**Improving Yarn and Fabric Production from Blended Fibers and Secondary Materials**

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**Abstract.** The aim of the research was to improve the technology for producing yarn intended for fabrics used in special clothing. The study objects included yarn obtained from a mixture of cotton and secondary fibers, fabrics, and the testing equipment used to evaluate their quality. As practical results and conclusions of the study, an improved technology was developed and experimentally tested to reduce yarn unevenness based on emulsification. The technology for producing yarn for special clothing fabrics was enhanced by twisting yarns obtained from fibers of various compositions, including recycled fibers. Low-cost, weaving-suitable yarns produced from secondary material resources generated in the sewing and knitwear industry, as well as fabrics intended for special clothing were developed. The technology for producing yarn from a mixture of cotton and secondary fibers and the corresponding fabrics for special clothing was improved, and their quality indicators were determined in accordance with national standards.

**Keywords:**Cotton, secondary material resources, polyacrylamide, emulsion, fabrics made from various amounts of secondary raw materials, technology, yarn from a mixture of secondary fibers, collagen.

**INTRODUCTION**

The application of energy- and resource-efficient new techniques and technologies in the recycling of secondary material resources from the global textile and knitwear industry occupies a leading position. Worldwide, secondary material resources generated from the textile and knitwear industry account for approximately 25% of the total raw materials. Furthermore, due to the advancement of scientific and technological progress and the expansion of product assortments, the volume of secondary material resources is steadily increasing. This necessitates the implementation of technological processes in the rational use of secondary materials. In this regard, the effective utilization of the technological capabilities of equipment and machinery in improving technological processes is of paramount importance [1].

Scientific research is being conducted globally to develop resource-efficient technologies and technical solutions aimed at the effective use of textile industry raw materials and the creation of a competitive textile industry. Particular attention is paid to developing technologies for the efficient use of secondary material resources, saving energy and materials, and producing finished products from recovered raw materials, as well as to substantiating technological processes, parameters, and operating modes [2].

In Uzbekistan, extensive measures are being implemented to develop resource-saving equipment and technologies that allow the expansion of the range of specialized clothing fabrics, reduction of labor and energy consumption, conservation of resources, and effective use of various fibers, achieving certain results [3].

The implementation of these objectives, including the production of new assortments of specialized clothing fabrics based on the effective use of secondary material resources from yarns, requires the creation of technically and technologically modernized machines. Globally, the increase in living standards is achieved through the exponential growth of gross products and the consumption of non-renewable natural resources. Urgent measures are required to reduce the consumption of non-renewable resources and environmental pollution [5].

In Uzbekistan, introducing new technological methods and technologies, improving existing methods and devices, and involving material and raw resources in the maximum production of consumer goods are of great importance for recycling secondary material resources in the sewing and knitwear industries [6].

Currently, all light industry enterprises generate textile waste. Such waste is produced in large volumes and is often not accepted by preparation and recycling enterprises, but rather sent for disposal, negatively impacting the country’s ecological state. Therefore, the effective use of textile waste in technological production processes constitutes a significant scientific and technical problem. In Uzbekistan, the volume of secondary material resources in the sewing and knitwear industry has been increasing sharply. Over the past five years, enterprises processing these secondary material resources have been established, primarily for technical purposes [7].

**METHODS**

The quality of textile materials and products largely depends on the efficiency of fiber processing. Cotton fiber has a hollow-channel structure with walls composed of several layers. The outer layer, known as the primary layer, is 1 μm thick and has a mesh-like structure consisting of pectic substances. The second, main layer is thicker, ranging from 6 to 8 μm in mature fibers. Various literature sources provide different explanations regarding the structure of fibers. Since cotton fibers consist of 95% cellulose, their surface is hydrophobic, which makes it more difficult for yarns to absorb moisture.

The hydrophobicity of cotton fiber is associated with the presence of a thin cuticle layer of wax on its surface. During processing, fibers undergo mechanical stresses that may cause breakage, fraying, or other types of damage. These defects often occur due to insufficient moisture and damage to the fiber’s outer layer. To restore cotton fibers from such losses, it is necessary to take all measures to emulsify the fibrous mass. Emulsification restores the fibers’ specific flexibility and elasticity. Additionally, this process reduces the amount of lint produced and improves moisture retention. Typically, emulsions are prepared based on oily substances. Observations indicate that the oily substances are mostly dispersed in small droplets, the size of which corresponds to the cross-sectional dimensions of the fibers.

The unique characteristics of fibers, as well as interacting factors such as normal pressure, humidity, air temperature and moisture, emulsion type, properties, concentration, and other variables, play a critical role. Various studies have examined the relationship between fibers’ electrical resistance and relative electric charge with moisture content. According to one such study, when the conditional moisture content of cotton fiber is 6–8% and the relative humidity is 75%, electrical charge-related difficulties arise during processing.

In the initial stage of cotton raw material processing, researchers have proposed a three-component aqueous emulsion consisting of water, a surfactant, water-soluble glycol, and water-soluble polymer. The use of polymer, polyhydric alcohols, and surfactant solution mixtures improves the technological properties of cotton fibers and allows for the reprocessing of yarn at various spinning stages.

Currently, surfactants are increasingly used for emulsification. Studies on the effect of emulsions on the physical-mechanical properties of cotton fiber show that a reduction in the emulsion content decreases the fiber’s breaking strength due to lower emulsion penetration into the fibers. In recent years, due to the introduction of technologies that efficiently maintain fiber moisture, spinning enterprises have paid less attention to cotton fiber emulsification. However, restoring the properties lost in cotton fibers during mechanical processing of waste is still rarely applied.

The production of yarn from fibers and secondary material resource mixtures was carried out in the following sequence:

At the “OYGUL PLYUS” LLC enterprise in Bukhara, knitted scraps were reprocessed using the following technological process. Samples were taken from carded fibers produced by the FA-233 carding machine from mixtures of knitted scraps of various compositions and treated with emulsions of different types (see Fig. 1).

The emulsion composition included collagen, polyacrylamide, glycerin, and distilled water. Collagen is an essential protein that forms the basis of textile structures, keeping fibers intact. The name “collagen” comes from the Greek word *kolla*, meaning glue. Collagen ensures the smoothness, tension, and elasticity of the fibers. Collagen molecules often form long and thin protein fibers that align side by side. They act like a spring, holding fiber structures together while providing strong inter-fiber connections.

Polyacrylamide [-CH2CH(CONH2)-]n is a polymer of acrylamide. It is a solid, amorphous, white or partially transparent crystalline substance, odorless. It dissolves in water, morpholine, formamide, glycerin, ethylene glycol, ice acetic acid, propionic acid, dimethyl sulfoxide, and propylene glycol. It does not dissolve in alcoholic beverages or ketones.

Polyacrylamide and acrylamide copolymers act as effective flocculants, measurement additives, flotation reagents, dispersants, thickening agents, hydrodynamic drag reducers, soil conditioners, and more.

Glycerin has osmotic, lubricating, and moisturizing effects. When applied to fibers, it wets and softens them. Its effect peaks after 1–1.5 hours and lasts 4–5 hours.

Industrial fabric cutting machine

**Fiber opening and tearing machine**

CH mixing bunker

10-section fiber opening and tearing machine

**Pressing process**i

FA-008B bale loosening machine

**FA-100 fiber cleaning and mixing machine**

JSB-102 fiber cleaning and mixing machine

FA-025 fiber mixing machine

FA-106 fiber mixing machine

**SFA‑201 8‑bin fiber mixing machine**

JFA‑226 carding machine

TMFD‑81 pilta‑forming machine, first pass

**FIGURE 1.** Technological process of reprocessing knitted scraps.

The emulsion was prepared in two variants and applied to the reprocessed fiber webs, which were left at room temperature for one day:

Variant 1: 10% – 50 mL collagen, 0.5% – 20 mL polyacrylamide [-CH2CH(CONH2)-]n, 5 mL glycerin, and 925 mL distilled water. Variant 2**:** 10% – 75 mL collagen, 0.5% – 20 mL polyacrylamide [-CH2CH(CONH2)-]n, 5 mL glycerin, and 900 mL distilled water.

The webs treated with the emulsion were processed at the Laboratory of “Spinning Technology” at Tashkent Institute of Textile and Light Industry. Using the HSR-1000 carding machine, six webs of 5 ktex linear density were combined, then fed into a pneumo-mechanical spinning machine to produce 29.4 tex yarn with a twist of 900–1000 turns per meter.

**RESULTS AND DISCUSSION**

Of the six webs on the HSR-1000 carding machine, four belonged to An-Bayaut-2 selection, type II, medium grade cotton fibers, and the remaining two were 100% secondary material resources. The quality characteristics of the cotton fibers are presented in Table 1.

**TABLE 1.** Quality Indicators of Cotton Fiber

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Type** | **Linear Density, mtex** | **Breaking Force, cN** | **Specific Breaking Force, cN/tex** | **Elongation at Break, %** | **Upper Half Mean Length, mm** | **Length Uniformity Index, %** |
| V | 183 | 5.38 | 29.42 | 11.65 | 27.41 | 85.60 |

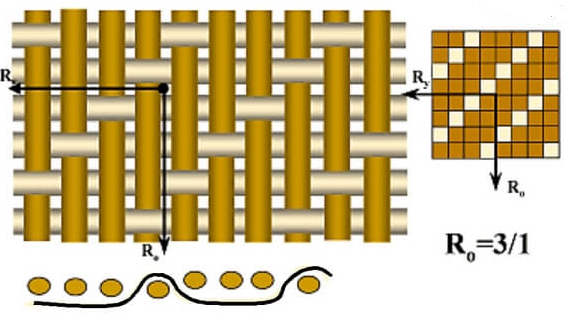
The quality indicators of the secondary material resources are shown in Table 2.

The yarns obtained with a linear density of 29.4 tex were processed at the “AL-HAKIM PLYUS” LLC enterprise in Bukhara city on a Picanol-190 model weaving machine. The warp yarn consisted of 100% cotton fibers, while the weft yarn contained a mixture of secondary fibers. Using a twill weave, fabric was produced (see Fig.2).

The distinctive feature of twill woven materials is that diagonal lines appear on their front side. These diagonal lines usually run from the lower left to the upper right (right-hand twill), but sometimes they go from the lower right to the upper left (left-hand twill). Right-hand twill is more commonly used. The angle of the diagonal lines in the twill depends on the number of threads in the twill repeat, as well as the density of warp and weft yarns. If the density and thickness of the warp and weft yarns are the same, the angle of the twill lines is 45°.

**TABLE 2.** Quality indicators of cotton fiber

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Linear Density, mtex** | **Breaking Force, cN** | **Specific Breaking Force, cN/tex** | **Upper Half Mean Length mm** | **Staple Mass Length, mm** |
| 27.0% Viscose + 6.6% Nitron secondary fiber | | | | | |
| 1. | 165 | 3,4 | 20,6 | 22,8 | 24,8 |
| 27.0% Lavsan + 6.6% Nitron secondary fiber | | | | | |
| 2. | 171 | 3,7 | 21,6 | 23,5 | 25,4 |
| 27.0% Nitron + 6.6% Cotton secondary fiber | | | | | |
| 3. | 170 | 3,3 | 19,4 | 23,2 | 25,6 |
| 27.0% Lavsan + 6.6% Viscose secondary fiber | | | | | |
| 4. | 170 | 3,5 | 20,6 | 23,5 | 26,4 |
| 27.0% Viscose + 6.6% Lavsan secondary fiber | | | | | |
| 5. | 165 | 3,5 | 21,9 | 22,9 | 24,9 |
| 27.0% Cotton + 6.6% Viscose secondary fiber | | | | | |
| 6. | 168 | 3,2 | 19,0 | 23,0 | 27,2 |



**FIGURE 2.** Fabric with 3/1 twill weave.

Warp twills are designated as 2/1, 3/1, 4/1, and weft twills are designated as 1/2, 1/3, 1/4, and so on. Typically, silk warp and cotton or blended weft half-silk fabrics are woven in warp twill. Twill woven materials are soft and smooth, but their strength is lower compared to plain weave fabrics, and they are more stretchable along the diagonal direction.

Based on the results of the study, the following conventions were used when constructing graphs and histograms:

1. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% viscose fiber + 6.6% nitron fiber secondary material resources.

2. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% polyester fiber + 6.6% nitron fiber secondary material resources.

3. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% nitron fiber + 6.6% cotton fiber secondary material resources.

4. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% polyester fiber + 6.6% viscose fiber secondary material resources.

5. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% viscose fiber + 6.6% polyester fiber secondary material resources.

6. For the weft yarn: a mixture of 66.4% cotton fiber with 27.0% cotton fiber + 6.6% viscose fiber secondary material resources.

The physical and mechanical properties of yarns and fabrics obtained from different compositions of fibers and secondary material resources were determined.

Method for Determining the Quality Indicators of Yarns and Fabrics Obtained from Cotton and Secondary Fiber Blends.

Sampling of yarns with different compositions of cotton and secondary fibers was carried out according to the GOST 6611.0-83 standard. The sample selection from yarns was determined with a relative error of 2.5%.

The quality indicators of yarns with different cotton and secondary fiber compositions were determined using the Uster Tester-5 device at the “UZTEX TASHKENT” LLC enterprise.

The unevenness (irregularity) of yarns with varying cotton and secondary fiber content was measured using the KMS-10 device. The quality indicators of fabrics containing different amounts of secondary material resources in the sewing industry were determined according to GOST R 57877-2017.

Before determining the linear dimensions and mass of fabrics with varying secondary material content, the samples were conditioned for 24 hours in a climatic chamber under standard conditions according to GOST 10681-2017 . The density of warp and weft yarns of fabrics with different secondary material content was determined according to GOST 3812-2017.

To determine the density and tensile strength of fabrics containing varying amounts of secondary material resources, three samples were taken for the warp and four for the weft. The length of each sample was 50 mm. The average value obtained for each sample was doubled to calculate the number of threads corresponding to a 100 mm sample length.

The tensile strength and elongation at break of fabrics obtained from blends of secondary material resources were measured using the WDW-5E device in accordance with GOST 3813-2017. The reliability error in determining tensile strength and elongation was 2.3% (relative).

The bending stiffness of fabrics obtained from blends of secondary material resources was determined using the PT-2 device according to GOST 10550-93. The reliability error in determining bending stiffness was 1.5% (relative).

The abrasion resistance of fabrics obtained from blends of secondary material resources was measured using the HD-YG401E-4 device according to GOST 18976-2017. The reliability error in determining abrasion resistance was 1.8% (relative).

The air permeability of fabrics obtained from blends of secondary material resources was determined using the AP-360 SM device according to GOST ISO 9237-2013.

The crease-resistance of fabrics obtained from blends of secondary material resources was measured using the AW-6 device according to GOST 19204-2018 . This device is used to test the crease-resistance properties of various types of fabrics. For operation, the room air temperature must be maintained under specified conditions. Samples were prepared with dimensions of 15 × 40 mm. The device complies with PS-1-1059-1 and ISO 2313 standards. The reliability error in determining crease-resistance was 1.2% (relative).

The shrinkage of fabrics after washing was measured using the M222 QVP device according to GOST 30157.0-2017. The reliability error in determining post-wash shrinkage was 3.5% (relative).

Here, we process the research results mathematically using formulas from mathematical statistics. For this purpose, the mean, standard deviation, and quadratic deviations of the obtained research data are determined.

The sample mean (average value) is calculated using the following formula, similar to the arithmetic mean:

 (1)

Here: - the number of measurements;  - individual measurement values. A simple measure of variability is provided by the **range** R of the values:

 (2)

Where: ** -** **maximum value** y; **** - minimum value.

The basis for all other measures of variability is the deviation from the mean, which is calculated for each measurement value using the following formula:

 (3)

Another characteristic of variability is the **standard deviation**, which is calculated using the following formula: i:

 or  (4)

To determine σ\sigmaσ, the square of each deviation is calculated:

 (5)

The **coefficient of variation** is the ratio of the standard deviation σ\sigmaσ to the mean xˉ\bar{x}xˉ, expressed as a percentage:

 (6)

In addition, the physical and mechanical properties of fabrics obtained from a blend of secondary material resources in the sewing and knitwear industry were evaluated based on a combination of empirical and theoretical distribution standards.

According to the research results, when tension is applied, a process of fiber straightening and consolidation occurs within the yarn structure, and the nature of this process depends on the degree of twist-setting of the spun yarn. As a result, the radial stress gradually increases across the cross-section of the ply yarn, which in turn leads to an increase in the stiffness index of the product during elongation.

For fibers arranged along helical lines, an increase in the inclination angle leads to an increase in their strength index, which reaches a maximum value after a certain period and then gradually decreases. This behavior is associated with the presence of fibers possessing different mechanical characteristics within the yarn, as well as with the wide variation of certain parameters (such as breaking force) typical of the deformation of multi-component ply yarn. Consequently, the real yarn, consisting of a set of elements with different constants, exhibits a deformation behavior that follows a general, yet complex, deformation law.

In the initial tension stage, the viscoelastic properties of each component within the fiber system are clearly manifested. As the tension increases, these properties gradually shift toward a compact fiber system characterized by a high modulus of elasticity and a low viscoelastic index.

In the present study, problems related to the formation of a slippage zone of fibers relative to the yarn, as well as conditions under which no mutual slippage occurs, were investigated. We consider a two-ply yarn whose mechanical properties vary across its thickness according to the law of uniformity along the cross-section. Here, it is assumed that the length of the yarn along the helical line is the same in each layer. For a point taken arbitrarily within the cross-section of the ply yarn, in the absence of mutual displacement of the fibers arranged along the helix, the deformation of the yarn is determined by the following expressions:

, when  (7)

 when  (8)

Where:

i - deformation of the yarn in the i-th layer,

i - Poisson’s ratio for the i-th fiber.

**CONCLUSION**

A method was developed for reprocessing secondary material resources from the sewing and knitwear industry to obtain yarns with low variability, elastic properties, and quality characteristics that meet standard requirements. This involved emulsifying the secondary fibers using two different compositions.

Yarns with varying compositions of cotton and secondary fibers were spun on a pneumo-mechanical spinning machine, with 900 to 1000 twists per meter, resulting in the production of 29.4 tex yarn.

By reprocessing and improving the secondary material resources from the sewing and knitwear industry, it was possible to produce yarns whose quality characteristics meet standard requirements with a high probability of reliability.

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