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SCIENTIFIC PRINCIPLES OF OPTICAL METHOD FOR DETERMINING THE SEMI-CYCLIC AND SINGLE-CYCLIC DEFORMATION OF TEXTILE YARNS

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ABSTRACT
The article elucidates the scientific foundations for determining the half- and full-cycle deformation of textile yarns using optical methods. The study analyzed the advantages of optical measurements over traditional mechanical techniques in terms of accuracy and non-contact operation. Using a device developed based on Digital Image Correlation (DIC) technology, the tensile, relaxation, and elastic properties of yarns were investigated. Experimental results demonstrated that the optical method allows high-precision, real-time monitoring of the deformation process. This approach holds significant importance for evaluating the quality of textile products and optimizing production processes.
Keywords: textile yarn, deformation, optical measurement, half- and full-cycle loading, elasticity, relaxation, DIC.

Introduction

In the textile industry, determining the mechanical properties of yarns is one of the most critical factors influencing product quality. In particular, studying the half- and full-cycle deformation behavior of yarns allows assessment of their tensile, elastic, and relaxation characteristics, thereby providing insight into the durability and operational stability of textile products. Recent research in this area has shown that conventional mechanical testing methods (such as tensile testing and dynamic mechanical analyzers) are limited in terms of measurement accuracy and repeatability [1].

Consequently, the application of optical measurement techniques, particularly Digital Image Correlation (DIC) technology, has emerged as a relevant scientific approach for non-contact, high-precision evaluation of yarn deformation properties [2]. This approach enables real-time monitoring of deformation processes, analysis of the mechanical state of yarns, and digital processing of measurement data.

The development of an optical measurement device allows for highly accurate determination of yarn deformation under half- and full-cycle loading, providing a new scientific basis for predicting the quality of textile products. The results of this research are practically significant for improving energy and raw material efficiency in production processes, as well as enhancing the mechanical stability of products [3].

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This study focuses on developing both the theoretical and practical foundations for measuring the deformation properties of textile yarns using optical methods, and on improving measurement accuracy through the refinement of existing testing equipment.

Materials and Methods

The experimental study was conducted using 100% cotton yarns of 20/1 Ne count. Each yarn sample was prepared with a length of 50 cm and tested under standard microclimatic conditions—23 ± 2 °C temperature and 65 ± 5% relative humidity—to ensure measurement accuracy [4].

For the optical determination of deformation, an advanced optical measurement device was developed. The system comprises a high-precision digital camera (120 fps), an automated clamping mechanism, a stable LED illumination module, and the "YarnDeform" software suite for image analysis. The setup operates based on the principle of Digital Image Correlation (DIC) [5].

In the optical measurement method, yarn elongation was recorded over time, and the initial (x, y) and deformed (x′, y′) coordinates of each point were determined. The degree of deformation was calculated using the following expression:

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L_t - L_0}{L_0},$$

Here, L_0 -is the initial length, and L_t -is the elongated length at a given time. The relationship between stress and strain is expressed using Young's modulus:

$\sigma = E \cdot \varepsilon$,

Here, E is the material's modulus of elasticity, and σ is the stress.

The experiment was conducted under two types of loading cycles: half-cycle ($0 \to F_{max} \backslash 2 \to 0$) and full-cycle ($0 \to F_{max} \to 0$) loading. During each cycle, the deformation behavior of the yarn over time was recorded, and the obtained data were digitally analyzed using the "YarnDeform" software. As a result, a time-dependent deformation curve was constructed, enabling real-time observation of the yarn's elongation and recovery processes [6].

The Maxwell model was adopted as the basis for evaluating the relaxation process. According to this model, the time-dependent variation of stress in the yarn is described by the following equation:

$$\frac{d_\varepsilon}{d_t} = \frac{1}{E}\frac{d_\sigma}{d_t} + \frac{\sigma}{\eta}$$

Here, η-is the viscosity coefficient. The relaxation time is determined using the expression $\tau = \eta / E$ This parameter allows evaluation of the rate at which the yarn returns to its initial state after loading.

The obtained experimental data were processed using mathematical analysis, and through regression analysis, the relationship between deformation and load was expressed in the following equation:

$\varepsilon = a + bF + cF^2$,

Here, a,b,ca, b, ca,b,c are empirical coefficients, and F-is the applied force. Using this approach, the deformation properties of the yarns were determined, and their mechanical behavior under half- and full-cycle loading was represented both mathematically and graphically [7].

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The results of the study demonstrated that the optical measurement method enables high-precision recording of deformation, providing a solid scientific basis for in-depth analysis of the mechanical properties of textile yarns and for optimizing production processes.

Conclusion

According to the study results, the determination of half- and full-cycle deformation of textile yarns using optical methods was found to be more accurate and reliable compared to conventional mechanical techniques. Using the improved optical device, yarn elongation, elasticity, and relaxation processes were monitored in real time. Mathematical analysis based on the Maxwell model allowed precise characterization of the yarns' deformation behavior. This method is recommended as an effective scientific approach for evaluating yarn quality and optimizing textile manufacturing processes.

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