MATHEMATICAL MODELING AND ENHANCEMENT OF THE ECONOMIC EFFICIENCY OF HIGH-QUALITY COTTON–POLYESTER BLENDED YARN PRODUCTION TECHNOLOGY

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Abstract

This paper investigates the improvement of cotton–polyester blended yarn production technology through a comprehensive mathematical and mechanical analysis of the spinning process. The influence of key technological parameters on yarn quality is quantitatively described using mathematical models, and optimal control strategies are proposed to enhance production performance. Furthermore, the study highlights the novelty, practical significance, and economic benefits of the proposed technology for the textile industry of Uzbekistan. The developed mathematical framework provides a scientific basis for optimizing production processes, improving yarn quality, reducing manufacturing costs, and facilitating the digitalization and automation of modern textile enterprises.

Keywords: mathematical modeling, blended yarn, cotton fiber, polyester fiber, deformation, stress, optimization, spinning technology, economic efficiency.

Introduction

In today's highly competitive global textile industry, the production of high-quality, cost-effective, and functional textile products has become one of the primary objectives of manufacturers. Among the most promising technological approaches is the production of blended yarns by combining natural and synthetic fibers, thereby integrating the advantages of both materials within a single textile structure.

As one of the world's leading cotton-producing countries, Uzbekistan has identified the deep processing of domestic cotton fiber as a strategic priority for increasing value-added production and enhancing export competitiveness. Consequently, the incorporation of polyester fibers into cotton yarn manufacturing offers several significant advantages, including:

increasing the export potential of textile products;

reducing production costs;

improving the mechanical and performance characteristics of yarns;

expanding the share of high value-added textile products in both domestic and international markets.

The scientific novelty of this research lies in the fact that the technological processes are optimized not only through experimental investigations but also through comprehensive mathematical and mechanical modeling. Such an approach provides a theoretical foundation for intelligent process control, digital manufacturing, and the implementation of automated spinning technologies within modern textile enterprises.

1. Mechanical Model and Structural Analysis of Cotton–Polyester Blended Yarn

A cotton–polyester blended yarn can be considered a multi-component composite structure consisting of fibers possessing different mechanical and physical characteristics. The overall tensile strength of the blended yarn can therefore be expressed by the following relationship:

$$\sigma_{yarn} = V_c \sigma_c + V_p \sigma_p + \tau_{int}$$

Here:

V_c, V_p – volume (or mass) fractions of cotton and polyester fibers, respectively;

σ_c, σ_p – tensile strengths of cotton and polyester fibers;

τ_{int} – interfacial bonding strength between the constituent fibers.

This mathematical model demonstrates that the overall tensile strength of the blended yarn depends not only on the intrinsic properties of the individual fiber components but also on the quality of the interfacial interaction and adhesion between them.

2. Relationship Between Twist and Tensile Strength

During the spinning process, the tensile strength of the yarn is directly influenced by the twist level. This relationship can be expressed as:

$$T = k * \sqrt{a}$$

here:

T – yarn tensile strength;

a – twist coefficient (twist factor);

k – experimentally determined constant.

The tensile stress developed within the yarn is calculated using the fundamental stress equation:

$$\sigma = \frac{F}{A}$$

here:

σ – tensile stress;

F – applied tensile force;

A – cross-sectional area of the yarn.

This equation is employed to determine the stress corresponding to yarn failure during tensile testing.

3. Deformation and Elasticity Model

The elongation behavior of the blended yarn is described according to Hooke's law:

$$\sigma = E * \varepsilon$$

here:

E – Young's modulus (modulus of elasticity);

ε – engineering strain (relative elongation).

The effective elastic modulus of the cotton–polyester blended yarn can be estimated using the rule of mixtures:

$$E_{mix} = V_c E_c + V_p E_p$$

where E_c and E_c denote the elastic moduli of cotton and polyester fibers, respectively.

This model provides a reliable theoretical basis for evaluating the deformation resistance and elastic performance of blended yarn structures.

4. Optimization Model of Technological Parameters

The spinning process can be optimized through the following multi-objective optimization function:

$Z=\omega_1 S+ \omega_2 U+ \omega_3 H \rightarrow min$

here:

S – yarn strength (to be maximized);

U – yarn unevenness;

H – yarn hairiness;

Ω_i – weighting coefficients assigned to each quality parameter.

The proposed optimization model enables the determination of optimal technological operating conditions while simultaneously improving multiple yarn quality characteristics.

5. Novelty and Practical Significance for Uzbekistan

The textile industry of Uzbekistan has experienced rapid development over recent years, driven by government-supported modernization and value-added manufacturing initiatives. The implementation of cotton–polyester blended yarn technology offers several important advantages, including:

deeper processing of domestically produced cotton fiber;

production of import-substituting textile products;

transition toward modern Smart Factory manufacturing systems.

Furthermore, the integration of artificial intelligence into spinning production lines provides the following benefits:

reduction of human intervention;

improvement of product quality consistency;

enhanced process monitoring and automated decision-making;

increased production efficiency.

6. Economic Efficiency Model

The economic efficiency of the proposed technology can be evaluated using the following equation:

$$E = \frac{R-C}{C} * 100\%$$

here:

E – economic efficiency;

R – total revenue;

C – total production cost.

The implementation of cotton–polyester blended yarn production contributes to:

lower raw material consumption costs;

higher market value of textile products;

increased export profitability;

improved competitiveness in international textile markets.

7. Future Research Perspectives

Future research directions include:

development of digital spinning technologies;

real-time optimization using artificial intelligence algorithms;

utilization of environmentally friendly recycled polyester (rPET) fibers;

production of functional yarns reinforced with nanomaterial additives.

Conclusion

The mathematical and mechanical modeling of cotton–polyester blended yarn production technology provides a scientific foundation for improving yarn manufacturing processes and enhancing product quality.

The proposed methodology enables:

scientific optimization of yarn quality parameters;

improvement of production efficiency;

reduction of manufacturing costs;

enhancement of the economic competitiveness of Uzbekistan's textile industry.

Consequently, the implementation of this technology will:

increase the production of export-oriented textile products;

accelerate the technological modernization of the textile industry;

generate higher added value through advanced fiber processing technologies.

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