Method of getting the composite fiber material with functional heat-resistant, heat-accumulating components

I Cherunova1,2,4, E Stefanova1, and G Radyuhina3

1Don State Technical University, Shevchenko, 147, Shakhty, 346500, Russia
2University of Rostock, Albert-Einstein-Straße, 2, Rostock, 18059, Germany
3Volga region state university of service, Gagarin street 4, 2, Tolyatti, 445017, Russia
E-mail: i_sch@mail.ru

Abstract. In the article research results are presented, which aim to development of an method of getting the composite fiber material with functional heat-resistant and/or heat-accumulating components. Their resources and prospects for their use are of interest for improving the clothing heat resistance by modifying the materials. A similar approach is relevant for technologies of protective clothing from the cold (modification of fibrous materials using heat-accumulating components). As a heat-resistant synthetic fiber, we considered the Kevlar fiber. For research and development, we selected a special fine fraction: pulp or PCM-capsules. As a fibrous basis for designing the new material, we considered a widely used fiber insulating material – Hollofiber. The method and scheme of the general layout of the method for modifying nonwoven fabric with fine aramid fiber - pulp or PCM are developed. The research results allowed us to find that the proportion of Kevlar in the insulating material equal to 30 ±3 g/cu.m virtually did not change the thickness, porosity, and density of the material pack (less than 1%), which indicates the constancy of the air volume, the presence of which determines the thermal resistance of the insulating material. The presented method has a similar application technology for PCM capsules, which are converted by standard fiber materials.

1. Introduction
In the design and production of professional winter clothing, materials and material systems are not only a means for protecting against cold, but also for reducing the clothing burning rate, if there are ignition conditions thereof. Such a protective function is provided not only by top fabrics, but also the properties of internal heat-insulating materials. High fire-resistant fibers include aramid fibers [1]. When manufacturing products from these fibers, there are useful products of secondary fractions and waste of the fiber itself [2]. Their resources and prospects for their use are of interest for improving the clothing heat resistance by modifying the materials [3,4]. This determines the relevance of new composite modified materials for protective clothing using aromatic hydrocarbon fractions [5,6]. A similar approach is relevant for technologies of protective clothing from the cold [7]. In this case, it is possible to develop modification of fibrous materials using heat-accumulating components [8].

2. Theoretical part
At the first stage, thermal risks, including ignition risks, result in the possible consequences of external destruction of clothing materials. This leads to a rise in temperature in the material pack. Insulating materials that are used in practice for oil-protective clothing are not standardized to be completely heat-resistant, hence the widespread use of materials that are efficient in terms of heat protection and
cost. However, they require increased attention to their heat resistance while preserving the effective price range of products.

For this purpose, we suggest to modify the insulating pack of materials by introducing a fraction of heat-resistant aramid fiber (products of recycling) in the structure of synthetic insulating material. As a heat-resistant synthetic fiber, we considered the Kevlar fiber. For research and development, we selected a special fine fraction: pulp (Figure 1-a) and PCM-capsules (Figure 2-b).

![Figure 1. Special fraction: a – pulp [9], b - PCM-capsules [10].](image)

As a fibrous basis for designing the new material, we considered a widely used fiber insulating material – Hollofiber [11, 12]. (Figure 2)

To obtain a new composite fiber material with heat-resistant aromatic polyamide components, we studied modern methods and technical means.

There is a known double-drive spray device and a coating application method by spraying on the product surface. It includes a coating material feeding system, as well as a motor that is functionally connected to the coating material supply system and adapted to its linear displacement. The coating process involves a spray device with one or more nozzles. The material is sprayed inside the product body, and the product body itself is rotated. A disadvantage of this method is that the coating is applied to the product surface, but it cannot be introduced inside the fibrous structure.

![Figure 2. Fiber insulating material – Hollofiber [12].](image)

There is an alternative solution in the form of a device for cutting fabrics and similar materials, mainly with high cutting resistance. This device includes a cutting table with a special coating and a vacuum device, a cutting knife, a knife movement unit, and knife movement unit drive. A
disadvantage of this method is performing only one cutting function without the possibility of filling the cut parts with a fine aramid fiber fraction.

3. Experimental part
When looking for relevant engineering solutions of the problem, we identified a method that is based on a mechanic arm that provides for linear movement of the equipment working body along a complex contour of the product. A disadvantage of this method is that the working body does not affect the internal structure of the product processed, and the material remains unchanged in terms of its composition and structure. As an alternative, we found a coordinate table that includes a base and movement devices consisting of separate units with connecting mounting surfaces. This method refers to two-axis devices powered by linear electric motors with program control; however, such designs are used to create systems for processing the product surface in mechanical engineering.

Therefore, to provide the possibility of filling the inter-fiber space with synthetic nonwoven insulating material and modifying its properties, we solved the problem by filling the inter-fiber space with a synthetic non-woven insulating material, using Hollofiber as an example, by using a specially designed device that includes a working table and a device for moving the working body relative to the table surface in rectangular coordinates and its control system.

A distinctive feature of the suggested method is that the container with fine aramid fiber fraction is connected by one flexible hose to the nozzle, and by the other hose, to the compressor. The unit with a mechanic arm installed on a special frame is moved on guides installed along the cutting table. The nozzles are lowered to the middle of the thickness of the synthetic nonwoven insulating material, piercing the same. The modifying substance (aramid fiber pulp or PCM-papsules) is fed by means of compressed air from the compressor through a flexible hose from the container to the nozzle. The substance is introduced into the inter-fiber structure of the insulating material. (Figure 3)

![Figure 3. General layout of the method for modifying nonwoven fabric with fine aramid fiber - pulp or PCM. 1 - Compressor, 2 - hose, 3 - modifier, 4 - flexible hose, 5 - manipulator, 6 - guide part, 7 - cutting table surface, 8 - nozzles.](image)

To determine the standard content of the modifying filler aramid - pulp [9] in the structure of a voluminous synthetic insulating material (using Hollofiber as an example) as per State Standard [13], we have carried out experimental research.
To determine the standard amount of Kevlar to be introduced into the insulating material (Hollofiber), we studied the dependence of its heat-protective properties on the mass fraction of the introduced aramid fiber.

To study the thermal conductivity of the modified material, we used the method as per Standard [14,15].

Input data: a limited-volume microclimate chamber with a temperature set in the enclosed space within the range of 24 to 27 °C at a relative humidity of 65±5 %.

To study the thermal conductivity of insulating materials, we used Hollofiber samples with an area of 0.01 sq.m and a surface density of 200 g/sq.m. The sample thickness was 0.02 m at a pressure of 0.2 kPa and a surface density. Samples were kept before testing in the microclimatic chamber for one day.

Spatial changes in the values inside the chamber did not exceed: ±1% for air temperature, ±5% for relative humidity, ±50% for air mobility considering average values thereof. Time changes in the values inside the chamber did not exceed: ±0.5% for air temperature, ±5 % for relative humidity, ±20% for wind speed considering average values in five minutes thereof. After reaching an equilibrium (± 0.1°C), the sample surface temperature was recorded every minute. The average values of these measurements taken over a 30-minute period were sufficient to determine the thermal conductivity with a heat flow meter ITP-MG4.03 “Potok”. The heat flux density indicator was recorded once a minute.

4. Results
The results are shown in Figure 4.

4. Results
The results are shown in Figure 4.

![Figure 4](image.png)

**Figure 4.** Experimental standard amounts of the aramid component based on the analysis of thermal properties of the composite synthetic insulating material.

The research results allowed us to find that the proportion of Kevlar in the insulating material equal to 300 ±3 g/m³ virtually did not change the thickness, porosity, and density of the material pack (less than 1%), which indicates the constancy of the air volume, the presence of which determines the thermal resistance of the insulating material.

5. Conclusion
To check the obtained result in terms of increasing the resistance of the new material to thermal risks and, in particular, ignition risks, we have carried out experimental research. We have found an increase in the combustion resistance of the modifying filler in the structure of voluminous synthetic insulating material with the established amount of the aramid component.

We evaluated the actual consequences of exposure to flame for the insulating material which was originally part of a material pack the top layer of which was destroyed. Depending on the presence of Kevlar pulp in its structure, the inner layer showed greater integrity and resistance of the modified
pack to thermal effects, thereby expanding its application in the field of providing methods for the manufacture of protective clothing and equipment, while maintaining the general price group of insulating materials used in the clothing production.

The standard amount found for the aramid component was introduced into the structure of nonwoven insulating material using the suggested method. The presented method has a similar application technology for PCM capsules, which are converted by standard fiber materials.

Acknowledgements
The reported study was funded by RFBR, project number 19-38-90324.

References
[1] Cherunova I, Tashpulatov S, Kolesnik S 2018 IEEE Xplore: 18168363 doi: 10.1109/RUSAUTOCON.2018.8501795.
[2] Palola S, Vuorinen J, Noordermeer J W M, Sarlin E 2020 Coatings, Vol 10, 556 doi:10.3390/coatings10060556.
[3] Cherunova I, Stenkima M, Cherunov Proc P 2017 of the VIII Int. Conf. on Textile Composites and Inflatable Structures (STRUCTURAL MEMBRANES 2017) Pp 210-216
[4] Makowskia T, Zhangb C, Olahb A, Piorkowskaa E, Baerb E, Kregie D 2019 Materials and Design, Vol 162, 219–228 doi: 10.1016/j.matdes.2018.11.026.
[5] Song G, Su Y 2020 Fibrous Materials for Thermal Protection. Handbook of Fibrous Materials: Chapter 30 doi.org/10.1002/9783527342587.ch30.
[6] Cherunov P, Cherunova I, Knyazeva S, Stenkina M, Stefanova E, 2015 Kornev Proc N of the conference on “Textile Composites and Inflatable Structures” (Structural Membranes 2015) pp 555-564
[7] Cherunova I, Dhone M, Kornev Proc N 2015 VI Int. Conf. COUPLED PROBLEMS-2015 pp1303-1311
[8] Nayak A, Gowtham M, Vinod R, Ramkumar G 2011 International Journal of Environmental Science and Development Vol 2(6) pp 437-441
[9] Cao X-H, Wang Y, Geng H, Hu J 2017 China Pulp and Paper, Vol 36(2):18-22 doi: 10.11980/j.issn.0254-508X.2017.02.004
[10] Encapsulated Phase Change Material in Thermal Storage for Baseload CSP Plants 2020
[11] Khulbe K, ChFeng, Matsuura T, Khayet M 2017 Journal of Applied Membrane Science & Technology Vol 4(1) doi: 10.11113/amst.v4i1.43.
[12] Feng C, Khulbe K, Matsuura T 2013 A Ismail Separation and PurificationTechnology Vol 111, 43–71 doi.org/10.1016/j.seppur.2013.03.017
[13] ISO 9073-5:2008(en) Textiles — Test methods for nonwovens (2020)
[14] Standard Test Method for Man-In-Simulant Test (MIST) for Protective Ensembles ASTM F2588 - 12; F23.30 (2020)
[15] Angelova R, Georgieva E, Markov D, Bozhkov T, Simova I, Kheaiova N, Stankov P FIBRES & TEXTILES in Eastern Europe 26 4(130): 122-129. doi:10.5604/01.3001.0012.13232019.