

Research of footwear lining materials thermoconductive properties

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Abstract. Protective properties of footwear are influenced by a number of factors and the most important of them are: design features of the top and the bottom of the footwear, it's shape, physical and mechanical properties of the components of which they are made. In course of work there were researched thermoconductive properties of different lining membrane materials used for production of high temperature protective footwear. Research results allow to select the appropriate materials by reference to thermoconductive properties during design of protective footwear for extreme conditions to prolong the wearer's time of comfortable stay in conditions of exposure of elevated temperatures to a stack.

1. Introduction.

Performance of duties and responsibilities by different specialists may be associated with a risk to their lives and health. With a purpose of the risk minimization the employee is given special-purpose ammunition; if the danger is exposed to the feet, then it is a question of special footwear. With reference to determination, these personal protective means protect the feet from stressed conditions which can be a reason of industrial injury.

Modern footwear for power and security structures employees and other different specialists is made by means of high-tech equipment and cutting-edge technologies, newest components and modern materials.

At footwear designing and materials selection a comprehensive solution of the problems of providing both heat-shielding and hygienic properties is necessary. To combine these sometimes contradictory requirements and to select materials meeting the requirements of footwear operating conditions the relevant research is needed.

Materials used for footwear production differ in both types and technological parameters. The industry uses a wide range of natural, synthetic and artificial materials and technologies for their processing; equipment for the synthesis of polymers, processing of rubbers and plastics, etc.

When footwear is used in different climatic zones, arises the situation of creating the conditions in which a person's foot should feel comfortable during the entire time of being in these conditions.

When technical requirements developing, an important role is played by the fundamental standards for the classification of footwear according to protective properties in general and the nomenclature of quality indicators, depending on the specific purpose. In this paper we research thermoconductive properties of special lining materials used for high temperature protective footwear production.



2. Theoretical research.

As already known [1], thermoconductive (heat-protective) footwear properties influenced by different factors. The most important are design features of footwear top and bottom, it's shape, thermal properties of the materials of which they are made as well as types of individual parts connection etc. Very important are the features of footwear materials' physical state from which it is necessary to note the most important factor - the heat-conducting properties of the component materials.

In order to consider more detailed the influence of separate footwear design features on its thermoconductive properties to approach the calculation of the heat-protective properties of the shoe design along with the total thermal resistance of the footwear, the values of the thermal resistances of the component materials.

Upon closer consideration of top and bottom design, research of material influence on the properties of the top and bottom it is calculated data on the thermal resistance of the top and bottom of various materials used in the construction of heat-protective footwear.

Heat-protective properties of footwear design vary widely, depending on used materials and design features of top and bottom. In the paper [1] are presented research results of different footwear components' materials where noted that the lowest heat-protective values has footwear design where used the following thin close textures: lining — twill ticking type, sole — monolithic rubber type, attachment methods (nail or screw), providing dense pressing of all details of footwear bottom design.

The highest heat-protective properties have footwear designs where used thick porous, fleecy and loose materials: top – heat-resistant leather; lining — special heat-insulating materials, fur and thick fleecy half-woolen baizes; bottom — porous rubber [2].

The lowest heat-protective properties have normal working boots with front and tarpaulin top on rubber monolithic molded sole of nail fastening method. Their total thermal resistance is of $0.16 \text{ m}^2 \times \text{hour} \times \text{degree} / \text{kcal}$, which is two times lower than similar heat-protective properties value of standard imported footwear for power structures.

Heat resistance of footwear top directly depending on lining material including in its design, varies widely. Highest heat resistance values has top design with linings of thick loose fleecy materials – fur and pile which have lower conductivity and significant thickness, and the lowest – top design with thin close texture linings. Thermal resistance of the top of leather boots with fur lining is two times higher than thermal resistance of the top of similar boots with lining of twill ticking.

If we consider footwear design with most commonly used interlining fabrics – cotton sheeting or calico, the influence of named fabrics types on heat-protective properties of footwear design will be insignificant. This is due to small thickness of these tissues and small decrease or increase in the thickness of the interlining when replacing one fabric with another. However, for interlining may be used another materials which have significant thickness and content large amount of “inert” or “fixed” air to create a stable air layer inside the footwear design.

At present as lining materials used a number of high-tech fabrics, called "membrane fabrics". This fabrics represent an original interlacting structure of different synthetic threads with various thickness and air layers inside the footwear top design. Of great interest are special knitted fabrics with different interlacing, different density and thickness, containing cotton, chlorine and capron. These materials are decade break-through which makes it possible to manufacture footwear with a completely new degree of reliability, strength and durability [3].

Membrane fabric is special waterproof material placed between lining and footwear top. The main properties of membrane materials are water and wear resistance. These properties it owes to the membrane, which is a very thin fluoroplastic film. Its pores are 20.000 times less than water drop, so they don't let the moisture come inside the boot and at the same time, 700 times more than vapor molecule so that the evaporations are removed from the footwear, which allows the foot to "breathe" and stay dry.

Membranes are of two types: hydroporous (the most famous is GoreTex) and hydrophilic (the most common is SympaTex). Hydroporous membranes consist of pores through which moisture (sweat) is discharged outside, and water does not penetrate from the outside. Hydrophilic membranes are a continuous film that does not allow the water to penetrate inside.

It is impossible to see membrane. It is securely closed by the upper layer of the footwear and the inner lining layer. First of all, membrane is high-tech micro-porous material which due to unique properties performs two main functions: it detains water from the outside and removes water vapor and natural evaporation of the body from within. This process illustrated in Figure 1. Presence of membrane fabric inside footwear provides good air circulation and microclimate inside the footwear. In table 1 presented membrane fabric types and countries of origin.

Table 1. Membrane fabric types

Membrane fabric	Country of origin
Gore-Tex	W.L.Gore Associates, Scotland
Thinsulate, AQUAT	Siretessile, Italy
Windtex	Vagotex, Italy
Triplt Point Ceramic	Unikita, Japan
Drycoat	MontBell, USA
Breathe	UCB Chemical, Germany
Cordura	DuPont, USA

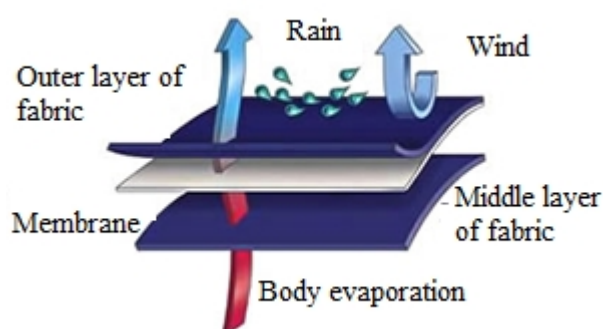


Figure 1. Structure of the material for footwear top using membrane fabric

3. Experimental research.

The modern transition to the production of footwear with lining materials, such as membrane fabrics, significantly increases the operational and ergonomic properties of special footwear. Wide range of different lining materials allows to design lining materials created by means of advanced technologies for each type of special footwear, depending on the requirements.

The heat-protective ability of footwear is understood as the ability to maintain the intensity of heat exchange beneficial to the body, i.e., the ability to prevent excessive heat transfer from the environment to the foot.

As is known, the process of heat transfer in a body under steady-state heat transfer is characterized by the heat-conductivity coefficient λ in kcal / mch-hour, and at the boundary of the body with the surrounding medium, the coefficient of heat transfer α in kcal / m²-hour.

In this paper investigated thermoconductive properties of different lining materials with waterproof breathing membrane «AQUAT» manufactured by Italian company «SIRETESSILE» and the following features:

1. «SANYHYGIENICAL» sample – lining antibacterial material made of polyamide with antibacterial impregnation. Disinfecting material controls formation of harmful bacteria, preventing an unpleasant odor. Has high abrasion resistance. The material recommended as lining material for special footwear. Duplication method – heat, fire.

2. «AERPLUSSZH33 NERO» sample – mesh waterproof lining material made of polyamide/polyester, light and breathing. The material is very durable at seams, sturdy and abrasion resistant, suitable as a lining material for special footwear production. Duplication method – heat, fire.

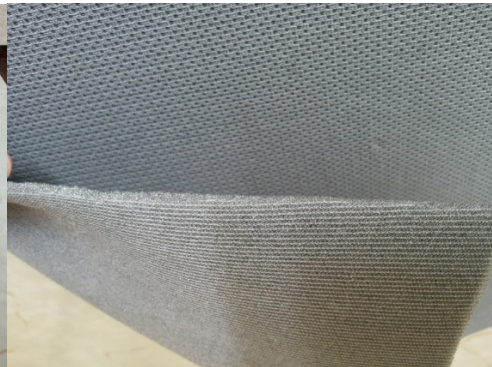
3. «DUBLINOAVIO» sample – classical 3-layer hydrophobic waterproof lining material consisting of knitted top + breathing membrane foam layer + film cover. A herringbone pattern and gray color allow combining it with shoe leather of a wide color range. Has high abrasion resistance and tensile strength. Side duplication method – thermal bonding.

4. «SPIGATINO» sample – waterproof lining material used in combination with breathing membranes. A herringbone pattern and gray color allow combining it with shoe leather of a wide color range. Has high abrasion resistance and tensile strength. Duplication method – thermal bonding.

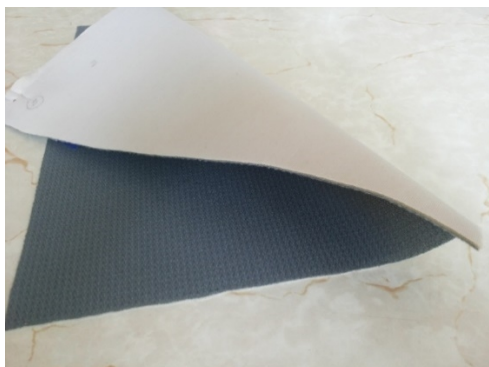
5. «CLOROFILLA» sample – innersole antibacterial material made of green antistatic foam which decrease the load when walking and quickly absorbs sweat. Duplicated with antistatic lining material made of polyester which is hydrophilic and in its turn creates comfortable environment and keeps foot dry. Due to its characteristics and high abrasion resistance, this material is recommended for special working footwear. Foam is sewn on both sides with knitwear. Duplication method – fire. The pictures of these samples are shown in Fig 2-6



Sample #1 «SANYHYGIENICAL»



Sample #2 «AERPLUSSZH33 NERO»



Sample #3 «DUBLINOAVIO»



Sample #4 «SPIGATINO»



Sample #5 «CLOROFILLA»

Figure 2. Pictures of samples of investigated membranes fabrics

Thermoconductive properties of lining materials are determined by means of AW-2 device in training and testing laboratory «CENTEXUZ» in Tashkent Institute of Textile and Consumer Industry.

In the device there are 3 heaters. Before testing, each of them must be heated up to 36,6°C. Testing of each sample lasts 4 hours: 2 hours without sample and 2 hours with sample. During testing it is necessary to maintain such climatic conditions in the room like temperature of 22°C and humidity of 65%.

Operation principle of the device based on comparative analysis. The heaters of the device are arranged so that they keep the set temperature (36,6°C) all the time. After the heaters of the device have been heated to the desired temperature, they stop working and when they begin to cool down they start working again. There are two timers on control panel of the device. A Timer intended for total time of testing – 7200 seconds. B Timer operates only during work of heater test board. Thus, for 2 hours (7200 seconds) B Timer counts duration of heater work without sample. It is necessary to remember the value and then reset counters to 0. After that device works another 2 hours but with sample. This time heaters operate relatively less since the test board covered with sample of tested fabric and it prevents heaters cooling down. Duration of device operation with sample also must be remembered and testing results are calculated using the formula below:

$$\text{Thermoconductivity } K = \left(1 - \frac{b}{a}\right) \times 100$$

a – duration of heater operation without sample (sec.)

b – duration of heater operation with sample (sec.)

Three samples of each kind of gasket material were tested. The thermoconductivity of the materials from the front and back sides was determined. The average statistical data are presented in Table 1.

Table 1. Results of materials testing for thermoconductivity

Material	Composition	Thic kness mm	Material of sides		Thermoconductivity, %	
			Front - A	Lining - B	Side A	Side B
SANYHYGIENI CAL	Polyamide with impregnation	1,4	Polyester film	Knitted wear	44,4	49,8
AERPLUSSZH3 3 NERO	Polyamide	1,4	Polyester film	Knitted wear	31,4	37,8
DUBLINO AVIO	Polyester / polyamide	1,4	Polyester film	Mesh knit	21,22	24,09

SPIGATINO	Polyamide	6,3	Polyester film	Knitted wear	48,72	52,52
CLOROFILLA	Polyamide	4,2	Knitted wear	Knitted wear	24,29	47,9

4. Analysis of testing results and conclusions.

Testing results on thermoconductivity of different lining membrane materials manufactured by Italian company «SIRETESSILE» allow to make following conclusions:

- thermoconductivity of tested materials on the front side is lower than on wrong side;
- lining materials thickness significantly affects thermoconductivity; – the thicker the material the higher the heat-protective properties of materials;
- the best heat-protective properties index of 4th sample consisting of top knit cover and polyester film on wrong side. High index of heat-protective properties are also due to considerable thickness and structure of the intermediate layer;
- location of interlining film in the structure of the membrane fabric significantly affects its heat-protective properties in final footwear.

Thus, when designing footwear for use in extreme conditions, in order to prolong the wearer's time of comfortable stay in conditions of elevated temperatures exposure to a stack, it is necessary to select the appropriate materials that form the bags for the top of footwear.

References

- [1] Kedrov L 1976 *Lyogkaya industriya* Warmed footwear, Moscow
- [2] Bessmertnaya T and Garkovenko S 2008 Problems of footwear characteristics improving and ways to solve it, International Collection of research papers, (Russia, Shakhty), , p. 58-61.
- [3] NPB 158-97 "Special fire safety footwear. General technical requirements. Testing methods"