18–21]. But standard methods do not always take into account the fatigue wear of material packs and the influence of environmental factors. To study the wear resistance of a pack of clothing materials, it is necessary to develop methods and devices that take into account the actual operating conditions of clothing. To achieve this task, we have developed experimental installations for studying the fatigue wear resistance of a pack of clothing materials under cyclic loads and an installation for studying the heat-shielding properties of clothing pack materials, taking into account the actual operating conditions of clothing, standard requirements [22–26] and literature analysis of the assembly of such products and preliminary calculations of heat-shielding properties.

In order to more objectively meet the needs of consumers in experimental studies, samples of a clothing pack were selected so that the most common outerwear materials were included. The tests were carried out on five samples of a pack of materials, the characteristics of which are given in Table 1.

Table 1

Characteristics of the studied samples

No.	Pack of materials	Area, cm^2	Thickness, mm	Weight, g	Surface density, g/m^2
1	Membrane fabric	50	25	2.618	254
	Hollow fiber				100
	Lining				71
2	Raincoat fabric	50	17	1.75	216
	Synthetic winterizer embroidered with lining fabric				151
3	Raincoat fabric	50	19	3.11	216
	Batting				150
	Lining				71
4	Raincoat fabric	50	21	1.85	216
	Synthetic winterizer				300
	Full-time lining				71
5	Membrane fabric	50	27	2.54	216
	Hollow fiber				100
	Fleece fabric				85

We have developed experimental facilities for studying the fatigue wear resistance of packages of clothing materials under cyclic loads and an installation for studying the heat-shielding properties of materials and packages of clothing, taking into account the actual operating conditions of clothing.

5. Results of examining the properties of the samples

5. 1. Analysis of the wear resistance of a pack of materials under cyclic loading

In order to investigate the fatigue wear resistance of a pack of clothing materials under cyclic and volumetric dynamic loading, an experimental setup was developed [27, 28]. On this installation, it is possible to load a sample of a pack of materials with cyclically changing forces of tension, torsion and abrasion with an abrasive material. Fig. 1 shows the layout of the main installation tools, and a photo of the appearance (Fig. 2).

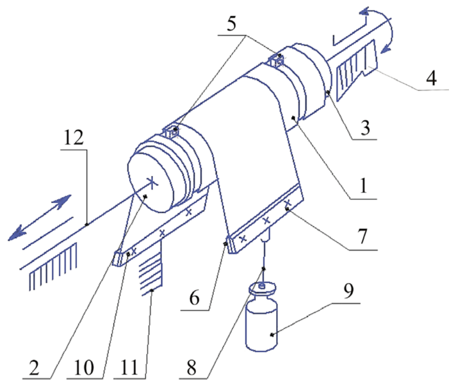

Fig. 1. Positions of the working tools of the installation, which allow simulating stretching, torsion and abrasion of the sample: 1 — pack of materials; 2 — nut cylinder; 3 — screw cylinder; 4 — bearing; 5 — clamps; 6 — abrasive material; 7 — clamp; 8 — cane; 9 — weight; 10 — clamping plates; 11 — housing; 12 — slider rod

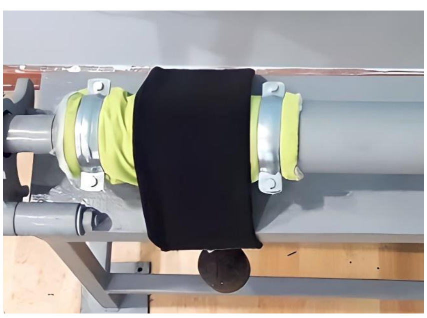

Fig. 2. Photo of the appearance of the installation

A pack of materials (Fig. 1) for outerwear 1 sewn in the form of a cylinder is fixed with clamps 5. One end of the pack of materials is fixed on the surface of the reciprocating nut cylinder 2, and the opposite end is fixed on the screw cylinder 3. The transfer of motion between cylinders 2 and 3 is carried out by a lead screw connection. Screw cylinder 3 performs reciprocating movements in bearing 4. The body of the latter is structurally composed of two hinged covers connected to each other, which open to fill and fix on the sample cylinders. To create a process of abrasive wear, a pack of materials 1 is wrapped around the abrasive material 6 and pressed with a clamp 7 suspended to them on a bar, a cane 8 with a weight 9. The second end of the abrasive material 6 with the help of clamping plates 10 is attached to the housing 11 of the installation. Nut cylinder 2 receives reciprocating motion along the kinematic chain: slider rod 12, crank drive mechanism.

The parameters of the sample sewn from the studied materials of the pack are: length 200 mm and diameter 81 mm. The sample is fixed on the cylinders with clamps (Fig. 1). When starting the gearbox motor, the rotation of the shaft is converted into the reciprocating movement of the nut cylinder 2 and the reciprocating movement of the screw cylinder 3. As a result, the fixed sample will cyclically experience tensile and twisting forces, and thus volumetric stress is created. The sample will experience fatigue wear. Along with stretching and torsion, to create friction, the installation is provided with abrasive material 6, which wraps around the test pack with a given force.

The fatigue wear time during the experimental study is measured by a chronometer, and the cycle frequency is recorded by a tachometer.

To evaluate the fatigue wear of a pack of materials, it is necessary to compare the breaking force with the reference value and the pack rupture force after the experiment.

The degree of wear of a pack of materials during its abrasion, A, %, is determined by the ratio of the difference between the indicators before and after the test to the initial value of the indicator (indicator of a standard pack, new pack):

$$A=100(P_1-P_2)/P_1,$$

where P_1 – the average value of the rupture force of the standard pack, kgF; P_2 – the average value of the rupture force of the worn pack, kgF.

Strength tests associated with checking the strength characteristics of a pack of materials for tensile strength were performed on an RM-50 tensile testing machine.

To obtain reliable results, homogeneous experiments were carried out with samples up to five times. Table 2 summarizes the results of the average test values of the outerwear pack for extreme sports athletes.

Table 2

Results of testing the strength loss of the pack after fatigue wear

No. samples	Material pack	Pack thickness, mm	For standard pack		For worn pack					
					Within 30 min		Within 60 min		Within 80 min	
			L_p breaking elongation, mm	P_P breaking load, kgF	L_p breaking elongation, mm	P_P breaking load, kgF	L_p breaking elongation, mm	P_P breaking load, kgF	L_p breaking elongation, mm	P_P breaking load, kgF
1	Membrane fabric, hollow fiber, lining	25	39	162.5	42	142	42	125	42	120
2	Raincoat fabric, synthetic winterizer, embroidered with lining fabric	17	24	89	26	65	24	63	22	60
3	Raincoat fabric, batting, lining	19	33	135.5	44	125	42	120	42	110
4	Raincoat fabric, synthetic winterizer lining full-time	2 1	36	154.5	42	132	40	120	27	72
5	Membrane fabric, hollow fiber, fleece fabric	27	29	60	32	52	Wear tear			

As a result of cyclic volumetric loading, sample No. 1 turned out to be the most wear-resistant.

To compare the test results on the developed installation and on the IT-3 device for testing the fabric for wear, changes in the breaking load for the membrane fabric «Mercury-tex» were determined under the same test conditions for both cases. Fig. 3 shows graphs of the degree of wear of samples depending on the number of loading cycles.

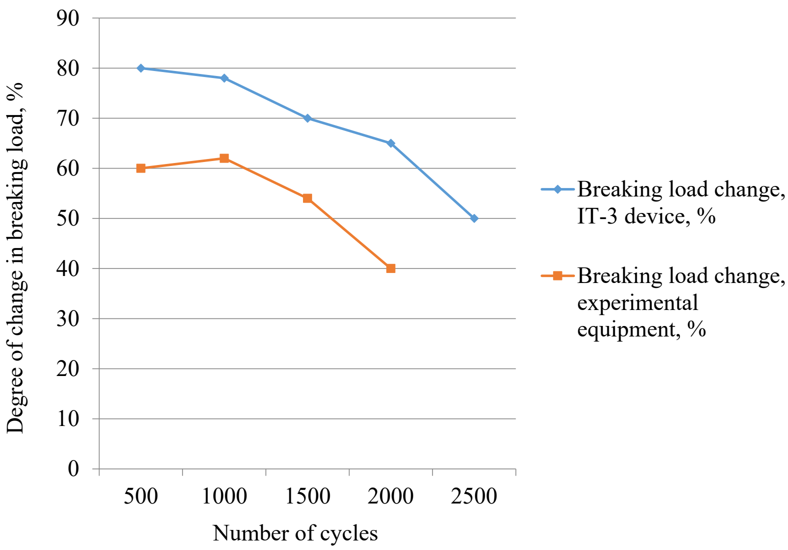

Fig. 3. Graphs of changes in breaking load depending on the number of cycles

As can be seen from the graphs, the wear of materials under cyclic loading is achieved faster than with abrasion on the IT-3 device. With the same number of test cycles, the magnitude of breaking forces compared to abrasion during fatigue wear is less by 10÷25 %.

5. 2. Analysis of the heat-shielding properties of a pack of clothing materials

Another indicator that caused the most criticism among tourists is the lack of clothing protection from natural phenomena such as precipitation and strong winds. Mountain tourism and mountaineering involve long, multi-day hikes, i.e. many hours of operation of clothing under various extreme and climatic conditions. Wetting of clothes is associated with discomfort, and in the presence of wind – rapid cooling of the body, which in turn will adversely affect the tourist's health.

The function of clothing is to protect a person from external factors such as rain and snow, which moisturize its surface and do not prevent the removal of moisture from the surface of the body.

Also, it should simultaneously perform such functions as protecting a person from cooling while at rest and preventing overheating during intense physical exertion [29]. In order to maintain thermal comfort, a clothing pack at light industry enterprises is formed from various heaters, the thermal insulation properties of which are largely determined by the thickness of the latter in the pack. At the same time, the clothing pack includes, in addition to the thickness of the material, the thickness of the air gaps.

It would seem, based on this, it is expected that an increase in the thickness of the air layers in clothing can increase its thermal resistance and the entire proposed pack. However, the results of studies carried out by the authors [30] show that this is effective only within certain limits of the thickness of the air gaps (≤5 mm). The thermal insulation properties of materials depend mainly on the presence of inert air enclosed in them and depend little on the type of fibers. There is a relationship between the thermal resistance of materials or a pack of materials and their thickness, which must be taken into account when designing clothing with the required thermal resistance. In the same work, the authors experimentally and theoretically substantiated that the heat-shielding properties of a clothing pack also depend on its physicochemical and operational properties [30]. Based on the results of the above works, it follows that the study of the heat-shielding properties of the pack material in order to solve functional problems and design rational clothing for people involved in mountain tourism and mountaineering is an urgent problem. In order to comprehensively take into account the factors that affect the heat-shielding properties of the clothing pack and the formation of layers of the pack with high heat-shielding properties, it is necessary to conduct a complex of experimental studies. At the same time, as objects of research, it is necessary to consider such factors as the influence of the environment and the under-clothing space on the heat-shielding properties of materials and clothing pack.

Used in practice for these purposes [31] do not take into account such parameters as environmental conditions, changes due to human activity, parameters of the air layer in the underwear space, and therefore the obtained values do not fully correspond to reality.

Therefore, to study the heat-shielding properties of materials and clothing pack, taking into account the actual operating conditions of clothing, an experimental setup has been developed to determine the heat-shielding properties of materials and clothing pack. The experimental setup allows measuring parameters such as temperature and humidity in chambers simulating the environment and underwear space. Using temperature sensors, the temperature between the layers of materials of the test sample of a clothing pack is measured.

The experimental setup (Fig. 4) consists of two chambers: in the first one, the air environment under the clothes is simulated. In the same chamber, there is a crank mechanism (crank 2 and connecting rod 3), piston 4, which, by reciprocating, reproduces the respiratory rate of the human body. The temperature in the chamber is supported by an adjustable electric heater 5 and a set of temperature and humidity sensors 6.

Appearance of the installation for determining the heat-shielding properties of materials and clothing pack (Fig. 5).

In the second chamber, such environmental parameters are simulated as: wind pressure, ambient temperature and humidity. This chamber has a refrigeration device 13, inside which a fan 12 and a nozzle in a wind tunnel 10 are installed to supply water. The pack of materials 7 with built-in temperature and humidity sensors 6 is fixed between the guide pipes 8 (simulating the microclimate of the environment), 9 (simulating the microclimate of the underclothing space) and fixed with a spring 15. Temperature and humidity sensors 6 are connected to the reading and control equipment (Fig. 4).

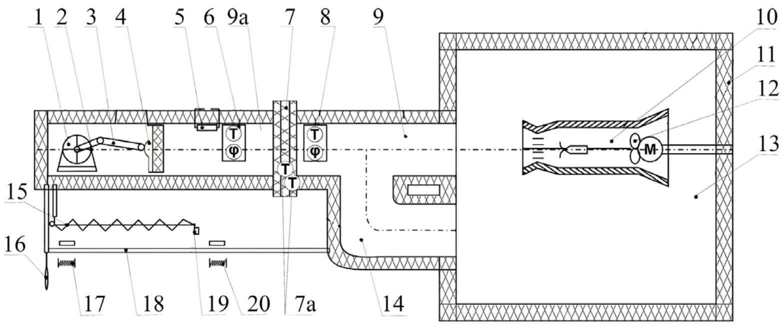

Fig. 4. Installation for determining the heat-shielding properties of materials and clothing pack: 1 — engine; 2 — crank; 3 — connecting rod; 4 — piston; 5 — electric heater; 6, 8 — sensors (temperature, humidity); 7a — temperature sensors; 7 — space for placing samples; 9a — branch pipe, simulating the underwear space; 9 — pipe guide, simulating the environment space; 10 — aerodynamic device; 11 — housing; 12 — fan; 13 — refrigerator; 14 — return pipe; 15 — tension spring; 16 — tension handle; 17 and 20 — guide bushings; 18 — guide link; 19 — spring mount

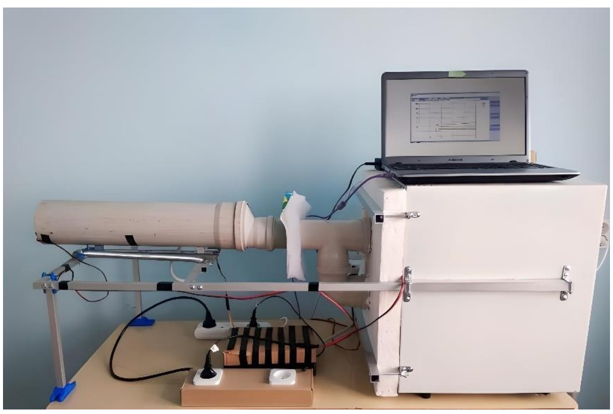

Fig. 5. Appearance of the installation for determining the heat-shielding properties

The installation (Fig. 4) is mounted on the body 11 and consists of the following elements: electric motor 1, crank 2, connecting rod 3, piston 4, electric heater 5, sensors (temperature and humidity) 6, space for placing the sample 7, guide pipe 9, return air pipes 14, pressure springs 15, handles for retracting the pipe simulating the underwear space, guide bushings 17 and 20, support profile 18 and spring attachment 19. The tested clothing pack 7, with temperature sensors 7a fixed between the layers of materials, is placed between the nozzles, simulating the environmental conditions and the underwear space.

Before the test, the air in the wind tunnel 10, which simulates the environment, is cooled to the required temperature, and the underclothes chamber is heated to the temperature of the human body. Humidity in the chamber simulating the environment is achieved by spraying moisture, and the pressure of the wind flow is achieved using a fan 12 built into the pipe. Compression from the breath of the body in the underwear space is created using a crank-slider mechanism.

Piston 4, reciprocating in the pipe, simulates the intensity of breathing, creates compression in the pipe 9a. Piston 4 receives movement with the help of connecting rod 3 and crank 2 from electric motor 1. The frequency simulating breathing is regulated, within 14–22 breaths per minute, by changing the speed of the motor shaft 1. Control over the system parameters is carried out automatically by the instrument control system. The readings of the temperature sensors between the layers of the pack of materials and the humidity parameters are displayed on the monitor in the form of graphs (Fig. 6).

The developed software makes it possible to evaluate the heat-shielding properties of each layer and the package as a whole.

The influence of the wind flow on the heat-shielding ability of the pack, fixed between the pipes, which imitates the space under clothes and the environment, was evaluated by blowing the sample in a wind tunnel at speeds of 2–15 m/s and an angle of attack of 90 deg. The test samples were in a hermetically sealed space, at initial temperature parameters of 36 °C and humidity from 60 %.

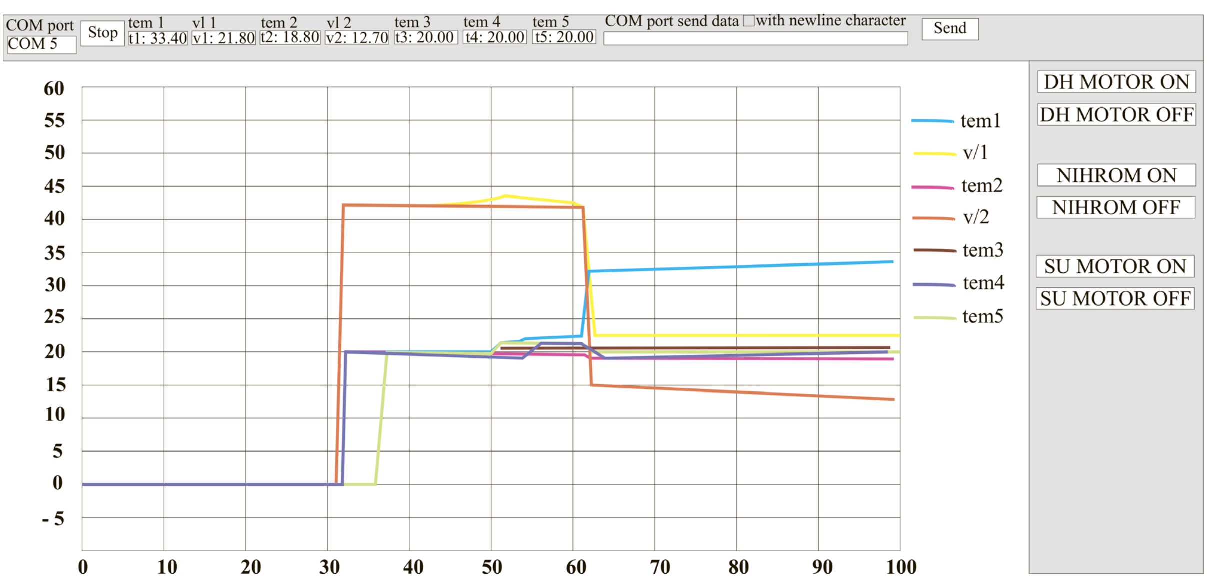

Fig. 6. Graphs of readings of temperature and humidity sensors when setting the initial data for research (temperature: tem 1, tem 2, tem 3, tem 4, tem 5; humidity: vl 1, vl 2)

As a result of the research, the indicators of humidity and temperature in the underwear space of clothes were measured (with the help of temperature and humidity sensors) every 10 minutes.

Before the beginning of the experimental studies, the parameters of the initial mode of the installation were preliminarily established. The initial parameters are: temperature T_{ok} and humidity W_{ok}, temperature in the underwear space T_{pp}, frequency of change of compression n in the underwear space, air humidity in the underwear space W_{pp}.

The temperature T_{ok} and humidity W_{ok} of the environment are recorded by changing the temperature of the cooling air in the refrigerating chamber and spraying water through the nozzles with a water pump. The creation of the initial temperature in the underwear space is carried out by regulating the electric heater. Changes in the parameters of these factors are recorded by the corresponding sensors and controlled on the monitor screen.

To carry out measurements in a stationary thermal regime, the fan and the water spray nozzle were turned off, and the readings of the temperature sensors on the surfaces of the material T_{ok}–T_{pp} were used. The total thermal resistance of the pack materials R_{sum} (Km^2/W) is determined by the formula:

$$R_{sum}=(T_{pp}-T_{ok})/q_n,$$

where q_n is the density of the heat flux passing through the material, W/m^2.

In a stationary thermal regime, the heat flux density q_n=const and is determined using an IPP-2 meter with a TXA-A-D1/D2-LP heat converter [32].

Thermal conductivity coefficient λ_p (W/K·m^2) of clothing material:

$$\lambda_p=\delta_p/R_{sum},$$

δ_p is the thickness of the studied material sample, m.

As a result, for the stationary mode, (the average value of the results of homogeneous experiments) thermal conductivity coefficients of the investigated pack were obtained (Table 3).

To analyze the error of the proposed method for measuring thermal conductivity, comparative measurements of the thermal resistance of a pack of materials were carried out using a PIT-2.1 device for measuring thermal conductivity and the proposed device. An analysis of the obtained results allows us to note that the error in determining the values of the thermal conductivity coefficient and thermal resistance by the proposed method does not exceed 5 %.

In order to study the effect of wind and ambient air humidity on the temperature in the underwear space, experimental studies were carried out, in which the wind flow speed was changed by a fan, and humidity was changed by spraying moisture through nozzles. The wind speed was measured with an AC-1 type anemometer with an RS-232 interface [33]. For the convenience of conducting experimental studies, the fan speed was previously calibrated with a wind speed measured by an anemometer. During the study of the thermal resistance of the tested samples of the pack, the wind speed was set by changing the engine speed according to the calibration schedule. Air humidity was recorded with a humidity sensor.

A fragment of the results of temperature changes in the under-clothing space for a pack of materials depending on the filtration time and wind speed is shown in Table 4.

Table 4

Temperature change in the underwear space depending on wind speed and ambient air humidity (for pack No. 1)

Filtration time τ, min	Temperature in the underwear space T_{pp}, °C					
	At ambient humidity W=60÷70 %			At ambient humidity W=80÷95 %		
	At wind speed, υ m/s					
	υ=5	υ=10	υ=15	υ=5	υ=10	υ=15
0	34	34	34	34	34	34
20	34	33	27	34	25	25
40	33	32.5	25	32	25	24 _
60	32	31	24	31	23	23
80	32	31	24	31	23	23

As can be seen from Table 4, at different wind speeds and humidity, due to air filtration through the pack, the temperature of the underwear space decreases. The pack under consideration provides a comfortable condition for a person in the absence of breathability and at a wind speed of 5 m/s; and at wind speeds of 10 m/s and 15 m/s, the temperature of the underwear decreases. The humidity of the air flow also affects the temperature in the underwear space. With an increase in air humidity in the chamber, which simulates the environment, the temperature in the underwear space decreases. Under conditions of wind exposure, the air flow penetrates inside the clothes and enhances heat transfer in the materials and in the underwear space, reduces its heat-shielding properties, which are mainly due to a fixed layer of air enclosed in clothing.

Fig. 7 shows the graphs of the influence of wind speed on the thermal resistance of the pack.

Table 3

Thermal conductivity coefficients

No. samples	Material pack	Pack thickness δ, m	Heat flux density q, W/m^2	Temperature in the underwear space T_{pp}, K	Ambient temperature T_{ok}, K	Total thermal resistance R_Σ, km^2/W	Thermal conductivity coefficient λ_p, W/K·m^2
1	Membrane fabric, hollow fiber, lining	0.027	55.2	309	291.1	0.624	0.0771
2	Raincoat fabric, synthetic winterizer, embroidered with lining fabric	0.017	55.2	309.35	290.7	0.541	0.0498
3	Raincoat fabric, batting, lining	0.019	56.1	308.65	290.1	0.431	0.05740
4	Raincoat fabric, synthetic winterizer, full-time lining	0.021	54.9	307.2	290.3	0.470	0.0601
5	Membrane fabric, hollow fiber, fleece	0.025	55.1	309.5	290.2	0.570	0.0771

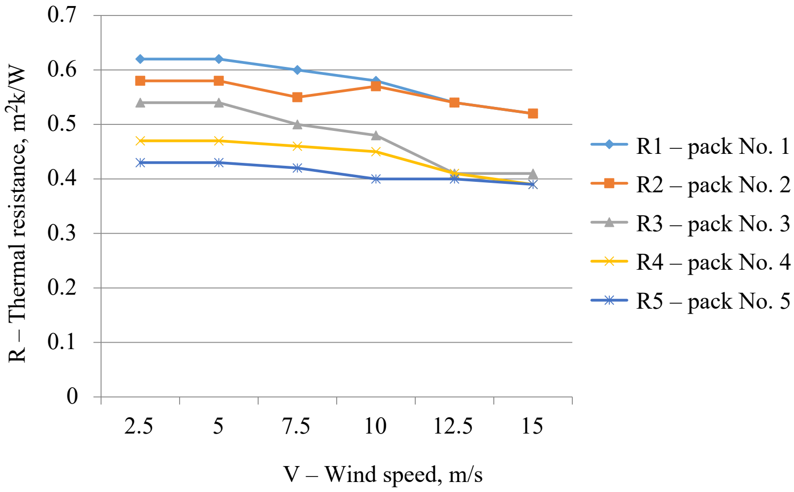

Fig. 7. Influence of wind speed on the thermal resistance of the pack

The test samples are deformed under the influence of wind pressure and, as a result, a change in the air space in the pack changes the values of thermal resistance.

In the course of experimental studies, changes in the state of the air in the underwear space due to the movement of the chest during human breathing were checked.

For this purpose, a series of experiments were carried out to measure temperature and humidity with the mechanism switched on and off, which simulates the movement of the chest.

At a crank 2 rotation frequency (Fig. 4) of 18 rpm, which corresponds to the breathing rhythm of a person in a calm state [34, 35], changes in temperature and humidity in the underwear space were measured. At the same time, the temperature and humidity of the environment corresponded to the norm. So, at ambient temperature T_{ok}=20 °C and humidity within 60–70 % for pack No. 1: when the breathing simulator was turned on, T_{pp}=26 °C, W=62 %, and when it was turned off, T_{pp}=27 °C, and the humidity value did not change. The slight decrease in temperature is obviously related to the heat exchange with the environment through the pack of materials. As studies have shown, the effect of chest movement on heat transfer in the underwear space is not significant and can be ignored when choosing materials for a clothing pack.

As a result of experimental studies of a pack of clothing materials, the determined parameters of the pack ensure a comfortable human condition during the operation of clothing. Taking into account the results of the research, clothing samples for mountain tourism athletes were developed [36–38], which were introduced into production and received positive consumer feedback.

6. Discussion of the research results

In the system of quality indicators of clothing for mountain tourism and mountaineering, operational and hygienic indicators are of paramount importance, which determine the wear resistance of clothing and the microclimate on the surface of the human body, heat exchange and gas exchange with the environment. Discussing the results of the study of wear resistance and thermal insulation of a pack of clothing when creating real operating conditions.

Wear of clothing materials is complex and depends on many factors. As the analysis showed, the methods used in practice for determining the intensity of wear [18–21] mainly take into account changes in the strength of the material only as a result of abrasion. Instruments used in practice for determining the abrasion resistance of textile materials do not allow taking into account fatigue wear, since clothing materials experience tensile, bending and torsion loads during operation. Moreover, the actions of these factors are not constant, but cyclical with an impact that is not constant in time. Based on the operating conditions of clothing in complex dynamic conditions, a device was developed [27, 28], which simulates wear from cyclic, volumetric load effects (Fig. 1, 2). As experimental studies have shown, the wear resistance of clothing is lost with an increase in the time of cyclic loading (Fig. 6).

The degree of wear of a pack of materials during its abrasion was determined by the ratio of the difference in indicators before and after testing to the initial value of the indicator (indicators of a standard pack, new pack). According to experimental studies, with the same number of test cycles, the values of breaking forces compared to abrasion during fatigue wear turned out to be less by 10–25 %, that is, under cyclic loading, due to fatigue wear, the material loses strength faster.

The results of testing the pack of materials show that the developed experimental setup is recommended to be used to assess the degree of fatigue wear, which makes it possible to choose a more objective composition of the pack of materials, taking into account external environmental factors.

Used in practice [31] for studying the heat-insulating properties of a clothing pack do not allow to simultaneously take into account the influence of all factors that affect the heat-shielding ability of the pack, do not allow to fully simulate environmental conditions, changes due to human activity, parameters of the air layer in the underwear space.

To study the heat-shielding properties of the materials of the clothing pack close to real operating conditions, an experimental setup has been developed [28]. The installation (Fig. 4, 5) allows you to reproduce the temperature of the underwear space and environmental parameters over a wide range. Thus, during experimental studies, the ambient temperature was changed in the range from –15 °C to –20 °C, ambient humidity 60÷80 %, wind flow speed 2÷15 m/s and angle of attack 90 degrees. To ensure the homogeneity of the experiments, the test samples were stored in a hermetically sealed space, at the initial temperature parameters of 36 °C and a humidity of 60 %. Before the start of experimental studies, the parameters of the initial state were set using standard methods (Table 3): temperature and humidity of the environment, temperature and humidity in the underwear space, frequency of compression changes in the underwear space, and parameters of the physical and mechanical properties of the test samples.

The heat-shielding properties of the clothing pack were evaluated by the thermal conductivity coefficient.

On the developed experimental installation, studies were carried out on the influence of wind flow and humidity, ambient air temperature on changes in the temperature of the underwear space. At an ambient temperature of 20 °C, the humidity was in the range of 60–70 %, and with the breathing simulator turned on, the temperature in the underwear space was 26 °C, the humidity was 62 %, and when it was turned off, the temperature was 27 °C, the humidity value did not change. The slight decrease in temperature is obviously due to heat exchange with the environment through the pack of materials. When exposed to a wind flow of air on a pack of clothes, heat transfer in the materials and in the underwear space increases (Fig. 7), the coefficient of thermal resistance of the pack decreases.

The error of the proposed method for measuring thermal conductivity was verified by the standard method. For this purpose, comparative measurements of the thermal resistance of a pack of materials were carried out using a PIT-2.1 device for measuring thermal conductivity and the proposed installation. An analysis of the obtained results allows us to note that the error in determining the values of the thermal conductivity coefficient and thermal resistance by the proposed method does not exceed 5 %.

The proposed method for determining the heat-shielding properties of clothing materials will allow at the design stage of clothing to select the composition of the pack that provides comfortable operating conditions for clothing.

Experimental studies have made it possible to determine a rational package of clothing materials that provides wear resistance and thermal protection of overalls for tourists. Using the results obtained, clothing samples were developed [39, 40] that received positive consumer feedback.

The developed installations and methods for studying the wear resistance and heat protection of clothing packages can be recommended for use at the stage of design in production laboratories of enterprises engaged in the production of special clothing for extreme, mountain sports.

To further deepen the study, computational justifications are needed for various values of wear resistance factors and heat-shielding parameters.

7. Conclusions

1. An experimental installation has been developed to study the wear resistance of clothing packages, which allows simulating the degree of impact of cyclic loads on a package of materials and assessing the degree of strength loss. Determination of the strength characteristics of packages of materials before testing – reference and after – worn packages were checked on an RM-50 tensile testing machine. Comparison of the wear results on the developed installation and the standard IT-3 device was carried out for the membrane fabric by measuring the breaking load. The results show that the wear of materials under cyclic loading on the proposed installation is achieved faster than during abrasion on the IT-3 device. With the same number of test cycles, the magnitude of breaking forces compared to abrasion, with fatigue wear, is less by 10÷25 %.

2. An experimental setup has been developed that makes it possible to reproduce the temperature of the underwear space and environmental parameters within a wide range, which will allow testing materials under conditions close to the actual operating conditions. The installation allows estimating the total coefficient of thermal conductivity and thermal resistance. The reliability of the results obtained on the developed device was verified by comparing the measurement of the thermal resistance of a package of materials with a standard PIT-2.1 device. The analysis of the obtained results showed that the error in determining the values of the thermal conductivity coefficient and thermal resistance by the proposed method does not exceed 5 %. The research results showed that the packages under consideration (at different speeds, humidity and wind temperatures) provided a comfortable condition for a person at a wind speed of 5 m/s. And at wind speeds of 10 m/s and 15 m/s, the temperature in the underwear space decreases. With an increase in air humidity in the chamber, simulating the environment, the temperature in the underwear space decreases. Under conditions of wind exposure, the air flow penetrates into the clothing and enhances heat transfer both in the materials and in the underwear space, reduces its heat-shielding properties, which are mainly due to a fixed layer of air enclosed in clothes. Experimental studies of changes in the state of air in the underwear space, due to the movement of the chest during human breathing, showed that the effect on heat transfer in the underwear space is not significant.

Conflict of interests

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, copyright or otherwise, which could affect the study and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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