

PREĐA KAO POROZNI FUNKCIONALNI MEDIJUM: POVEZIVANJE STRUKTURE, TRANSPORTA I EKOLOŠKIH PERFORMANSI

Professional paper
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APSTRAKT: Pređa se tradicionalno posmatra kao strukturni element odgovoran za mehaničku koheziju u tekstilnim sistemima. Međutim, savremena istraživanja pokazuju da se pređa ponaša kao složen porozni funkcionalni medijum sposoban za transport vlage, toplote i hemijskih supstanci, uz istovremenu interakciju sa okolinom. Ovaj pregled analizira pređu kroz integrisani okvir koji povezuje strukturu, transportne fenomene i ekološke performanse. Strukturni parametri kao što su pakovanje vlakana, uvoj i površinska morfologija povezani su sa arhitekturom pora i propustljivošću. Transportni mehanizmi, uključujući kapilarni tok i difuziju, razmatraju se zajedno sa primenama u oblasti filtracije, apsorpcije zagađivača i pametnih reaktivnih sistema. Poseban naglasak stavljen je na ulogu naprednih analitičkih alata, posebno obrade slike i veštačke inteligencije, u prediktivnom dizajnu pređe.

Cljučne reči: Pređa, poroznost, transport, funkcionalni tekstili, održivost

YARN AS A POROUS FUNCTIONAL MEDIUM: LINKING STRUCTURE, TRANSPORT AND ENVIRONMENTAL PERFORMANCE

ABSTRACT: Yarn has traditionally been considered a structural element responsible for mechanical cohesion in textile systems. However, recent studies demonstrate that yarn behaves as a complex porous functional medium capable of transporting moisture, heat, and chemical species while interacting with its environment. This review analyzes yarn through an integrated framework linking structure, transport phenomena, and environmental performance. Structural parameters such as fiber packing, twist, and surface morphology are correlated with pore architecture and permeability. Transport mechanisms, including capillary flow and diffusion, are discussed alongside environmental applications such as filtration, pollutant absorption, and smart responsive systems. The role of advanced analytical tools, particularly image processing and artificial intelligence, is emphasized in predictive yarn design.

Keywords: Yarn, porosity, transport, functional textile, sustainability

1. INTRODUCTION

Yarn has traditionally been considered a structural element in textile systems, primarily responsible for mechanical integrity. However, increasing demands for functional and sustainable textiles have shifted attention toward understanding yarn as a porous and reactive system [1–3].

The internal structure of yarn consists of interconnected voids formed by fiber arrangement, twist, and surface morphology. These voids enable transport processes such as moisture movement and chemical diffusion, making yarn an active functional medium. Additionally, surface modifications of yarn, including oxidation and bio-functionalization, significantly influence its interaction with the environment [4-6].

The conceptual relationship between yarn structure, transport mechanisms, and environmental functionality is presented in Figure 1, where yarn is positioned as a multifunctional porous system linking structure to performance.

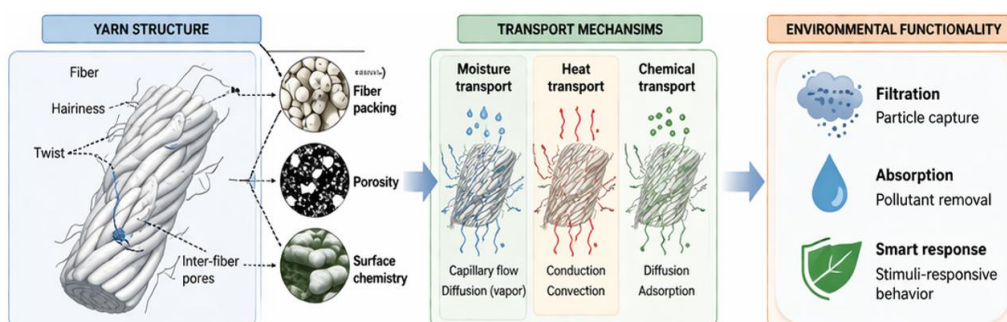


Figure 1: Conceptual framework linking yarn structure, transport mechanisms, and environmental functionality

2. STRUCTURAL CHARACTERISTICS AND POROSITY OF YARN

The porous structure of yarn is governed by fiber packing density, twist level, and surface morphology. Increased twist reduces pore size and limits permeability, while lower twist enhances porosity and fluid transport [2,7,8]. This balance between compaction and openness directly determines the efficiency of mass and heat transfer within the yarn system. Hairiness contributes to increased surface area and influences interactions with liquids and particles, particularly in absorption and filtration processes. Furthermore, chemical treatments such as selective and non-selective oxidation modify fiber surface properties and improve reactivity [4,5], while chitosan-based treatments introduce antimicrobial functionality and enhance adsorption capacity [6]. These modifications also alter wettability and interfacial energy, further affecting transport behavior. The hierarchical pore structure of yarn is illustrated in Figure 2, showing micro-, meso-, and macro-scale pores that collectively define permeability and functional behavior. The influence of structural parameters on yarn porosity and performance is summarized in Table 1, highlighting trade-offs between permeability, strength, durability, and surface reactivity.

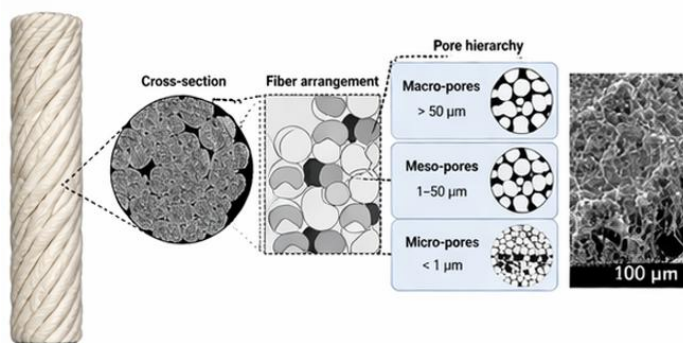


Figure 2: Schematic representation of yarn structure showing fiber arrangement and pore hierarchy

Tabela 1: Structural parameters influencing yarn porosity and functionality

Parameter	Effect on Porosity	Functional Impact
Twist level	Decrease pore size	Reduces permeability
Fiber packing density	Decreases void fraction	increases strength
Hairiness	Increases surface area	Enhance absorption
Surface modification	Alters pore chemistry	Improves reactivity

3. TRANSPORT MECHANISMS IN YARN

Transport processes in yarn are governed by its porous architecture and fiber properties. Moisture transport occurs through absorption, capillary flow, and diffusion [9-11].

Capillary action is driven by surface tension and pore geometry, enabling directional liquid movement along inter-fiber channels [12]. Diffusion governs vapor and chemical transport and depends on porosity, tortuosity, and environmental conditions.

These combined mechanisms are illustrated in Figure 3, where fluid pathways within yarn are shown as interconnected transport channels.

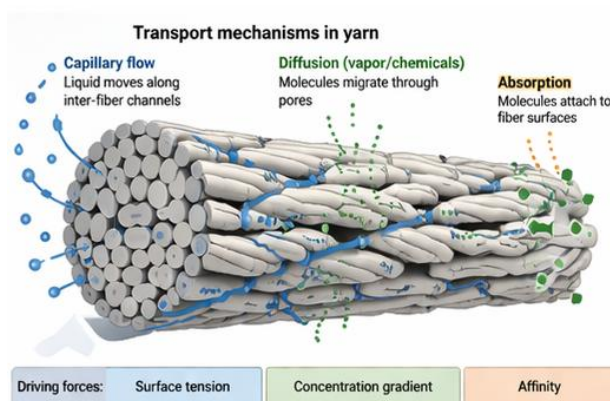


Figure 3: Mechanisms of moisture and mass transport in yarn

Surface treatments significantly influence transport behavior. Oxidized cotton yarns exhibit enhanced wettability and moisture absorption due to increased surface polarity [4, 5], while chitosan-functionalized yarns improve interaction with aqueous systems [6].

4. ENVIRONMENTAL AND FUNCTIONAL PERFORMANCE

The porous nature of yarn enables diverse environmental applications. Yarn structures can capture particles in filtration systems through interception and diffusion mechanisms [13,14].

Additionally, yarns can absorb pollutants such as heavy metals and organic compounds, particularly when functionalized with reactive groups [15]. Functionalized cotton yarns demonstrate enhanced antimicrobial and adsorption properties [6].

Durability remains a key factor influencing long-term performance. Studies have shown that repeated laundering significantly affects structural integrity and functional behavior of cotton textiles [16–18].

The relationship between structure and performance is illustrated in Figure 4, where porosity is directly linked to permeability, absorption, and mechanical strength.

A summary of key environmental functions of yarn systems is provided in Table 2, emphasizing their application potential.

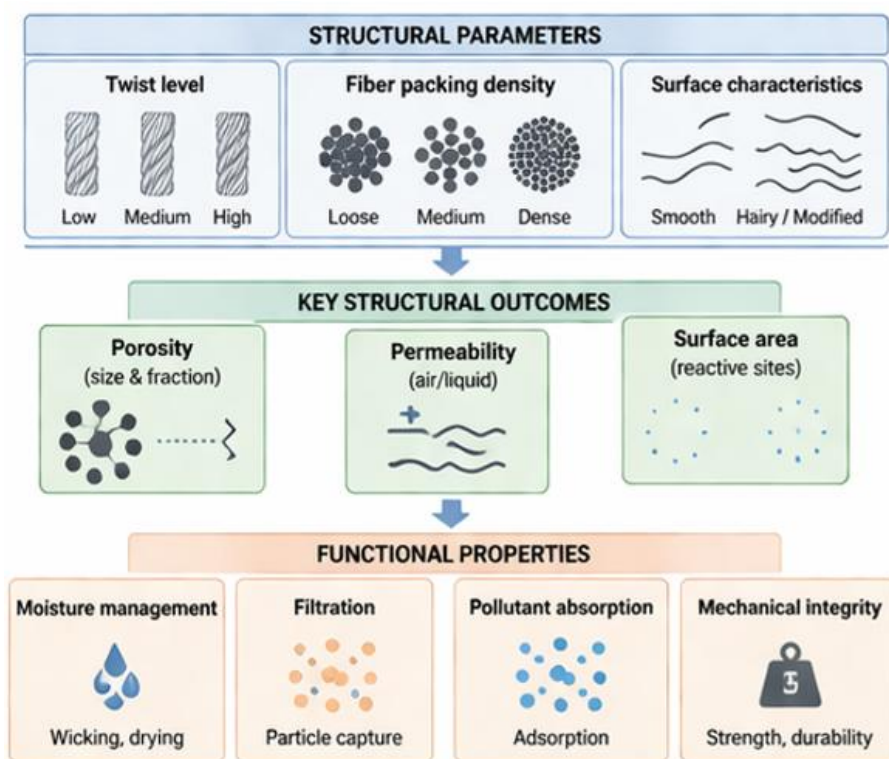


Figure 4: Structure-properties relationship in yarn

Tabela 2: Functional properties and structural drivers

Property	Structure Parameter	Application Impact
Filtration	Pore size distribution	Air and water purification
Absorption	Surface chemistry	Pollutant removal
Moisture transport	Capillary channels	Comfort textiles
Antimicrobial	Functional coatings	Medical textiles

5. ANALYTICAL AND AI-BASED APPROACHES

Advanced analytical techniques enable detailed characterization of yarn structure and performance. Image processing methods allow quantification of porosity, fiber orientation, and surface morphology. Recent studies have demonstrated the effectiveness of digital image-based approaches, including GLCM texture analysis and process parameter evaluation, for assessing structural irregularities and their influence on textile performance [19-21]. These methods provide rapid and non-destructive evaluation and contribute to the digitalization of textile characterization.

Artificial intelligence further enhances this capability by enabling predictive modeling of yarn properties. Machine learning models can integrate structural parameters and experimental data to optimize yarn design.

The integration of image processing and AI is presented in Figure 5, which illustrates the workflow from image acquisition to predictive modeling of yarn performance.

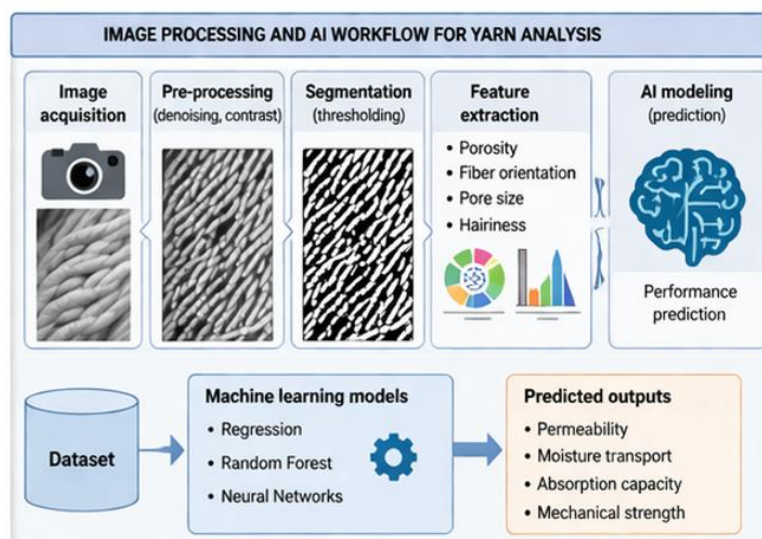


Figure 5: Workflow for yarn characterization using image processing and artificial intelligence

6. FUTURE TRENDS

Future yarn systems will focus on integrating functionality, sustainability, and intelligence. Smart yarns capable of sensing environmental changes will enable real-time monitoring and adaptive behavior, forming the basis of next-generation wearable and responsive textile systems [22].

Sustainable development will emphasize biodegradable fibers and bio-based surface modifications. However, challenges remain in balancing durability and environmental compatibility.

Artificial intelligence will play a central role in predictive material design, enabling the development of optimized yarn systems with multifunctional properties [23].

7. CONCLUSION

Yarn should be redefined as a porous functional medium rather than solely a structural element. Its internal architecture governs transport processes and enables environmental and smart functionalities.

The integration of structural analysis, transport modeling, and advanced analytical tools provides a comprehensive understanding of yarn behavior. Future developments will focus on smart, sustainable yarn systems capable of adaptive and high-performance functionality.

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