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THEORETICAL AND INSTRUMENTAL ASSESSMENT OF COTTON FIBER CHARACTERISTICS

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Abstract: The article examines the prospects for manufacturing competitive products in the textile industry and modern methods for evaluating yarn quality. A comparative analysis of the methods by A.N. Solovyov and L. Van Langenhove in determining yarn strength is conducted, emphasizing the importance of yarn structure and fiber elasticity modulus. The research results enable the instrumental assessment and prediction of the mechanical properties of yarns spun through various methods. The research provides a detailed overview of the technical specifications of the world-class USTER HVI 1000 system, its modular structure, and its significance in determining the physical and mechanical properties of cotton fiber.

Keywords: Textile industry, yarn strength, yarn structure, young's modulus, ring spinning, instrumental method, USTER HVI 1000, quality parameters, micronaire, staple length, strength, calibration.

Today, processing cotton raw materials to manufacture competitive finished products constitutes one of the key strategic priorities for advancing the national economy. In accordance with Decree No. UP-60 of the President of the Republic of Uzbekistan dated January 28, 2022, and based on the principle 'From the Action Strategy to the Development Strategy', the Development Strategy of New Uzbekistan for 2022–2026 was formulated across seven priority areas. This strategy focuses on sustaining an industrial policy aimed at ensuring macroeconomic stability and increasing the share of industry in the Gross Domestic Product (GDP), while establishing justice and the rule of law as foundational prerequisites for national development. Furthermore, by advancing the chemical and petrochemical sectors and increasing the gas-processing depth from 8% to 20%, the chemical industry aims to reach a production output valued at 2 billion USD. Concurrently, comprehensive measures are being implemented to double the production volume of the textile industry [1].

In practice, the efficiency of spinning methods and equipment is determined by yarn quality parameters. It is universally acknowledged by researchers that yarn quality metrics are categorized into end-use (functional) and technological properties, both of which are intrinsically dependent on the yarn structure. To evaluate these quality indicators, specialized methodologies have been developed and implemented in the industry. These primarily include the organoleptic method, computational (theoretical) modeling, and the micro-sampling (experimental) approach [2].

In the organoleptic method, the visual appearance of the yarn is evaluated by quantifying thick and thin places, as well as various structural defects. The quality grade of the yarn is subsequently determined by comparing these results with established standard reference samples or regulatory specifications [3].

In practice, cotton yarn is wound onto a black inspection board to determine its grade and assign appropriate quality ratings using specialized reference standards. In developed nations, the visual appearance of yarn remains a critical quality indicator and receives significant emphasis. Consequently, foreign experts operating within joint ventures assess yarn quality primarily based on its visual characteristics.

However, rapid advancements in engineering and technology have necessitated swift and objective evaluations of yarn appearance, driving the development and adoption of instrumental methods. Beyond visual characteristics, another critical quality parameters of yarn is its tensile properties, specifically its tensile strength [4].

This parameter is incorporated into all regulatory and technical documentation. It depends on yarn linear density, the number of fibers in the yarn cross-section, fiber fineness and length variations, fiber length non-uniformity, yarn twist, and the technical condition of the spinning machinery. Considering these factors, numerous researchers have conducted extensive studies to theoretically determine yarn strength, resulting in several empirical formulas recommended for various fiber types. Since the yarn breaking tenacity is determined via mathematical equations, this approach is classified as the computational method. In this method, yarn quality parameters are primarily evaluated based on raw fiber properties [5].

Research indicates that computational formulas developed by A.N. Solovyov for cotton yarn, V.A. Usenko for viscose yarn, V.G. Komarov for flax yarn, and A.A. Sinitsyn for wool yarn remain in practical use to date. Because ring spinning was the exclusive commercial technology available when these equations were formulated, they were validated and recommended specifically for ring-spun yarns. Concurrently, the subsequent development and industrial implementation of novel spinning technologies have led to the emergence of yarns with diverse structural configurations. Applying these existing empirical equations to alternative spinning systems demonstrated that these strength-prediction formulas are highly accurate only for ring-spun yarns and prove inadequate for other types. This limitation arises because the formulas do not account for the specific dynamics of the spinning process and the resulting yarn structural characteristics. Although various correction factors were proposed to adapt these equations, they failed to yield reliable results and were not widely adopted. Contrasting with traditional approaches and explicitly accounting for yarn structure, Professor L. Van Langenhove of Ghent University (Belgium) developed a computational method to predict yarn strength based on fiber spatial orientation, offering several critical recommendations. According to her methodology, calculating yarn strength requires incorporating the fiber elastic modulus, Poisson's ratios, and the shear modulus. In other words, fiber strength should not merely be defined as resistance to a breaking force; instead, it must incorporate elasticity—a parameter that accounts for internal stress during fiber deformation. Despite the inherent complexity of this methodology, it provides highly precise results, as sophisticated, high-precision instrumentation is utilized to determine the elastic modulus for specific fibers and yarns. In accordance with end-user requirements, this method evaluates yarn strength via the elastic modulus (Young‘s modulus) at fiber deformations of up to 1%.

The HVI 1000 is a high-volume instrument developed by the world-renowned USTER company. Commonly known as the USTER HVI 1000, it measures the most critical cotton fiber properties for classification purposes. This system serves as a globally standardized analytical tool for cotton grading, delivering accurate and reliable results. Its development is backed by over 60 years of worldwide fiber testing experience and more than 30 years of expertise in cotton classification.

The HVI 1000 SA system consists of two primary hardware sections: the larger section, which houses the length/strength module, and the smaller section, which contains the color/trash and micronaire modules. The system configuration includes an alphanumeric keyboard, a monitor, and a precision balance. Measurement results are displayed on the monitor and, upon completion of the testing cycle, are transmitted to a printer or an external computer database. The system comprises the following specific measurement modules: the length/strength module, the micronaire module, and the color/trash module. Depending on analytical requirements, individual modules can be operated independently to determine specific parameters, or the integrated system can be utilized to evaluate the comprehensive quality profile, including: cotton fiber grade and class, reflectance coefficient (Rd, %), yellowness degree (+b), micronaire value, staple length, length uniformity index, specific breaking tenacity, and elongation at break.

The HVI system must be operated under standard atmospheric conditions: an ambient temperature of (21±1)°C and a relative humidity of (65±2)%, monitored via an Assmann psychrometer with a 0.1°C scale graduation or equivalent high-precision climate-monitoring instrumentation. According to the O‘zRSt 614-2009 standard, the samples selected for testing must possess a moisture mass fraction between 6.75% and 8.25%. To achieve the required moisture level prior to evaluation, samples must either be processed using a specialized rapid conditioning unit or conditioned under the specified standard atmospheric conditions for 24 hours. Before determining cotton fiber quality, the HVI 1000 system must be calibrated using standard reference cotton calibration samples in strict compliance with the manufacturer's operational manual. Calibration refers to verifying and adjusting the measurement accuracy of the instrumentation against established standard references. It is highly recommended to perform calibration twice a day: prior to commencing shifts and subsequently every 4 to 5 operating hours. Because ambient air parameters significantly influence fiber properties, the standard calibration cotton samples must also be stored under identical standard atmospheric conditions.

Currently, to achieve the yarn parameters mutually agreed upon by spinning, weaving, and knitting mills, spinning enterprises have established normative technical requirements for raw materials customized for both weaving and knitting yarn production. Below, Table 1 presents the data regarding cotton fiber quality profiles obtained using the USTER HVI system.

Table 1

Cotton Fiber Quality Parameters obtained on the “USTER HVI” System

№	Quality indicator	Designation	Unit of measurement
1	Spinning Consistency Index	Spinning Consistency Index – (SCI)	-
2	Mikroneyr	Micronaire – (Micronaire)	-
3	Maturity Index	Mat	-
4	Upper Half Mean Length	UHML	mm
5	Length Uniformity Index	Uniformity Index – (UI – Unit:%)	%
6	Short Fiber Index (SFI)	Short Fiber Index – (SFI)	%
7	Fiber Strength	Bundle Strengh, - (StrenghUnit:gf/tex)	g/teks
8	Elongation at Break	Elongation –(Elg, %)	%
9	Reflectance Degree	Reflectance – (Rd, Unit:%)	%
10	Yellowness	Degree of yellowness – (+b)	%
11	Trash Content	Trash	-

Based on the research findings, it can be concluded that raw material classification using the USTER HVI 1000 system in accordance with global standards is crucial for manufacturing competitive products within Uzbekistan's cotton-textile clusters. Implementing this innovative technology acts as a primary mechanism for optimizing the Spinning Consistency Index (SCI) in spinning enterprises and enhancing the export potential of finished goods. Consequently, implementing quality control via the HVI system guarantees the rational use of raw materials and ensures the technological efficiency of the textile industry.

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