ABSTRACT

of the dissertation by Atashikova Nargiza Aslanbekovna entitled “Development of a Technology for Producing Smart Textiles Incorporating Polymer Optical Fibers and a Membrane Layer”, submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D07206 – Technology and Design of Textile Materials

The textile industry remains one of the key sectors of Kazakhstan’s light industry, contributing significantly to employment, export revenues, and the processing of domestic raw materials. As of the beginning of 2025, Kazakhstan had 485 textile manufacturing enterprises, accounting for approximately 34% of all enterprises operating in the light industry. The country’s major textile production facilities are concentrated in Turkestan region and Shymkent city, owing to their access to cotton raw materials and an available labor force.

The relevance of this research is driven by the growing demand for smart textiles, particularly adaptive textile materials, including light-emitting products and textiles with membrane properties. Polymer optical fibers (POFs) offer several advantages, including high flexibility, low weight, and the ability to be integrated into textile structures without compromising their functional performance. These characteristics make POFs highly suitable for the development of smart garments used in medical textiles, sportswear, personal protective equipment, and decorative illuminated textile products. Despite the rapid advancement of smart textile technologies, methods for the production and adaptation of polymer optical fibers specifically intended for textile applications remain insufficiently developed. Existing manufacturing techniques often fail to provide the required levels of flexibility, light transmission, abrasion resistance, and compatibility with conventional textile manufacturing processes, such as weaving, knitting, and embroidery.

Therefore, the development of an efficient technology for integrating polymer optical fibers into textile fabric structures represents an important scientific and technological challenge. Addressing this challenge will expand the functional capabilities of textile products, enhance their level of intelligence and market competitiveness, and promote interdisciplinary research at the intersection of materials science, optics, and textile engineering.

Thus, polymer optical fibers are considered a promising material for the advancement of smart textiles and the development of multifunctional textile products with enhanced performance characteristics. This underscores both the relevance of the present research and the scientific and practical significance of further investigations in this field.

Another important area of this research concerns polymer-textile materials (PTMs) with membrane properties. The growing interest in these materials is driven by increasing demands for enhanced functionality, comfort, and protective performance in modern textile products. With the rapid development of high-technology industries, healthcare, sports, and personal protective equipment, there

is a growing need for materials capable of combining excellent barrier properties with high air and water vapor permeability, while maintaining resistance to external environmental factors.

Polymer-textile membrane materials are multicomponent systems in which the textile substrate provides mechanical strength and dimensional stability, while the polymer membrane ensures selective permeability to gases, water vapor, and liquids. Despite the wide range of membrane materials currently available, optimizing their structure and manufacturing technology remains a significant challenge. Such optimization is aimed at achieving a balanced combination of performance characteristics while maintaining manufacturing feasibility and economic efficiency.

Recent studies have demonstrated that the properties of polymer-textile membrane materials are largely determined by the type of polymer membrane, the method of its fabrication, and the nature of its interaction with the textile substrate.

Despite the wide variety of waterproof and breathable membrane textile materials currently available, significant challenges remain in optimizing their manufacturing technology, balancing water resistance with water absorption, air permeability, and water vapor permeability, and further improving their functional performance. The development of such materials requires achieving an optimal balance between the inherently conflicting properties of waterproofness and air permeability. To address this challenge, studies have been conducted to develop a simple and practical method for producing air- and water vapor-permeable polymer-textile materials capable of absorbing large amounts of water while preventing its penetration. In this research, a single-sided terry cotton fabric was used as the textile substrate. Nevertheless, the potential for employing textile fabrics of different fiber compositions and weave structures in the development of waterproof and breathable membrane textile materials remains an open area for further investigation.

Research Aim and Objectives

The aim of this research is to develop a technology for producing smart textiles incorporating polymer optical fibers and a membrane layer.

To achieve this aim, the following objectives were established:

- to conduct a comprehensive review of the current state of research and technological developments in smart textiles incorporating polymer optical fibers (POFs) and polymer membrane layers;
- to select and substantiate methods for the fabrication and characterization of knitted fabrics incorporating POFs;
- to investigate and justify a method for producing polymer-textile materials (PTMs) with membrane properties;
- to develop a technology for the formation of polymer membrane layers;
- to apply a second-order experimental design (Box-Hunter design) to predict the waterproofness and water absorption of PTMs.

Research Objects

The research objects include woven and knitted fabrics manufactured from cotton, polyester, and cotton-polyester yarns; polymer optical fiber in the form of a

smooth-surfaced monofilament; and an acrylic emulsion consisting of a 40% aqueous polymethyl acrylate (PMA) emulsion of white or light milky color, manufactured by JSC Navoiyazot (Republic of Uzbekistan).

Research Subject

The research focuses on the fabrication, composition, structure, physical, mechanical, and hygienic properties of knitted fabrics incorporating polymer optical fibers, as well as polymer-textile materials with membrane functionality.

Scientific Novelty of the Research

The scientific novelty of this research lies in the development of improved and practical technologies for manufacturing smart textile materials based on polymer optical fibers (POFs), as well as polymer-textile materials (PTMs) with membrane properties. The main scientific contributions of the study are as follows:

- the concept of smart textiles as multifunctional materials has been experimentally validated;
- the technological parameters for producing knitted fabrics incorporating polymer optical fibers as inlay yarns have been determined;
- scientific principles for the fabrication of waterproof, water-absorbing, air-permeable, and water vapor-permeable polymer-textile materials with predetermined properties have been established;
- scientifically substantiated technologies for producing a new generation of smart textile materials with enhanced functionality have been developed.

Practical Significance of the Research

The practical significance of the research lies in imparting enhanced functional properties to polymer-textile materials (PTMs):

- the incorporation of polymer optical fibers (POFs) as inlay yarns into knitted fabrics provides high tensile strength, improved abrasion resistance, and light-reflective properties;
- the polymer-textile membrane material based on an acrylic emulsion and terry cotton fabric exhibits high water absorption, high waterproofness in the case of the single-sided terry fabric and moderate waterproofness in the case of the double-sided terry fabric, while maintaining a well-balanced combination of high air permeability and water vapor permeability.

Main Provisions Submitted for Defense

- the technology for producing knitted fabrics incorporating polymer optical fibers (POFs) as inlay yarns, providing enhanced mechanical strength;
- the technology for producing membrane polymer-textile materials and the method for achieving a balanced combination of water absorption, waterproofness, air permeability, and water vapor permeability.

Main Research Findings

The comprehensive study yielded the following results:

1. Knitted fabrics incorporating polymer optical fibers (POFs) in the form of polymethyl methacrylate (PMMA) monofilaments were successfully produced. The most practical method for integrating polymer optical fibers into the fabric structure was found to be their insertion into the knitted courses as inlay yarns.

2. The relatively large diameter and limited elasticity of the polymer monofilament hinder the loop-forming process; therefore, fabric production requires careful selection of the fabric design, knitting parameters, and knitting needles. Plain and plush knitted fabrics were produced in which the polymer optical fiber participated in loop formation together with cotton yarn. The resulting fabrics exhibited high tensile strength, excellent abrasion resistance, and light-reflective properties.

3. Spray coating of textile substrates with an acrylic polymethyl acrylate (PMA) emulsion provides a simple and effective method for producing waterproof, air-permeable, and functional polymer-textile materials. The PMA content in the resulting composites ranged from 8 to 15 wt.%. The functional performance of the materials was found to depend on the fiber type, fabric structure, and the number of polymer coating layers.

4. During the modification process, PMA macromolecules penetrate the porous structure of cotton fibers, forming a stable network of intermolecular interactions. These interactions include hydrogen bonding between the ester groups of PMA and the hydroxyl groups of cellulose, together with partial physical anchoring of the polymer within the microfibrillar structure of the fibers. As a result, a quasi-homogeneous interpolymer system is formed, in which thermal degradation proceeds cooperatively rather than independently. In polyester fabrics, the intimate contact between PMA and the fibers leads to the formation of a two-phase system, where degradation occurs through the combined decomposition of the polyester and acrylic phases, accompanied by increased enthalpy and greater overall mass loss.

5. The morphology of the inner surface of terry cotton fabrics remained virtually unchanged after emulsion application. The hydrophilic terry pile absorbed a substantial amount of water, while a microporous hydrophobic polymer layer on the reverse side retained the absorbed moisture (water contact angle: 135-140°). The pore size of this layer prevented the penetration of liquid water (water resistance: 400-450 mm H_2O), while allowing the passage of air (air permeability: 1.5-3.0 $m^3/(m^2 \cdot s)$) and water vapor (water vapor permeability: 150-500 $g/(m^2 \cdot h)$), thereby producing the desired membrane effect. These findings were confirmed by scanning electron microscopy (SEM).

6. For practical applications, the choice of fabric can be tailored to the required performance characteristics. Double-sided terry cotton fabrics are recommended where high water absorption, moderate water resistance, and high air and water vapor permeability are required. Single-sided terry cotton fabrics are preferable for applications requiring high water resistance, moderate moisture absorption, and the retention of good air permeability.

Description of the Doctoral Candidate's Contribution to the Publications

The doctoral candidate made a direct contribution to the preparation of the publications through active participation in the design and implementation of the research, including the fabrication of knitted fabrics incorporating polymer optical fibers, the development of the structure and composition of polymer-textile

materials with membrane functionality, and the investigation of their physical, mechanical, and hygienic properties. Together with the academic supervisors, the doctoral candidate participated in the analysis and interpretation of the experimental data, the synthesis of the research findings, and the preparation of the manuscripts for the following publications:

1. Nargiza Atashikova, Vladimir Solgalov, Abdugani Azimov (2025). Use of Polymer Optical Fibers to Determine Friction and Pressure in Special Clothes. The Journal of The Textile Institute, 116(12), 2953-2962. https://doi.org/10.1080/00405000.2025.2468525. Scopus: Q2 (57rd percentile); Web of Science (SCIE): Q2.

2. N.A. Atashikova, A.S. Rafikov, D.O. Abdusamatova, M.X. Shirinova, A.M. Azimov, N.Y. Botabayev. Analysis of Waterproof "Breathable" Functional Polymer-Textile Materials Based on Acrylic Emulsion and Various Types of Fabrics. Polymer Engineering & Science, 66(5), 3799-3813 (2026). https://doi.org/10.1002/pen.70468. Scopus: Q1 (80th percentile); Web of Science (SCIE): Q2.

3. N.A. Atashikova, A.S. Rafikov, K.Z. Yunusov, E. Ramazan, A.M. Azimov. Modification of Knitted Fabrics Using Polymer Optical Fibers in Smart Textiles. Mechanics and Technologies, No. 91(1), 139-147 (2026), Taraz.

4. N.A. Atashikova, A.M. Azimov, N.Ye. Botabayev, B.B. Turakulov, D.S. Kadyrova. New Generation Textile Fibers. Bulletin of Science of South Kazakhstan, Special Issue. M. Auezov South Kazakhstan University Publishing House, Shymkent, 2024, pp. 568-570.

5. N.A. Atashikova, A.M. Azimov, A.S. Rafikov, N.Ye. Botabayev, D.S. Kadyrova. Smart Textiles as a Modern Development Trend. Bulletin of Science of South Kazakhstan, Special Issue. M. Auezov South Kazakhstan University Publishing House, Shymkent, 2024, pp. 8-10.

6. Gulnoza A. Jurayeva, Nargis R. Kadirova, Nargiza A. Atashikova, Adham S. Rafikov. Biochemical Modification of Leather-Containing Waste for Paper and Cardboard Production. Proceedings of XI International Annual Conference "Industrial Technologies and Engineering" (ICITE-2024), 14-15 November 2024, Shymkent, Kazakhstan.

7. Nargiza A. Atashikova, Kamola S. Fayzullayeva, Dilfuza O. Abdusamatova, Adham S. Rafikov, Abdugani M. Azimov. Biochemical and Waterproof Modification of Textile Materials. Proceedings of XI International Annual Conference "Industrial Technologies and Engineering" (ICITE-2024), 14-15 November 2024, Shymkent, Kazakhstan.

8. D.O. Abdusamatova, N.A. Atashikova, M.X. Shirinova, F.U. Nigmatova. Preparation and Properties of Waterproof Composite Laminated Materials with Membrane Properties for Medical Bed Sheets. Proceedings of International Scientific and Technical Conference "Innovations in Textiles, Clothing and Footwear (ICTAI-2025)", dedicated to the 60th anniversary of Vitebsk State Technological University, 18-19 November 2025, Vitebsk, Belarus.

Keywords: smart textiles, intelligent textiles, polymer optical fibers, membrane materials, functional textiles, innovative technologies, textile materials, optical sensors.

Structure and Scope of the Dissertation

The dissertation comprises 110 pages, including 11 tables, 32 figures, and appendices. It consists of a list of normative references, terms and definitions, symbols and abbreviations, an introduction, four chapters, conclusions, and a bibliography containing 107 references.