

KAUNAS UNIVERSITY OF TECHNOLOGY

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INVESTIGATION AND DEVELOPMENT OF
BICOMPONENT COTTON-SILK YARNS WITH
SILK COMPONENT FROM SILK WASTE

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KAUNO TECHNOLOGIJOS UNIVERSITETAS

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LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviations

AKR-2	–	Cocoon shearing machines
BD 330	–	Spinning machine
d_f	–	Fiber diameter, mm
d_y	–	Yarn diameter, mm
ε	–	Breaking elongation, %
F	–	Tensile force (tensile force), N
F_c	–	Centrifugal force, N
F_p	–	Pulling force, N
F_{fr}	–	Friction force, N
G	–	Shear modulus, Pa
G_t	–	Lateral pressure, Pa
H	–	Instant modulus of elasticity, Pa
HARADA	–	Cocoon spinning machines
HSR-1000	–	Roving machine
K	–	Yarn twist, rpm
K_f	–	Actual yarn twist, rpm
K_n	–	Nominal twist of yarn, rpm
KMS-10	–	Cocoon machine
LPK-1	–	Separation machine
M_t	–	Torque, N.m
m_f	–	Fiber mass, mg
n_r	–	Spinning chamber speed, m^{-1}
n_s	–	Spindle speed, m^{-1}
r_0	–	Reduced fiber radius, mm
r_1	–	Radius to the investigated fiber, mm
r_f	–	Distance from the center of the spinning chamber to the fiber moving on its inclined surface, mm
v	–	Fiber movement speed, m/min
v_1	–	Shock wave propagation speed, m/min
v_y	–	Yarn output speed, m/min

Definitions

"Gurlanteks" – Textile cluster company, Khorazm, Uzbekistan.

JV "BF Textile" LLC – Textile cluster company, Tashkent, Uzbekistan.

JV "SUNTEX" LLC – Textile cluster company, Namangan, Uzbekistan.

"Sifat" – Product quality center, Tashkent, Uzbekistan.

TITLI – Tashkent institute of textile and light industry.

TITLI "CentexUz" – Textile laboratory center of Tashkent institute of textile and light industry, Tashkent, Uzbekistan.

"TRUETZSCHLER" – German textile machinery manufacturer.

"ZINSER" – German cutting machinery manufacturer.

INTRODUCTION

The processes of cocoon growing, production of raw silk, and production of silk products as well as recycling of waste products from them have a special place in the world silk industry. In this regard, China, India, Uzbekistan, Iran, Thailand, Vietnam, North Korea, Brazil, France are the leading countries in this field [1].

Nowadays, the widespread use of the achievements of world science is an important factor in the rapid development of all spheres of life of society and the state, building a decent future for the country. The development of the economy on the basis of attracting investments is one of the priorities in the development of the silk industry. It is planned to build, modernize, and re-equip new silk enterprises based on the modern techniques and technologies using investment programs [2].

All the fibrous wastes generated in the process of cocoon growing and raw silk production in the world are used as the main and valuable raw material in the production of spun silk yarn. In silk spinning plants, the secondary fiber waste is formed during the processing of silk fiber waste with different properties. Such short-fiber wastes are not used in the textile industry, despite the fact that the indicators of physical and mechanical properties are at the required level. However, such fibrous waste can be mixed with other fibers, including cotton fiber, to obtain a bicomponent cotton-silk yarn. The possibility of producing woven and knitted fabrics from such yarns will help to expand the range of textile products. Therefore, based on an in-depth study of properties of the fiber obtained from the secondary waste of silk, it is urgent to improve the technology of production of bicomponent yarn by mixing them with cotton fibers [3–5].

Extensive measures are being taken in the country to modernize silk industry, deep processing of local raw materials, increase the production of quality, competitive and export-oriented finished products, and certain results are being achieved [6–7].

In the world silk industry, Uzbekistan has a scientific basis for the production of high-quality cocoons, raw silk, and silk fabrics that can compete with other countries, and these problems need to be addressed. During the production of silk yarn and the processing of fibrous waste generated during its processing, many scientists have been involved in the separation of secondary short fibers as well as the production of yarn spun from the processing of fibrous waste. Among the foreign scholars: M.A. Becker, N. Tuross, A.K. Gupta, M.L. Gulrajani, Rajkhowa (India), Y. Hsia, C. Vierra (USA), R. Kothari, W.E. Hearle (England), S. Nakamura, J. Magoshi, Y. Magoshi, M. Babu, M. Tsukada, G. Freddi, M. Nagura, H. Ishikawa, N. Kasai (Japan), K. Sen (China), and AB Ishmatov (Tajikistan) have done researches, and others analyses continue to be done.

In the CIS countries and the Republic of Uzbekistan, a number of scientists are conducting theoretical and practical research to study the technological processes of obtaining the quality of raw silk, create, improve, and increase the efficiency of processing of silk fiber waste. In particular, V.A. Usenko, E.B. Rubinov, G.K.

Kukin, X.A. Alimova, I.Z. Burnashev, A.I. Isayev, L.A. Amzayev, Y.E. Ergashev, A.Y. Raximov, A.E. Gulamov, A.D. Daminov, O. Axunbabayev, G.N. Ilayev, S.A. Yusupovs have been contributing to the development of the industry with their significant research work.

The **aim of the research** is to develop high-quality bicomponent yarns by adding fibrous waste from silk spinning mills to cotton fiber and improve the spinning technology by mixing cotton fiber and silk from the secondary fiber waste.

Based on the aim of the research, the following **objectives** were identified:

- To analyze the possibility of yarns manufacture from silk waste;
- To analyze and investigate the properties of silk waste from the initial and secondary processing;
- To develop a technology for the production of bicomponent cotton-silk yarn by mixing cotton fiber and silk from the secondary fiber waste;
- To investigate the quality of developed fabrics woven from bicomponent cotton and silk yarn;
- To analyze the cost-effectiveness of developed technology in production.

The **object of research** was cotton fiber, silk fiber waste, the method of their mixing, bicomponent yarn, fabric, and woven fabric.

The **subject of research** is cotton-silk mixed fiber spun yarn production technology, fabric and woven fabrics properties as well as methods and tools in these processes.

The research process used yarn mechanics, experimental analysis and mathematical statistics, computer software, standard and non-standard **methods** for determining the quality of spun silk yarn.

The **scientific novelty** of the research is as follows:

- alternative values of quantitative fractions of a mixture of silk and cotton fibers have been determined;
- a technology for adding fibers during spinning have been developed;
- based on the possibility of spinning yarn by mixing secondary silk fiber waste into cotton fiber, an advanced technology of cotton-silk bicomponent spinning has been developed.

The **scientific significance** of the research results is explained by the creation of an advanced technology for the production of yarn from the mixed fibers.

The **practical significance** of the results of the research is explained by the increase in the range of yarns introduced into the production and the increase in the range of fabrics, knitted fabrics as well as finished products.

The practical results of the research are as follows: an improved technology for obtaining cotton-silk bicomponent spun yarn was created, and the optimal parameters were developed; alternative values of the quantitative shares of the mixture of silk and cotton fibers have been determined; the raw material for the production of textile fabrics, i.e., bicomponent spun yarn preparation technology, was created.

1. LITERATURE REVIEW

One of the most important raw materials for the world textile industry is natural silk. Silk is a valuable natural fiber that has a wide range of beneficial properties and, among other fibers, high strength, hygroscopicity, bactericidal, antistatic, glossy, and elastic properties [8, 9].

While natural silk accounts for only 0.5% of all textile fibers produced in the world, today, it accounts for 12% due to its positive properties. The fabrics made of silk yarn do not cause allergies on human skin, are well ventilated, and absorb moisture well. That is why the human body "breathes" when wearing clothes made of silk.

The fabrics and products made of natural silk yarn are in great demand in the world due to their high sanitary-hygienic properties and easy to use, durable and good appearance, and it is one of the most expensive textile materials. At the same time, the limited raw material base, the complexity of processing technology, and the improper use of cocoon raw materials make the products made from them expensive [10, 11].

One of the fastest growing rules in the world is to produce competitive and quality products, improve the existing technological processes, and reduce the cost of production. Implementing all of this on a large scale requires highly professional experience and knowledge of the professionals as well as a high level of entrepreneurship.

Much attention is paid in the world to the development of scientific and technological progress, increasing production capacity, as well as achieving high product quality. In this direction, the investments are being made in equipping the existing enterprises with modern technologies, increasing the volume and variety of products and organizing deep processing. At the same time, cocoon processing, the establishment of new production facilities in non-productive areas, the establishment of new enterprises are developing as well [12, 13].

In all countries, in the past, the cocoon breeders fed cocoons only in one season, i.e., in May of spring. Up to date, live cocoons have been grown up to 3 times a year, and in recent years, the yield of cocoons has been increased 4 times in a new way. As a result of this research, as well as the great work of cocoons, the world has grown 3.85 mln tons of cocoons in 2020 and 4.08 mln tons in 2021. This year, 4.5 mln tons of cocoons have been planned to be grown in the world countries, and 4.54 mln tons of live cocoons have been grown in practice (Fig. 1.1) [14, 15].

One of the most pressing issues in silkworm rearing is the establishment of mulberry plantations and the further expansion of the fodder base. This will lead to an increase in the number of silkworms and cocoons grown, which will increase the raw material base in the country. As a result of the work that has been carried out, it is forecasted to produce 4.82 mln tons of live cocoons in 2023, 5.16 mln tons in 2024, 5.6 mln tons in 2025 and more than 6.0 mln tons in 2026.

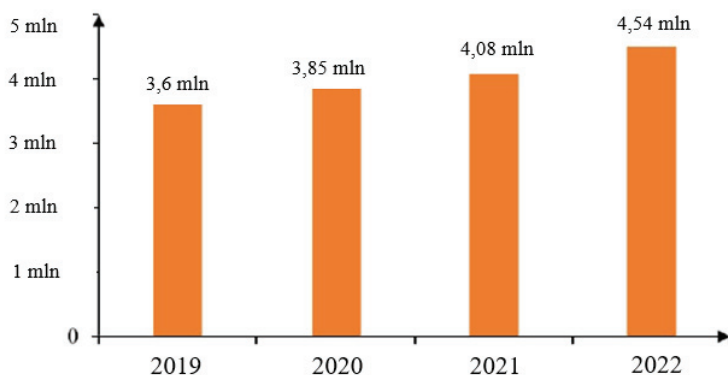


Fig. 1.1. The situation with live cocoons in the world

In all countries of the world, the yield of live cocoons has increased in recent years, the use of new modern technologies of cocoon cultivation has reduced the amount of leaves provided for feeding, and the silkworm cocoon has increased significantly. The results of the work that has been carried out in the field of silk with a new innovative approach show that the rise of science and enlightenment in the field of silk will be the basis for further development of this profession [15, 16].

The researchers have developed new technological regimes of worm feeding in Uzbekistan with the introduction of new advanced technologies in the field of silkworm breeding as well as on the basis of foreign agro-technical measures and recommendations. There was scientifically researched new technological regimes of mulberry silkworm feeding for each age, feeding times, amount of mulberry leaves consumed, set room temperature, standard humidity, and improvement of feeding conditions. It as well describes the methods of feeding worms under cellophane, the defined parameters and ways to prevent silkworms from contracting various infectious diseases when they reach adulthood.

At present, the scientists of the Silk Research Institute are conducting a lot of research work on the creation of new high-quality local breeds and hybrids. There can be seen the results of silk production in the shells of newly created varieties of cocoons, which are regionalized in accordance with the climatic conditions and have a high viability in all regions of Uzbekistan, more than 56 percent. Achieving such results is an indication of the production of raw silk that meets all the standard requirements, of course, from the cocoons of high quality and silk.

1.1. Classification of natural fiber waste and study of their emergence

The silkworms produce a large amount of fibrous waste during the production of raw silk. For every kilogram of raw silk spun, there is the same amount of fiber waste. This, in turn, is a valuable raw material from which it is possible to produce a wide range of spun yarns.

Typically, more than 10–12 kilograms of live cocoons, or 3–4 kg of dry cocoons, are used to produce one kilogram of raw silk. The amount of silk in the cocoon shell is 54–56% of the total cocoon weight, but the output of raw silk by enterprises does not exceed 27–29%. In the production of one kilogram of raw silk in the silk factories, almost as many kilograms of fibrous waste are generated [17, 18].

Currently, 19–21% of silkworms produce defective cocoons. Such indicators are caused by the lack of new breed silkworm seeds for quality cocoons, low nutritional value of mulberry leaves, slow transition of industrial feeding of worms, and a number of negative factors during the feeding of silkworms. The large amount of waste as well depends on the processes at the cocoon's primary processing bases.

In the research, the methods of processing and primary processing of cocoons and the technology of the aggregates, their condition, as well as operating modes, were analyzed according to the characteristics of cocoons. On this basis, the research was carried out to anesthetize the sponge in the drying of cocoons under infrared light, preserve the technological properties of the shell in new methods, and obtain from them high-quality raw silk yarn and raw materials for the production of spun silk.

The efficient use of raw materials in the silk industry cannot be solved without a comprehensive analysis of its initial state, processing problems, physical, mechanical, and technological properties of semi-finished products. From this point of view, there is no fixed classification of raw materials and wastes in the silk industry, only certain types of raw materials and semi-finished products have been analyzed. Therefore, it is advisable to classify the main types of raw materials and natural silk wastes, and if possible, study their technological properties [19–21].

The technological processes for the production of raw silk from mulberry silkworm cocoons, dry cocoons and the processing of natural silk waste involve separate independent technologies. These include the preparation of live cocoons and their initial processing at the bases of cocoons, the production of raw silk by spinning dry cocoons, twisting of raw silk (spinning process) and baking yarns, processing of cocoon and silk fiber waste and spinning yarn, various textiles from silk, production of knitted goods, surgical and sewing threads, as well as various silk products. Each of these processes is very complex, and they are multi-operational, and more different wastes are generated from these processes.

Depending on the type of waste generated by the cocoon mills, it is divided into the waste from the sorting plant, the cocooning plant (main shop), and the control collection department (including the testing and production laboratory). It is as well important to pre-treat the waste in the recycling plant.

If these sections were looked at one by one, it seems to be the waste from the sorting shop: cotton loose, unsightly cocoons, i.e., very spotty, stack marks on the surface of the shell or coarse cocoons with a smooth glossy surface (cotton, felt, ugly, shell hole, thin shell spongy cocoons), double cocoons (i.e., two silkworms wrapped around a single cocoon), super crushed, non-standard, i.e., deaf cocoons, and other defective cocoons [22–24].

Cotton wool from the sorting shop comprise 0.3–0.5% of the weight of the imported dry cocoon. Typically, cotton sorghum contains various contaminants, i.e., mulberry leaves, weeds, and up to 40% sericin, and after processing, they are divided into two varieties and placed in wedges. The first variety includes cotton loams of the same color and variety, separated from the cocoons entering the sorting shop, in which the plant contaminants do not exceed 1%. The second variety includes cotton wool, which is obtained by manual and mechanical cleaning of cocoons, is not the same color, contains up to 3% plant contaminants. Cotton loin is placed on the wedges weighing no more than 40 kilograms and sent to silk spinning mills [25, 26].

It is possible to bite the cocoons: the size of the spots on the shell of the cocoons is larger than the norm specified in the standard; the shape is slightly changed; the handle trace is high, and the apex is pointed. They produce raw silk with a thicker linear density than usual, but it is advisable to separate the spotted cocoons from the other defective cocoons and spin them according to a special technological regime. According to this mode, the spinning speed should be 60–70 m/min, the temperature of the spinning water should be 50–55 °C, the spinning length should be 4–5 cm, and 20–25% of raw silk can be obtained from them.

In order to make an efficient use of double-spun cocoons that are unsuitable for spinning, it is possible to spin them to produce raw silk yarn with a linear density of 5 tex and above. After the cocoons are steamed before washing and then boiled for 30 minutes, the wooden brushes on the KMS-10 machine are used. The temperature of the water in the cooking pot of the machine should be 90–95 °C, in the oval powder, 60–65 °C, and in the grinding powder, 52–56 °C, and the immersion length should be 4–5 cm, and the boiling speed should be 90–93 m/min. It should be noted that the temperature of the water in the powder during the process of sorting cocoons is 40–42 °C. Double-spun cocoons could be used to spin silk without spinning. In this case, it is advisable to separate the sponge inside in order to further increase their chances of reuse. For this, LPK-1 automatic lines are used. The cycle of turning cocoons into canvas lasts 6 minutes; during this time, 500–100 g of canvas are produced from 1.2–1.5 kg of double-spun cocoons [27–29].

Uncooperative cocoons are cut on AKR-2, MKRA-1 aggregates. Processing in this way has a number of serious drawbacks. The main reason is that the fibers shrink in length, swell, and become oily. The chances of the sponge oil coming out are very high. That is why it is advisable to turn them into canvas. In order to do this, it is better to separate silk from them without cutting the cocoons, which are not suitable for weaving.

The waste from the cocoon spinning shop includes cocoon loose, torsion loose, unwashed cocoons, cocoons, rolled silk threads and cocoons, raw silk rings, knotted threads, sponge, and invisible waste.

Mechanical and automatic machines are mainly used to cut cocoons and obtain raw silk of continuous length. During the period of finding the single end of the cocoon, the loss up to two meters long is separated in the oval dust on the

mechanical devices. As this process is done by manual labor, in some cases, the length of the separated loss can exceed two meters.

When sorting defective cocoons that do not deserve to be removed from the sorting shop, their output should be 6–12% of the total cocoon mass. These figures vary depending on the breed and hybrid of the cocoons (Table 1.1) [37].

Table 1.1. Output of defective cocoons

№	The name of the defective cocoons	Amount, %
1	Double silkworm cocoon	1–2
2	Ugly shaped	0.1–0.2
2	The bark is soft cocoons	1.7–2.4
3	The surface of the shell is stained	0.9–1.6
4	Non-auditory cocoons	0.6–0.9
5	Partly wrapped	0.4–0.8
6	Thin shell	0.4–0.5
7	Hole	0.2–0.3
8	Other defective cocoons	0.7–1.3
9	Total:	6–10

If the technological regime is violated during the process of preparing the selected dry cocoons for spinning and during the evaporation of the cocoons, i.e., in the cooking machines, the cocoons will be overcooked or undercooked. When this happens, a large amount of fibrous waste is released, as well as when the mode of the cooking process is violated, the silk fibers in the shell come out in bundles (one package contains 17–25 octagonal loops).

Up to date, almost 90–94% of silk enterprises in Uzbekistan are equipped with automatic machines. Up to 50 cm in HARADA machines and up to 1 meter in FY 2000 machines are used as waste. The cocoon sludge coming out of the spinning mill may be no more than 1% of the total silage mass of the cocoon, the spun cocoon and the cocoon, no more than 0.5% of the knots. In addition, during the preparation of cocoons for spinning, the rings appear due to the changes in the technological regimes of evaporation. As a result, the cocoons with many breaks and not washed to the end become waste.

The unwashed cocoons return on the conveyor located on the bench and again along the stream of water to the single end shaking mechanism. According to the Chuvash rule, this process is allowed up to 3 times. Unwashed cocoons are first soaked in a soda solution at a temperature of 80–900 °C for 4–5 hours, then boiled, and squeezed in a centrifuge. In subsequent technological processes, the pile is machined on a toothed drum, and the second time on a needle-mounted drill, and then, the canvas is dried and placed at the normal level. The content of silk fibers from these processes is required to be 2–3% fat and up to 10% contaminated with sponge residues.

The rings are formed during the production of raw silk, when there is a break in the distance from the bottom of the cocoon to the formation of raw silk and

winding on the wheel, during the assembly of the yarn on the wheel, rewinding raw silk from 0.65 perimeter wheel to 1.5 perimeter yarn, sewing yarn, as well as standard requirements for raw silk formed during the inspection of the test strips wrapped and wrapped around the seriplan board for inspection. In each case, all the rings are fully assembled, scraped, and cleaned of foreign contaminants. Raw silk rings may contain no more than 0.5% foreign yarn and no more than 10% short raw silk shears. They weight no more than 50 kg and are placed in wedges at a humidity of not more than 11%.

In short, the cocoons are recycled to make efficient use of the waste generated during the cocooning process. It should be noted that all of the above-mentioned wastes are valuable raw materials for the silk spinning mill [30–32].

1.2. Study on the existing technology of producing functional textile from the waste of natural fiber

Spinning is a set of processes from which short and thin fibers are obtained to have a certain linear density, strength, and a continuous yarn. The spinning industry is one of the main branches of the textile industry.

Taking into account the technological characteristics of fibrous wastes released during the production of natural silk, their recycling and production is one of the most complex technological processes in the silk industry.

The waste from silk factories is suitable for use as a valuable raw material in silk spinning mills and textile mills.

Fiber waste from the processing of natural silk in silk enterprises has a significant share. The processing of 1 ton of dry cocoon can produce 32–34% of raw silk, 15–17% of production waste, 30–32% of cotton, and 17–19% of technological losses. Such wastes are suitable for use as raw materials and semi-finished products in silk and textiles.

The efficient use of fibrous waste is of great importance to the national economy. It is as well important to note that this should be aimed at reducing the types of waste from all technological processes of silk production at all times, i.e., in the production process. Of course, in the production of products, it is necessary to look for comprehensive plans for their output.

Due to the extremely complex biological structure of silkworm waste and mulberry silkworm cocoons, the problems of waste-free technology have not been fully resolved. American university scientists Florentso Ovunetto and David Kaplan have proposed a new approach to solving the problem of obtaining artificial fibers that are close to the properties of natural silk [22–23].

A number of scientific studies [24–26] that have focused on the causes of defective cocoons and ways to eliminate them study the amount of fiber waste, create a waste-free technology, affect the length of fibers in the silk spinning process and the quality of the finished product.

In her research work, Sh.M. Esonova [38, 39] studied the degree of influence of biologically active substances on the technological properties of cocoons to reduce the amount of waste in order to improve the quality of raw silk. The

researcher N.J. Kobulova as well studied the technological properties of cocoons grown under the film and raw silk yarns obtained from them for such purposes and considered the possibility of producing quality products and reducing fiber emissions from them [40, 41].

Professor I.Z. Burnashev, as a result of his research, studied the classification of defective cocoons. The results of this research show that defective cocoons are almost impossible to remove. It was noted that raw silk that meets the quality requirements cannot be obtained even when spun; thus, such defective cocoons should be prepared as a raw material for spinning in special ways [42].

According to scientists from Fitza Vollart University in Oxford [43], an important problem in obtaining artificial silk that matches the properties of real natural silk is that the mechanism of construction of silk fibers consisting of successive amino acids surrounded by concrete protein chains that do not allow to create such strong synthetic fibers is not fully understood.

In the process of silk spinning, the waste, which is separated into individual fibers and stapled to the required lengths, as well as from all passes, serves as a secondary raw material for the silk industry. Natural silk waste varies in length from millimeter fractions to several meters.

J.G. Latsman [44] developed a mathematical model and theoretical foundations of composite fabrics. This model consists of a generalized structural-functional scheme of management and quality control as well as a mathematical method of forming at the level of production of spun yarn and finished fabric, which allows to produce combined yarn in the method of forming a bicomponent yarn from mono yarns and short staple fibers.

Fiber-rich wastes include raw cotton, cocoon, torsion loops, rings, control rods, rings on the seriplan board, shells of seed cocoons, rings during re-wrapping, spinning and scraping [45–47].

Since this raw material contains foam, in order to separate it, after the raw material has passed inspection and sorting, if it is wet, it is slightly dried and cut in cocoon cutting aggregates, i.e., MKRA-1. Worm husks and sponge residues are removed from the two-stage horizontal cleaners, sorted, and placed in paper bags of 10–12 kg and sent to the consumers. The cocoon shell, cleaned from the sponge, is cut from the fan barrier grilles, and the condenser enters the chambers of the boiling shop through the condenser; then, it is placed in special bags and fed to the boiling shop (Table 1.2) [37].

Table 1.2. Output indicators of raw materials from the sorting and control shop

№	Types of raw materials	Amount, %
1	defective cocoons	45.4
2	double cocoons	46.5
3	seed cocoons	95.9
4	non-washable cocoons	54.0
5	cocoon loss	99.1

The main reasons for the inability to use fibrous waste wisely are that the amount, length, and linear density of sericin in the raw material are not the same. Therefore, the technology of recycling silk waste should be constantly improved. In the silk spinning industry, in addition to the above-mentioned products, secondary short-fraction wastes are generated, which are not used in practice in the textile industry. That is why the creation of secondary waste recycling technology, which arises in silk spinning, was considered an urgent problem of great importance.

The silk fibers of mulberry silkworm cocoons are composed of sericin and fibroin protein substances: sericin content comprises 20–30%. In order to increase the level of processing of fiber in subsequent technological processes as well as reduce the electrical charge, it is necessary to keep the amount of sericin in it to a minimum, i.e., 0.5% fat, 2% sericin. In order to do this; silk fiber waste must undergo a technological process of degreasing and degreasing. This technological process is processed depending on the amount of sericin and fat in the raw material, in which the fibrous waste of natural silk is divided into 3 groups [37].

Table 1.3. The composition of sericin and fat content in the raw material

№	Groups	Quantities
1	1 group	Sericin-rich raw materials: rings, seed cocoon shells, sheared cocoon shells, seriplan yarns and control threads, the sericin content is up to 24–27%, the oil content is less than 0.5%.
2	2 group	In spinning raw materials with a moderate amount of sericin: cocoons, nodules, in the shell of unwrapped cocoons, sericin content is 23–24%, the fat content is around 0.5%.
3	3 group	Seritsin is low in raw materials: kaznak, I-pass, and II-pass canvases as well as in the return seritsin 19–22%, fat content 1.5%.

Although these invisible wastes have valuable consumer properties; today, there are no ways to collect them and use them. This is a problem that needs to be solved now, and the scientific research needs to be done.

Waste can be wet, dry, damp and require recycling when evaluated based on its appearance. Boiled raw materials are first washed, dried, crushed and then rested. After the process of degreasing and degreasing, the fat content in the fibrous waste, i.e., cocoons, knots and cuts, is up to 0.5%, and in the canvas and cocoon shell, 0.8%.

Due to the lack of alternative technology for the production of high-quality spun silk yarn from fibrous waste, the amount of product obtained from the raw materials does not exceed 50 percent. This is due to the low output of the product in the process of silk spinning technology as well as the processing of waste, which varies in nature, according to a single technology.

1.3. Characteristics and parameters of natural silk fiber waste

Improving waste-free technology after the initial processing of cocoons and raw silk production processes is one of the key issues that the scientists are facing around the world. Taking into account the specific characteristics of natural silk

products and the prospects for future use, the expansion of new types of assortments, the production of various products with the efficient use of separated fibrous waste is one of the most pressing issues that the industry is facing today.

According to the classification of natural silk waste, they have about 20 species. All types of fibrous wastes are divided into two main groups, i.e., the individual fibrous parts of the shell that are unsuitable for the production of raw silk, the defective cocoons of the shell, and the process of spinning. These wastes differ from each other in physical and mechanical properties of fibers, their condition, and characteristics.

Fiber waste from silk occurs in various processes: from worm feeding, cocoon cultivation, cocoon sorting, preparation for spinning, spinning and raw silk production, silk spinning, weaving, and even sewing. Each of these processes is a very complex, multi-passive, and multi-character waste-generating process. Therefore, the fibrous waste of silk, which arises from the passage of each technological process of silk and weaving enterprises, will have different performance.

According to the study of sources, natural silk has high physico-mechanical properties and shows a wide range of uses. The two elemental threads are glued together to form a cocoon thread, which is unevenly wrapped around the thread. In some places, there will be less, and in some places, it will accumulate.

The main component of cocoon yarn is fibroin, which makes 70–80 percent, and sericin, which is 20–30 percent. In addition, cocoon yarn contains a certain amount of esters (0.4–0.6%), alcohol (1.2–3.3%), and minerals (1.7–1%). In the process of cooking the cocoons, all the substances are released, except the fibroin substance and a small amount of sericin.

Fibroin is white in color, and its surface is smooth, shiny, soft and has good staining properties. Fibroin is resistant to the condition of microorganisms: it loses significant strength in sunlight. The moisture content of fibroin is 1–2% lower than the moisture content of raw silk. Fibroin is able to absorb various substances. It adsorbs copper salts, iron, chromium, tin, sugar, starch, glue, enamel, tannin, soap from the solution. For neutral gases, fibroin is inert, but absorbs acidic and alkaline gases rapidly. When heated to 135 °C, fibroin does not change its properties, but at a temperature of 180 °C, it breaks down.

The fibers that have derived from silk waste are high in a number of properties in terms of durability. Although low in shear ($3.5 \div 8$ mkm), they are more robust ($\sigma = 2,740$ MPa). However, their molecular structure is chaotic, and this is characterized by its high defect.

The use of recycled fiber waste of natural silk expands the raw material balance of the textile industry and allows the production of various fabrics and knitted products from a mixture of natural fibers. This can be achieved by correctly selecting the spinning capacity of the mixture, which can produce spun yarn with high productivity and low number of breaks on different looms, which characterizes the minimum possible linear density.

When chemical fibers are mixed with natural cotton and silk fiber wastes, the yarn yield, which is characterized by the amount of yarn spun, increases. At the same time, the possibilities of positively changing the properties of spun yarn and products are expanding. In these processes, the unevenness of the spun yarn and the number of breaks are reduced [48–49].

In preparing natural fibers for processing, it is necessary to sufficiently thoroughly grind and separate them, clean them of impurities and remove foreign defects, and seriously process the raw material (boiling, bleaching, dyeing, etc.) in accordance with the technological requirements. The adequate sifting of the secondary waste of silk will be required to prevent the fibers from breaking and passing.

The structure and its influence on the physical and mechanical properties of yarn have been studied since the 1950s [50]. The studies carried out in this direction are reviewed and summarized by the Indian scientist A. Basu [51]. They analyze the relationship between the discontinuity characteristics of yarn and its structure, in particular, the dependence of mechanical properties, i.e., the discontinuity characteristics of the yarn on its twist, density, and migration of fibers along the product. It is noted that the structure of the yarn as well depends on the radial arrangement of the fibers along the length, which is commonly known as migration and the density of the arrangement of fibers in the cross section of the yarn, which depends on the properties of the fiber, yarn performance, and the dynamics of spinning processes.

A. Basu does not consider well-known scientific works devoted to the prediction of mechanical characteristics based on the theory of elasticity, taking into account the structural formation of yarn and threads [52]. As a result of the analysis of research works devoted to the study of the structural formation of yarn of various spinning methods, it has been found that the structure of yarn from the fibers of limited length, regardless of the spinning method, is mainly estimated by the angle of inclination of the fiber to the yarn axis (twist), density, and arrangement of fibers, and migration of fibers along the yarn. In these works, the structure of various yarns is mainly studied by the method of labeled fibers, and the change in elastic properties is not considered. In contrast, J.W.S. Hearle (Great Britain) [53], L.V. Langenhove (Belgium) [54, 55], V.P. Shcherbakov [56] studied the mechanical properties of yarn and threads, taking into account their elastic properties, and they considered the yarn as an anisotropic body.

J.W.S. Hearle considers mainly mechanical, in particular, deformation properties of both textile threads and yarn [53]. L.V. Langenhove [57], X. Shao, Y. Qiu, and Y. Wang [58, 59] consider the pre-rupture characteristics of the mechanical properties of the ring and pneumo-mechanical yarn, taking into account its structural formation of yarn, based on the theory of elasticity. In this case, the number of twists, yarn density, and fiber migration are taken as criteria for assessing the structure. In contrast, V.P. Shcherbakov evaluates the mechanical properties of yarn based on the theory of elasticity, taking into account the coordinates of the location of fibers in the cross section of the yarn [60].

The modulus of elasticity of yarn at its 0.5–1.0% elongation well illustrates the relationship between the physical and mechanical properties of yarn and its structure. Therefore, in European countries, this indicator is often determined at the request of the consumer. Various models that are offered are, of course, acceptable for evaluating the mechanical properties of yarn, but they have certain drawbacks. For example, J.W.S. Hearl model [53] does not take into account the coordinates of the location of fibers in the cross section of the yarn, and G.I. Chistborodov does not take into account the axial stress of the product, which has a small deflection [61]. A number of researchers consider the propagation of twist along the yarn [62, 63] as well as the arrangement of fibers [64, 65] and the effect of migration on the elastic modulus of yarn [66].

Chinese scientists do not take into account the change in the proportions of torn and slipping fibers during torsion. In these studies, although the yarn is considered as an anisotropic body, its structure and properties are evaluated without taking into account the influence of technological processes, i.e., the influence of conditions and parameters of yarn formation. In addition, these studies almost do not consider the management of structure, ways to reduce the loss of twist, methods for regulating the density of the yarn. In this regard, the problem arises when studying the stress-strain state of yarn, taking into account its structural change under the influence of variable parameters of technological processes of spinning [67].

The purpose of spinning is to form a continuous product from the fibers of a limited length, i.e., a yarn of a given linear density, strength with high elastic properties and uniformity [68].

Spinning is carried out on the spinning machines, which operate in various ways.

The essence of the processes carried out on a spinning machine is to thin the feed semi-finished product (tape or roving) to a given linear density by stretching, to give the product a certain structural formation of yarn and the necessary strength breaking by twisting or otherwise, and forming a package of yarn in the form of a spinning cob. Thus, the yarn is formed as a result of the processes of drawing, twisting, and winding. The formation of yarn can as well be carried out without torsion, and its strengthening can be carried out by bonding the fibers of the yarn with an adhesive. Therefore, the spinning method is determined mainly by the way the yarn is formed, i.e., a method for forming the structural formation of the yarn and a method for imparting tensile strength to it. Spinning methods are classified differently in different countries. However, the basis of the classification is its division according to the method and means of strengthening the yarn.

As a result of the analysis of literary sources devoted to the study of mechanical properties, it has been found that their performance depends to a greater extent on the structure and conditions of yarn formation. Recently, the studies that have been carried out in this direction are often found in periodicals [69]. They consider the deformation of the yarn, taking into account the location (orientation) of the fibers in the yarn structure. The below presented study focuses on the behavior of fibers in the structure of the web (bundle, matrix) before yarn formation, i.e.,

before the twisting process. In order to assess the influence of the structure of the sliver on its mechanical characteristics, the deformation of the low-twist yarn is considered.

Spinning methods and machines for their implementation are constantly being improved. A new ring spinning machine equipped with a fundamentally new “ring-runner” pair has successfully passed preliminary tests [70]. As the authors note, for the first time in the world, the principle of sliding the slider along the ring has been replaced by the principle of rolling. This allows to significantly reduce the friction force of the runner on the ring, and therefore, solve the issues of increasing the speed of the runner up to 100 m/s or more. The new system uses a new interaction of the runner with the ring and the thread, which reduces the friction of the runner, and the thread moves smoothly with minimal tension. The new system is very complex in design and has not found practical application yet.

The main concept for the further development of ring spinning is to reduce the level of total production costs to achieve the required productivity, optimize the basic model, and increase the spinning speed, the level of process automation. The ring spinning machine has been improved with a twisting and winding device with a rolling runner [71].

The research continues to determine the most optimal combination of types of rings and runners in the development of yarn on ring spinning machines [72]. For each assortment at a certain spindle speed, a method has been developed to determine the optimal combination of rings and runners. In Russia, the problems in the creation and serial production of promising ring spinning machines, i.e., high-speed and an increased number of spindles, have been analyzed. It is noted that with an increase in the speed mode of ring spinning machines, the tension and density of yarn winding on the package increase. Therefore, the capacity of packages on new machines operating at a higher speed was taken higher in calculations than on the standard machines [73–75]. The perfect addition to the Saurer Schlafhorst machine range was the integration of Zinser ring spinning technology. Zinser roving and ring spinning machines are exceptionally attractive and have an excellent reputation worldwide [76].

One of the modern directions for improving the ring spinning is the production of compact yarn. There are many proposals for methods and devices for producing compact yarn. In this regard, there are often studies related to compact yarn, which can be obtained by pneumatic, mechanical, and aerodynamic methods [77–79]. Thus, for example, a comparison was made of two systems for producing ring-spun compact yarn developed by Suessen and Zinser (Germany). The physical and mechanical properties of traditional and compact yarn produced under the same technological conditions are analyzed [80]. The main advantages of the produced yarn are increased breaking load, breaking elongation, and reduced hairiness. The increase in the breaking load of the yarn is 10–20%, and the decrease in its hairiness reaches 80–90%. The use of such yarn makes it possible to increase the productivity of looms and knitting machines. At present, the compact spinning technology is currently only carried out on the ring spinning machines. It should be noted that the

spinning technology is as well evaluated by comparing the quality, i.e., physical and mechanical properties of the resulting yarn. Therefore, the influence of various spinning methods on the quality of produced yarn was investigated. During the study, ring, pneumatic, pneumo-mechanical, and tubeless pneumo-mechanical spinning methods were compared. The specific properties of polyester fibers and their influence on the manufacturability of processing and filling parameters of spinning equipment are considered. It is noted that the tubeless pneumomechanical method is the least suitable for processing polyester fibers [81–89]. It follows that the spinning method must as well be distinguished by the suitability of the fiber. In another work, it is noted that the use of devices for interlacing (piecing) the ends of the broken yarn with small sizes increase the frequency of rotation of the spindles and make the automation of the spinning process more cost-effective [90–95].

The technology of spinning Siro yarn, the method of its implementation on a spinning machine for processing cotton fibers is considered. The quality of Siro yarn is compared to that of traditional ring yarn. It has been found that in terms of hairiness, uniformity, and breaking load, Siro yarn exceeds the traditional ring-spun yarn and is inferior to the traditional ring-spun yarn in terms of the number of thin spots [96]. Along with Siro yarns, it is widely practiced to obtain thin samples of reinforced yarn with a thin, highly elastic core. This yarn has low hairiness and properties that ensure its trouble-free further processing. The technological improvement of the Compact-Core spinning method allows the precise entry of a highly elastic rod into compacted cotton yarn, which makes it possible to obtain thin elastic cotton yarn up to 4 tex [97].

The work [98] deals with pneumo-mechanical, fiber wrapping, and pneumatic spinning methods. As a result of the analysis of the methods, it is concluded that the rotor spinning is widely used for the production of yarn with a linear density of 16 tex and above. This method is evolving towards increased productivity, automation, and increased versatility.

Moreover, there was proposed a method for obtaining yarn by Siro [99]. The main difference between this yarn and twisted yarn obtained on a twisting machine is the equality of the twist of single threads and twisted yarn, which leads to its increased smoothness.

The pneumatic method of spinning Vortex is designed to obtain yarn used for the manufacture of technical and denim fabrics, fabrics for work and protective clothing, and knitwear. The advantage of the method lies in the high speed of yarn release and its low hairiness [100].

Interesting research has been carried out on the technology of self-twisting spinning. The potential possibilities of self-twisting spinning are considered. The suitability of this method for obtaining a balanced two-ply yarn, which can be successfully used in knitwear production, is noted [101]. In [102], there was reported the launch of Corespun yarn, the core of which is Elite textured elastic yarns made of polybutylene terephthalate by Nilstar. The shell of the yarn is formed from viscose, cotton, or mixtures of linen and silk fibers. This yarn is intended for the manufacture of elastic fabrics [103].

1.4. Features of blended yarn structure formation and ways of its improvement

The above considered researches use of calculation formulas for designing specific breaking load of yarn and solving the inverse problem, i.e., finding the indicators of fiber properties that ensure the production of yarn of the required quality. In the normative documents and reference book, the assortment of yarn is given with an indication of the requirements imposed on it to ensure high performance properties of the finished products [104, 105].

An objective approach to the design of the yarn properties will make it possible to scientifically analyze and evaluate the results of the technological process and establish the patterns associated with the structure and properties of the yarn. Ultimately, it will make it possible to control the technological process and achieve the release of higher quality yarn. This should contribute to a more rational use of raw materials in the industry and an increase in the competitiveness of products. The physical and mechanical parameters that affect the quality of the final product largely depend on the structural formation of the yarn. It is characterized by the following indicators: a) the degree of twist; b) the nature of location of the fibers along the length of the thread; c) the number of fibers and their location in the cross section (density) of the yarn; d) uneven distribution of fibers in the yarn, both in quantity and quality. The last indicator is not taken into account in the studies discussed above, and the emphasis is placed on the first three.

In addition to the properties of fibers, the structure of the yarn is influenced by the conditions for the technological process of yarn formation, the processes of drawing, twisting, and winding. The structure of the yarn is determined by the conditions of the forming process, which on the ring spinning machine include the width of the web, the height of the torsion triangle, the ratio between the number of revolutions of the yarn around its axis, and the feed rate of the fibrous web. From this, the speed of the spindle, the number of twists, and the shape of the torsion triangle determine the structure of the yarn. However, in reality, the regularity of the deformation of the ribbon is violated due to the action of the tensile force on the thread in the torsion zone as well as the presence of the angle of flow around the web of the surface of the front cylinder. In the twist triangle, the maximum tension is obtained by the extreme fibers passing a longer path from the clamping line to the apex of the twist triangle, and then, they tend to move to the center of the yarn cross section, i.e., migrate towards the center.

The magnitude of the stress of individual fibers in the spinning triangle is influenced by their location in relation to the axis of the thread as well as the heterogeneity of the staple along the length and fineness of the fibers. The greatest tension is obtained by a group of long fibers when their middle part is located in a torsion triangle [106]. Short fibers, clamped at only one end in the exhaust pair of the drafting apparatus as well as fibers with one end of which enters the yarn receive minimal tension and slip in relation to the adjacent fibers in the spinning triangle. The most stretched fibers during movement will tend to be located closer to the axis of the yarn and thereby wedge between adjacent fibers. As a result, the fibers are arranged in spirals with a variable pitch of turns and a variable radius of the cylinder

on which they are wound. This arrangement of fibers, partially equalizing their tension in the thread, prevents a regular increase in normal pressure from the stretched peripheral fibers to the center of the thread.

The uneven tension of the fibers in the cross-section of the yarn is reduced with a decrease in the base of the torsion triangle using compact pneumatic [107] devices from Rieter or mechanical action [108], such as RoCoS from Rotorcraft. With the help of these devices, the base of the torsion triangle is narrowed, and the fibers are located almost parallel, acquiring almost equal tensions, as a result of which both structural unevenness and unevenness in properties are reduced.

From the point of view of the mechanical properties of the yarn, it is of interest to determine the amount of deformation that the fibers undergo during the twisting process. It has been found that the linear density of the yarn insignificantly affects the tensile deformation of the fibers, the value of which decreases with a decrease in the linear density of the yarn.

Usually, when the yarn is formed on the spinning machines, it is given a tension twist, which partially prevents the length of the twisted section from shortening; the fibers undergo tensile deformation, the value of which depends on their location in the cross section of the yarn.

As the results of the experimental studies show, the degree of deformation is mainly influenced by the amount of tension created by the spindle speed and the number of twists of the yarn. Consequently, the structural formation of the yarn as well changes depending on the parameters of the spinning machine [109]. According to the results of the study of the influence of the spindle speed on the yarn tensile curves, the dependence of the yarn structure on the kinematic parameters of the spinning machine was established [110–112].

Structural formation of rotor yarn

The structure of pneumo-mechanical yarn is well described in the works of professor A.G. Sevostyanov [113], in which it is noted that the structure is certainly associated with the process of yarn formation [114–119]. It is known that the open end of the yarn is withdrawn from the chute of a rotating spinning box. If impurities or fiber complexes enter the take-off point, yarn formation is impaired. Fiber defects that are larger than the yarn diameter cannot be twisted along the yarn. As a result, the yarn either breaks off immediately or begins to form in the opposite direction with poor quality. Therefore, it is believed that the structure of the discrete fiber flow significantly affects the yarn formation process. Part of the discrete fibers with each revolution of the spinning box, of course, ends up at the take-off point. This obviously affects the structure and properties of the yarn.

In order to assess the fibers adhering to the yarn, an indicator is used, i.e., the coefficient of capture, which is characterized by the ratio of half-length of the fiber to the perimeter of the spinning box. The fibers reaching the take-off point can be of various shapes [120–124].

The pick up ratio is directly proportional to the fiber length and inversely proportional to the diameter of the spinning box. Wrapping around the take-off point

or beyond takes place mainly on different fiber lengths. The grip factor takes into account the twisting of the fiber at its half-length ($\ell_f/2$). Thus, not one, but two open ends of the yarn being formed are formed in the spinning box. The long end of the yarn twists well and makes up its main, core part. The fibers of the short end are entwined and constitute the loose, outer part of the yarn. The wrap-around outside counts towards the linear density, but does not provide yarn break resistance. The core portion formed from the long end resists tearing and determines the strength of the yarn. Thus, rotor yarns, in contrast to the ring yarns, have a two-layer structure.

If the yarn is removed from the spindle of the spinning box in the opposite direction, then the core part is formed from the short end, and the long end will be wrapped around it. Such yarns will have a reduced strength because the fibers of the outer wrap are higher in the cross section of the yarn. Of course, such yarn is considered out-of-grade, and in order to prevent its formation, it is necessary to ensure perfect sampling, i.e., there should be less than one fiber in the cross section of the discrete flow. Therefore, many designs of sampling devices have been developed. By improving them, a new design of the sampling device has been developed [125].

It should be noted that in order to reduce the value of the capture coefficient, it is necessary to increase the diameter of the spinning box. It is this position that has a great influence on the breaking load of the yarn. In this case, the conclusion is made without taking into account the influence of the speed of rotation of the spinning box on the density of the fibers in the chute of the box. Density is one of the main indicators of yarn structure. Other indicators of the structural formation of the yarn are the number of twists, migration (location) of fibers, and uneven distribution of fibers in the yarn, both in terms of quantity and quality. These indicators of the structural formation of the yarn, of course, affect its physical and mechanical properties.

Silk is referred to as the "queen of textiles" for being a fiber with superior strength coupled with excellent drape, luster, and hand. Silk is as well one of the costliest textile fibers. Silk is produced from sericulture activities, which are basically agricultural practices associated with silkworm insect rearing. During the process of sericulture, by-products and wastes are produced in addition to the silk fiber. Since silk is associated with a high cost, even the by-products and wastes have been exploited commercially to generate extra income and thus to increase the profit. Therefore, by-products such as silkworm pupae and sericin protein along with the generated silk waste are covered with regards to their economics, characteristics, and processing for product development and diversification [126].

It accounts for less than 1% of the total textile fiber produced worldwide and about 1.3% of the total fiber production in India. About 75% of raw silk is used for making saris, the most preferred traditional attire amongst women in the country. Saris made of silk with intricate woven designs on handlooms are unique and exquisite. However, once a sari becomes old or damaged, its value is reduced to that of a scrap. Little attempts are made to repurpose/recycle the garment. The source [127] discusses various options for maintaining the value of used silk saris through

reusing/recycling the material. It can be concluded that this garment was traditionally designed with a zero-waste, cradle-to-cradle concept. By extending the life of a sari, the maximum benefits can be extracted from it, which benefits the environment as well as economy and leads to sustainable development.

1.5. Conclusions of the chapter

Fiber waste from silk occurs in various processes: worm feeding, cocoon cultivation, cocoon sorting, spinning, spinning and raw silk production, silk spinning, weaving, and even the production of finished products. Each of these is a very complex, multi-pass waste-generating process. Therefore, from each transition, the fibrous waste of silk formed in the technological processes has different properties.

It is necessary to improve the technology of production of a new type of bicomponent yarn that meets the requirements of domestic and foreign markets, using natural silk and its fragments, one of the raw materials of the country, by mixing them with other natural and chemical fibers.

Such fiber-rich and expensive wastes are not used at all in the silk industry. When silk fiber waste is used in combination with cotton fiber, it is possible to produce a large reserve for the textile industry by producing cotton-silk bicomponent spun yarn. In recent years, research has been conducted on the improvement of spinning systems, including the use of much shorter technology and new technological spinning machines. It should be noted that most of the work that has been done in this direction is of an experimental and exploratory nature.

According to the literature, it is necessary to fully utilize the recycled waste of silk, improve and justify the technology of production of new high-quality bicomponent yarns and fabrics made from them as well as to conduct research on these topics.

2. BLENDED YARN CHARACTERISTICS AND RESEARCH METHODOLOGY

In this dissertation, when analyzing the features of technological processes, the structure and mechanical characteristics of yarn, the materials of the basics of spinning fibrous materials, and the methods of yarn mechanics, mathematical statistics were used, as a result of which the corresponding results were obtained, and the conclusions were determined.

The experimental yarn samples were obtained on a BD 330 spinning machine installed in the experimental laboratory. The indicators of the physical and mechanical properties of the yarn were determined on the tensile testing machine Statimat C installed in the accredited certification center at TITLI "CentexUz". The principle of operation of this tensile testing machine is to deform the test specimens by using a hydraulic drive and measure the pressure load in the working cylinders by balancing the pressure with the elastic deformation force of the rod as well as the devices in the laboratories of the enterprise "Gurlanteks" and JV LLC "BF Textile", and then processing the results of experimental studies to determine the indicators of the physical and mechanical properties of the yarn.

In order to determine the mechanical properties of yarns, the yarns were selected by taking 10 point samples from each unit of production for half-woolen and pure wool yarns, and 5 for other types of yarn. The units of products were to be released from the outer packaging and kept in climatic conditions of 20 °C temperature and 65% humidity. The tests were carried out under the same conditions. The duration of keeping the yarns in climatic conditions is 24 hours. The graphs of simple functions in Cartesian and polar coordinate systems, as well as graphs showing realistic images of complex figures intersecting in space, as well as systems of differential equations, were obtained in the Maple program. Inventor Pro were used to simulate the rotation of EO rotor in order to investigate the path of each fiber in the inner surface of the rotor.

Depending on the definition and type of the fiber waste given above, the modes of the spinning process are selected. Since these raw materials have different fiber length, thickness, strength, elasticity, and other technological properties, their processing technology becomes more complicated. There are 3 known systems for processing silk fibers. The first of them is the old classic method, in which the fibers are separated by length, passed through four passes of the combing machines, and then passed through the technological processes of obtaining the pile. These processes consist of more than 40 steps; thus, this technology is not used at all in silk spinning enterprises today.

The second method consists of carding processes, based on the stapling of long fibers by combing the silk fiber waste with a large number of carding machines.

The third method is the combing method, based on the combination of length of silk fibers and cutting in guillotine stapling machines with successive combing in shaft and carding machines.

It is impossible to effectively use natural silk fiber waste without a comprehensive analysis of the technological properties of natural silk fiber waste in the weaving industry, without taking into account their physical and mechanical properties in the process of preparing them for spinning and processing.

In silk technology, the waste is divided into fibrous and non-fibrous groups. In turn, fiber waste is divided into groups with high fiber and low fiber.

The wastes rich in fiber in the raw materials include cotton lint, cocoon lint, stringy lint, rings, control pads, rings on seriplan boards, husks of seed cocoons, rings in the process of re-wrapping and carding, wastes from carding. Low-fiber groups include fibrous waste containing sponge and its residues.

Silk spinning mills produce a variety of spun silk threads. They are produced in 20, 25, 100, and 125 tex, adding 2 of 5, 10, 7, 14 tex, depending on the purpose of use. From these assortments, the fabrics for ties, shirting, and feather dukhoba and spun silk thread are widely used in textile, knitting, and other industries. It is as well used in the production of shaped yarns by combining the spun silk threads with artificial and chemical threads, and in the production of various nets and hosiery products.

Uster Statistic 2018 was used for checking the obtained results, and the existed Spinning method was used. In order to get experimental data, it has been done min 100 tests for each type and number of yarns.

2.1. Properties and indicators of natural silk fiber waste

The improvement of waste-free technologies after the initial processing of cocoons and raw silk extraction as well as the increase of new types of assortments, taking into account the specific characteristics of products made of natural silk and the prospects of future use, and the production of various products using the separated fiber waste effectively, are among the urgent issues.

According to the classification of natural silk waste, they have about 20 types. All kinds of fiber waste are divided into two main groups, namely cocoons with defective husks, which are unsuitable for raw silk production, and separate fibrous parts of the husks formed during spinning. These wastes differ from each other in the physical and mechanical properties of the fibers, their condition, and characteristics.

Silk fiber wastes are produced in various processes: worm feeding, cocoon cultivation, cocoon sorting, spinning and raw silk production, weaving, and even garment manufacturing. Each of these processes is a very complex, multi-pass, and waste-generating process of different characteristics. Therefore, the silk fiber waste arising from the transitions of each technological process of silk and weaving enterprises will have different indicators [126].

According to the research of sources, natural silk has high physico-mechanical properties and shows a wide range of its uses. The two elementary threads are glued together by sericin to form a cocoon thread that wraps the thread unevenly. It will be less in some places and more in other places.

The main composition of the cocoon thread, i.e., fibroin 70–80 percent and sericin 20–30 percent, consists of proteins.

In addition to them, cocoon thread contains a certain amount of ethers (0.4–0.6%), alcohol (1.2–3.3%), and mineral substances (1.7–1%). These indicators are the same as in the used silk fibers, but they differ slightly in their waste. In the process of cooking the cocoons, all substances except fibroin substance and a small amount of sericin substance come out. Fibroin is white in color, and its surface is smooth, shiny, soft, and has good staining properties. Fibroin is resistant to the condition of microorganisms; it significantly loses its strength in sunlight. The moisture content of fibroin is 1–2% lower than the moisture content of raw silk.

Fibroin is able to absorb various substances. From the solution, it adsorbs copper salts, iron, chromium, tin, sugar, starch, glue, enamel substances, tannin, soap. Fibroin is inert to neutral gases but quickly absorbs acidic and alkaline gases. When it is heated up to 135 °C, fibroin does not change its properties, but under a temperature of 180 °C, it breaks down.

The swelling index of the fiber depends on the absorption of moisture from air, and the greater is the relative humidity of the air, the larger is the diameter of the fiber. For example, when silk fibers are placed in water at room temperature of 18 °C, it can be seen that the technological parameters of the fibers increase by 16–18% in width, 30–35% in weight, and 1–2% in length.

The properties of silk fiber waste, i.e., cross-section, surface defects, and physical-mechanical parameters of fibers obtained from the defective cocoons are presented in Tables 2.1–2.3 [38–39].

The fibers obtained from silk waste are high in a number of properties in terms of durability. Although they are low in shear (3.5–8 mkm), they are considered to be very strong ($s = 2,740$ MPa). At the same time, their molecular structure is irregular, and it is characterized by its high defect.

The study of the physical-mechanical and technological properties of silk fiber waste in the table and pictures showed that they are superior to cotton fibers. Therefore, it can be concluded that if a bicomponent spun yarn is produced by mixing silk waste with cotton fiber, its relative breaking strength and relative elongation to break will be higher.

Table 2.1. Cross section surface of silk waste

Indicators	Type of fibers					
	cocoon string	raw silk control mats	fibers from the well	combing waste	boiled waste	raw silk rings
Cross section surface, mm ²	0.0147	0.0121	0.14	0.0132	0.0145	0.0149
Average quadratic deviation, mm	0.019	0.0019	0.013	0.0039	0.0021	0.003
Variation coefficients, %	13.5	14.1	11.5	31.9	15.9	18.7

Table 2.2. Surface defects of silk fibers

Defects		Type of fibers	Cross section surface, mm ²	Sericin flux to water surface %	Compression, %	Cross section cracks, %	Separation of silk fibers, %	Dust, surface contamination %	Thickening, small defects, %	Crushing, breaking, %
1	Cocoon string		0.0142	39	65	21	-	-	-	23
2	Nodes		0.0125	31	39	34	-	-	-	-
3	Raw silk		0.132	-	-	-	37	33	-	-
4	Silk waste film		0.0136	3.0	10	-	-	21	21	-
5	Combing machine waste		0.0142	0.4	-	-	-	-	-	-
6	Waste		0.0148	8.1	-	20	-	-	-	12
7	Raw silk rings		0.0781	13	-	31	69	-	12	-

Table 2.3. Physico-mechanical parameters of different silk fibers

Fiber types	Cocoon string	Nodes	Raw silk	Combing waste	Combing machine waste	Bleached waste	Raw silk rings
Secondary indicators (n_1-n_2)	0.0280	0.0470	0.032	0.03	0.041	0.036	0.03
Average square deviation (n_1-n_2)	0.0043	0.013	0.0050	0.0139	0.0059	0.0081	0.05
Coefficient of variation (n_1-n_2), %	16.0	27.1	16.1	44.7	15.04	21.1	15.7

2.2. Preparation of silk fiber waste for spinning and optimal technology of producing yarn from the waste of natural fiber

Obtaining spun yarn from silk fiber waste is a very complicated process, and in order to use it effectively, the physical and mechanical parameters of the II-passage waste were studied at the beginning of the research work. For this purpose, secondary silk fiber waste was tested in the certification center of the Republic of Uzbekistan "Sifat" in the modern HVI system under standard climatic conditions (air temperature 20 ± 20 °C, relative humidity $65 \pm 2\%$, 0.10 °C according to Assman psychrometer control).

The test results are shown in Table 2.4.

The use of secondary fiber waste of natural silk expands the balance of raw materials of the textile industry as well as makes it possible to produce various fabrics and knitted products from a mixture of natural fibers. By properly choosing the spinnability of the mixture, it is possible to produce spun yarn with a high productivity and a low number of breaks in various looms, characterized by the minimum possible linear density [127–129].

When natural cotton fiber is mixed with silk fiber waste, the yarn output, characterized by the amount of spun yarn, increases. At the same time, the possibilities of positively changing the properties of spun yarn and products are expanded, and the unevenness of the spun yarn, as well as the number of breaks, is reduced.

Table 2.4. Physico-mechanical parameters of II-pass fiber waste

№	Indicators	Designation	Unit of measure	Value
1	Micronaire	Mic		4.4
2	Relative breaking strength	Str	cN/tex	32.1
3	High average length	Len	inch	1.21
4	Uniformity in length	Unf		84.4
5	Short fiber index	SFI		4.8
6	Stretching to break	Elg	%	11.8
7	Pollution code	T		2
8	Amount of waste	Cnt	piece	6
9	Area of waste mixtures	Area	%	0.2
10	Sort by color	CG		13-1
11	Light return	Rd	%	77.6
12	The degree of jaundice	+b		12.0

In the process of preparation of natural fibers for processing, it is necessary to thoroughly and completely grind them, separate them from each other, clean them from dirty additives, sort, boil, and dry them in accordance with the technological requirements. The adequate screening of secondary silk waste is required to eliminate fiber breakage and slippage.

The short fibers separated from the shearing process are secondary wastes of silk spinning. These short fibers are valuable wastes of silk fibers from the first and second weave spinning according to the classical system of silk spinning. The analysis of the research work devoted to the production of yarn from composite fibers shows that it is mainly and often focused on the combined use of natural and chemical fibers.

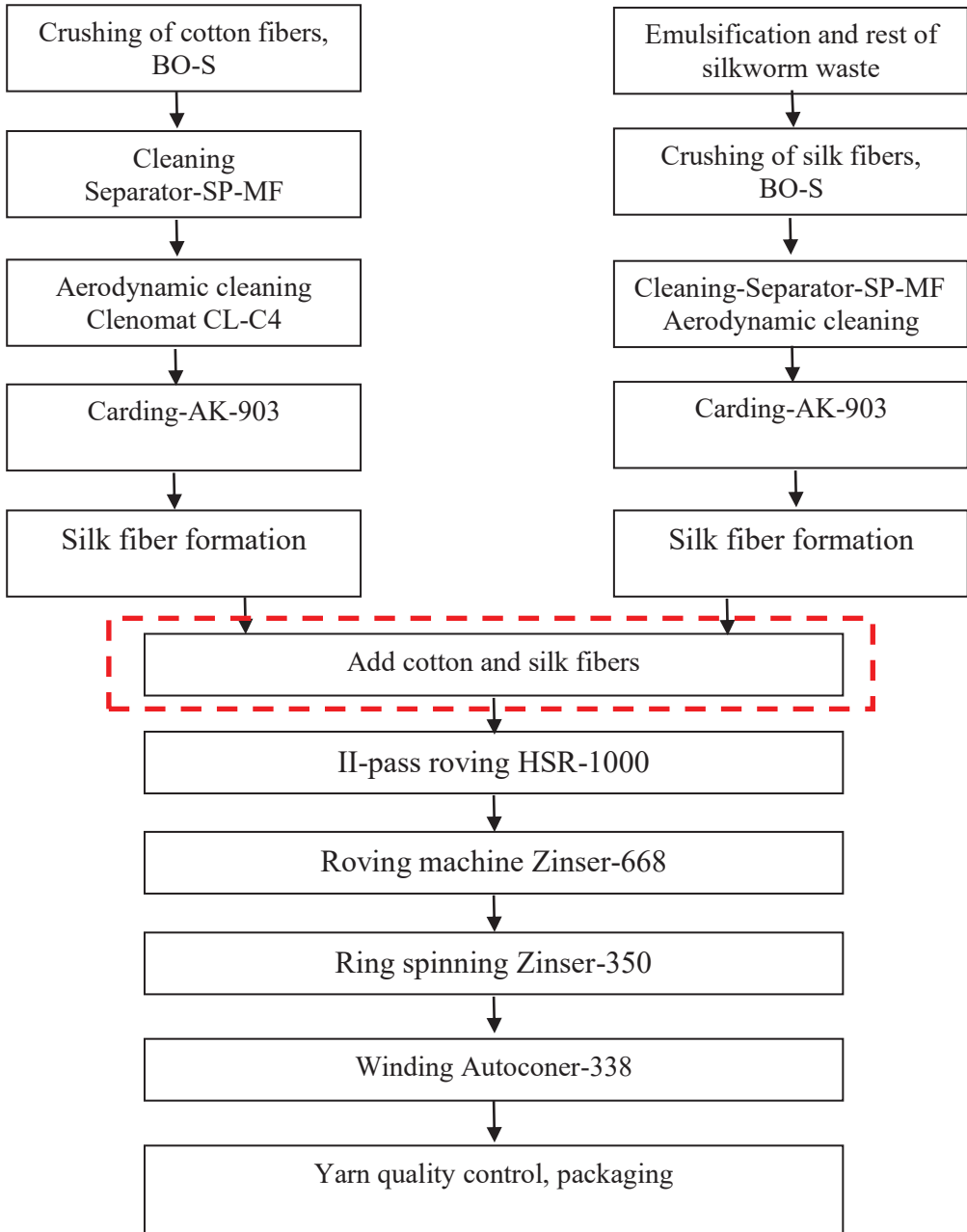


Fig. 2.1. Improved technological scheme of bicomponent yarn production from mixed fibers

By selecting the staple lengths of silk secondary fiber waste to the staple length of cotton fiber (29–35) mm, such a fiber length allows to obtain cotton-silk yarn on typical machines of the cotton spinning industry.

When recycling recycled silk waste, it is first necessary to emulsify or moisten it with a soapy solution containing 8% soap and 92% water. After the fibrous waste is emulsified, the solution should be left in the lab for at least 72 hours to be absorbed evenly.

The research is carried out on each option of wicks made of silk and cotton fibers. Due to the wide range of fiber lengths (from 1 mm to 70 mm), the secondary short waste is subjected to a carding process, silk spinning, and a wick forming system to prepare it for mixing.

Taking into account the structure, properties, and research results of some types of natural silk fiber waste, there has been developed a method for obtaining yarn mixed with cotton and silk fibers (Figure 2.1). Based on the experimental studies of staple lengths of cotton and silk (secondary waste) fibers as well as studying the modern technological chain of the card system of cotton spinning, it was considered appropriate to obtain cotton-silk spun yarn according to the indicated technology.

The card spinning system produces yarns with an average linear density of 15.4 to 33.3 tex. For the experimental process, the following technological chain is recommended in the production of bicomponent cotton-silk yarn, taking into account the compatibility of silk waste from the second combing machines of silk spinning and the staple lengths of the raw material being mixed.

For the production of cotton-silk yarn, the existing technology for spinning cotton fibers was used as a basis.

A new range of yarns with a linear density of 20 tex was made from bicomponent yarns on the following technological equipment of the companies "TRUETZSCHLER" and "ZINSER" (Germany) installed in the training laboratory of the department "Spinning Technology" (Table 2.5).

Table 2.5. Technological equipment

№	Naming of machines	Workshop model
1	Supplier mixing machine	BO-C
2	Fast condenser	LVSA
3	Single-drum fiber grinder	BE-935
4	Three-drum fiber cleaner	CLEENOMAT-CVT-3
5	Dusting machine	DX-385
6	Shaving machine	DK-903
7	I-pass threshing machine	HS-1000
8	II-pass threshing machine	HSR-1000
9	Roving machine	Zinser-668
10	Spinning machine	Zinser-350
11	Rewrapping machine	Autoconer-338

One of the main stages of work is a uniform mixing of the raw material, a uniform distribution of the fibers of each component over the entire volume, which is the essence of the mixing process. In each part of the mixture, all the component fibers must be contained in the specified recipe.

The cocoons were taken from the cotton fiber, and the cocoon was obtained from the secondary waste of silk, i.e., the secondary fiber waste generated in the production of the spun silk. In the I-pass spinning of the technological chain on the existing machines for the production of cotton yarn, an improved technology for the production of bicomponent yarn with the addition of both cotton and silk spinning has been created.

2.3. Spinning plan for the production of yarn from a mixture of cotton and silk fibers

The essence of the mixing process is to mix the two components uniformly over the entire volume of the mixture. It is necessary to have all bicomponent fibers from any part of the mixture in a proportion corresponding to the established relationship. As a result of mixing, semi-finished products with the given properties and quality spun yarn should be formed.

The initial experimental works were carried out in the equipment installed in the educational laboratory of the "Spinning Technology" department: a thread with a linear density of 20 tex was obtained from a mixture of cotton-silk fibers, and its physical and mechanical properties were studied.

In the production of thread and semi-finished products, 4 types, selection grade S-4727 II-grade cotton fiber was used as the first component, and natural silk II-weeding waste was used as the second component [130–136].

Table 2.6 below shows the quality indicators of cotton fiber.

Table 2.6. The quality parameters of the selection type S-4727 4 type II cotton fiber obtained on the "TexTechno" device

№	Indicator name	Indicators
1	Selection variety	C-4727
2	Micronaire, Mic	4.70
3	Staple length, mm	35.7
4	Upper average length, inch*100	112.1
5	Relative breaking strength, cN/tex	30.2
6	Breaking strength, cN	6.4
7	Linear density, tex	0.158
8	Coefficient of variation in staple length, %	23.1
9	Homogeneity index, %	82.9
10	Reflection coefficient, %	78.9
11	The degree of jaundice	8.3
12	Elongation at break, %	8.0
13	Fiber code	2.0
14	Short fiber index	4.8
15	Elasticity index in unity	135.79

16	The calculated stiffness of the thread is in unity	2,194.13
17	Class	Good
18	Pollution level	3.5
19	Amount of short fibers	9.2
20	Ripeness	1.6

The quality of cotton fiber meets the requirements of UzGSt [49].

Semi-finished products and yarn spinning with the following mixture percentages, i.e., from the secondary wastes from silk fiber spinning and the mixture of type II cotton fiber, 20 tex yarn was produced. The following spinning plan was used to produce a 20 tex yarn from the blended fibers (Table 2.7).

Table 2.7. Spinning plan for the production of yarn with a linear density of 20 tex

The name of the machines	Semi-finished product, yarn linear density, tex	Number of additions, d.	Elongation magnitude, E	Winding		Speed		Theoretical efficiency, kg/h. 1 exit.	Useful time coefficient
				α_t	tw/m	V m/min	n_1 min ⁻¹		
Combing machine DK 903	5,848	1	-	-	-	-	80	64.4	0.94
Carding machine HSR-1000	5,000	8	8	800	6,704.6	240	0.8	5,000	8
Roving machine Zinser-668	678	1	7.37	11.3	43.4	-	1,000	0.94 for one	0.8
Ring spinning Zinger-350	20	1	33.9	33.5	749.4	-	13,000	0.02 for one	0.97

Sliver obtained from the cotton fibers and sliver made of silk waste, sliver mixed in percentages of mixtures were prepared on the HSR-1000 carding machine.

The technological parameters of the carding machine installed in the educational laboratory for the production of bicomponent yarn are presented in Table 2.8 below.

Table 2.8. Technological indicators of the carding machine

№	Naming	Unit of measure	Indicators
1	Model of the machine	HSR-1000	
2	The linear density of the roving sliver	tex	5,000
3	Number of roving sliver	Nm	0.2
4	The number of additions		8
5	Total stretch amount	E	8.0
6	Type of stretching tool		3 x 4
7	Production speed	m/min	700
8	Machine performance	kg/h	210

The machine is equipped with "Uster Silver Control USC" autoregulation, in which the unevenness of the silver is controlled, and the transmission devices are installed in the computer system.

The quality of the semi-finished product (Sliver) and yarn developed by the mixture is evaluated by the following indicators:

- flatness and degree of parallelism of fibers in sliver;
- cross-sectional unevenness of the product, i.e., linearity and coefficient of variation;
- unevenness in long cut, i.e., 1 m for sliver, 200 m for yarn;
- unevenness in relative tensile strength and relative tensile strength of yarn;
- thread elongation;
- number of interruptions in spinning machines.

The quality indicators of semi-finished products and yarn were determined by the standard method given in STANDARD and modern PREMIER (India) measuring equipment.

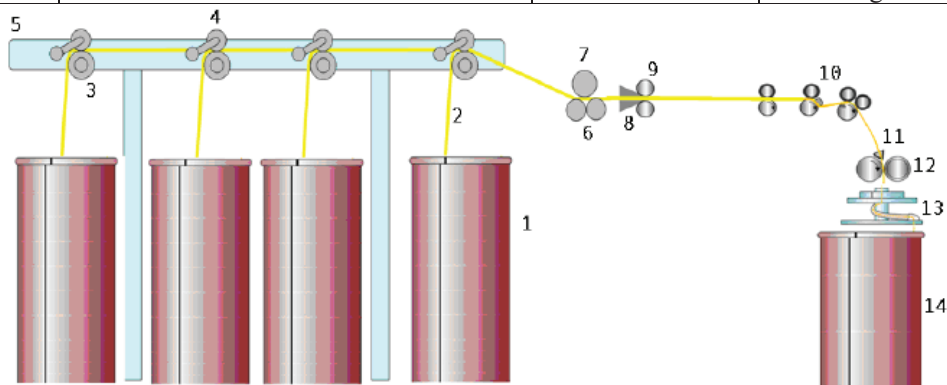
Table 2.9 shows the percentage composition of cotton fibers and silk secondary waste fibers in the Truetzschler NSR-1000 carding machine under laboratory conditions.

Table 2.9. Percentage composition of sliver

Options	Number of basin		The composition of the added slivers, %	
	Sliver (cotton)	Sliver (silk)	Sliver (cotton)	Sliver (silk)
1	7	1	87.5	12.5
2	6	2	75	25
3	5	3	62.5	37.5
4	4	4	50	50

Table 2.10. Technological indicators of Zinser-350 spinning machine

№	Naming	Unit of measure	Indicators
1	Make of the machine	Zinser-350	
2	The linear density of the roving sliver	tex	20.0 (50.0)
3	Type of the stretching tool		SKF 3 x 3
4	Total stretch amount		33.9
5	Ring diameter	mm	48
6	Packing density	g/sm ³	0.48
7	Yarn weight	g	100
8	Number of twists	tw/m	850
9	Type of packaging		Conical
10	Twist direction		Right

**Fig. 2.2.** HSR-1000 crimping machine

(1 – basins, 2 – pilta, 3 – supply roller, 4 – loading roller, 5 – supply device, 6 – transmitting rollers, 7 – loading roller, 8 – compressor, 9 – adjuster supply pair, 10 – stretching tool, 11 – compressor, 12 – output rollers, 13 – sliver upper plate, 14 – sliver basin)

In the experiment, in order to obtain yarn spun from mixed components, the method of adding rovings on the roving machine HSR-1000 was used. For this purpose, five of the eight dusts in the carding machine were made from 100% cotton fibers, and three dusts were made from 100% silk fiber waste, and a mixed slub was developed.

The main purpose of mixing slivers in the carding machine is not to lose the stability of the components of the mixture at the same time, which leads to the preservation of the required properties of semi-finished products and yarns.

From the produced sliver, the roving silver was removed on a Zinser-668 carding machine, and then, the spun yarn was prepared on a ring spinning machine. The technological parameters of the “Zinser 350” (SAURER) spinning machine installed in the laboratory are presented in Table 2.10.

2.4. Conclusions of the chapter

Based on the study of silk fiber waste, a process has been selected to obtain a mixed spun silk yarn, leaving a staple length and a certain amount of boiled sericin suitable for the secondary waste that can be mixed with cotton fiber.

In order to obtain the fabrics by weaving chemical yarns with yarns derived from natural fibers, the properties of chemical fibers were as well applied, and the polyester yarns were selected.

As a result of theoretical and practical research, it was established that the indicators of raw materials for the production of yarn from fibrous waste of cotton and silk correspond to each other.

Based on the lengths of the secondary fiber waste of silk, the correspondence of the cotton fiber to the staple lengths, the elongation processes in the strands were studied theoretically and practically, and the staple length of the fibers was 66% and 87% by weight. The length of this range has been tested in practice by the possibility of mixing silk fibers with cotton fiber.

From the cotton fibers and secondary waste fibers of silk, in the existing technologies, the cotton and silk fibers are made separately.

The cocoons were taken from the cotton fiber, and the cocoons were obtained from the secondary waste of silk, i.e., the fibers formed in the production of spun silk yarn. An improved technology for the production of bicomponent yarn, combining both cotton and silk, has been created on the I-pass spinning machine of the existing technological chain for the production of yarn from cotton fiber.

3. THEORETICAL RESEARCH OF YARN PROPERTIES

An important parameter of the structure of yarn that has been obtained by the pneumomechanical spinning method is the assessment of the structure of the outer (twisting) layer. The density and migration of fibers in compact yarn were as well studied by the method of labeled fibers. In these works, the influence of the yarn structure on its physical and mechanical properties is evaluated. In all cases, the breaking load is noted as an indicator of the mechanical properties of the yarn. This is probably due to the fact that it is given in regulatory and technical documents (in standards) as the main indicator.

3.1. Theoretical modelling of deformation of linear and nonlinear yarn of small twist

A textile thread in the form of a yarn is a structural formation of systems of interconnected fibers of a certain length and thickness. The force of interaction is realized both through the friction of a separate fiber in the matrix (bundle) and the elastic contact between the ends of the fibers (Fig. 3.1).

The yarn deformation process as a whole depends on the deformation of the individual fiber during loading and unloading. It is assumed that the pre-stretched fibers are stretched under loading, and under unloading, their length is reduced.

In work [94], a theoretical model is proposed for describing the deformation properties of small twist yarn based on the following assumptions:

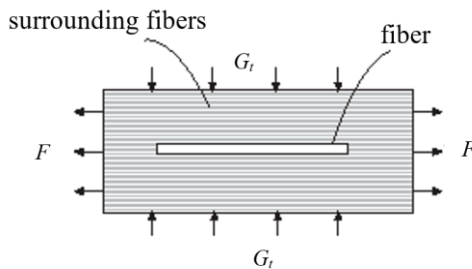


Fig. 3.1. Layout of the fiber in the spinning triangle

For yarns with zero twist:

- a) all fibers are located strictly parallel to each other;
- b) pressure G_t acts on the lateral surface of the yarn, which creates a compact packing of parallel fiber systems (Fig. 3.2);
- c) a dry friction force acts on the surface of each individual fiber, the value of which is $\tau = \mu \cdot G_t$;
- d) under the action of a tensile force F , a slip zone begins to form from the ends of each fiber, which spreads to the center of the fiber.

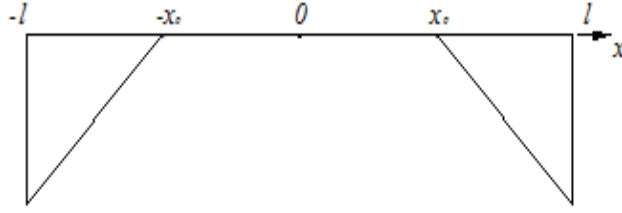


Fig. 3.2. Fiber-beam interaction diagram

There was installed the origin at the center of the fiber, and taking into account the symmetry conditions, the right half of the fiber should be considered. The axis $0x$ is directed to the right from the center of the fiber. The frictional force is directed against the axis $0x$, and then, the stress for the right side of the fiber in the presence of frictional forces, and the action of the axial force satisfies the equation:

$$\frac{d\sigma}{dx} = \frac{4\mu}{d} G_t \quad (3.1)$$

Equation (3.1) is integrated under the condition:

$$0 \leq \sigma_f \leq \sigma_f^*, \quad \sigma_1 = \sigma_f = F/S_f \quad \text{at} \quad x = l. \quad (3.2)$$

$S_f = \pi d_f^2 / 4$ is the cross-sectional area of the fiber. The fiber crumple zone consists of two parts. The first part $0 < x < x_0$ is the rest zone, where $\sigma = 0$; the second part $x_0 < x < l_e$ is the slip zone, where the stress is calculated by the formula:

$$\sigma_1 = \sigma_f + \frac{4\mu}{d_f} G_t (x - l_e) \quad (3.3)$$

The length of the rest zone is determined from the condition $\sigma = 0$ at $x = x_0$, which gives:

$$x_0 = l_e - \frac{\sigma_f d_f}{4\mu G_t} \quad (3.4)$$

It can be seen from the formula (3.4) that at $\sigma_f^* \geq \frac{4\mu G_t l_e}{d_f}$, the rest zone disappears ($x_0 = 0$), and along the fiber, the stress is distributed according to the law (3.3). Thus, in contrast to the results of work [94], where the stress in the loading zone has a constant value $\sigma = \sigma_f = E_f \varepsilon_f$, in the case under consideration, the stress linearly depends on the variable x .

Several cases should be considered, e.g., a case in Fig. 3.4. If the separation of the ends of the fiber in the matrix occur at $\sigma_f^* \leq \frac{4\mu G_t l_e}{d_f}$, then the stress along the fiber is distributed according to the laws:

$$\begin{aligned} \sigma = \sigma_1 = \sigma_f - \frac{4\mu}{d_f} G_t (l_e - x) & \quad x_0 \leq x \leq l_e \\ \sigma = 0 & \quad \text{at} \quad 0 \leq x \leq x_0. \end{aligned} \quad (3.5)$$

When $0 \leq \sigma_f \leq \sigma_f^*$ (in the absence of unloading the ends of the fibers (dotted lines)),

$$\begin{aligned} \sigma = \sigma_2 = \frac{4\mu}{d_f} G_t (l_e - x) & \quad \text{at} \quad x_1 \leq x \leq l_e, \\ \sigma = \sigma_1 = \sigma_f^* - \frac{4\mu}{d_f} G_t (l_e - x) & \quad \text{at} \quad x_0 \leq x \leq x_1, \\ \sigma = 0 & \quad \text{at} \quad 0 \leq x \leq x_0, \end{aligned} \quad (3.6)$$

after tearing off the ends from the matrix (a solid line).

Flat $\sigma_2 = \sigma_1$ at $x = x_1$, it is found:

$$x_1 = l_e - \frac{\sigma_f^* \cdot d_f}{8\mu G_t}. \quad (3.7)$$

Since $\sigma_f^* \leq \frac{4\mu G_t l_e}{d_f}$, then $x_1 \leq \frac{l_e}{2}$; Figure 3.3 shows the diagram of the stress distribution at $\sigma_f^* = \frac{4\mu G_t l_e}{d_f}$.

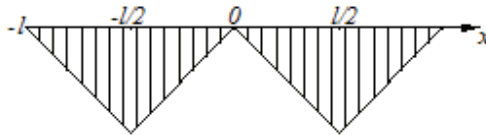


Fig. 3.3. Stress distribution plot along fibers at

$$\sigma_f^* = \frac{4\mu G_t l_e}{d_f} \quad (x_1 = \frac{l_e}{2}; \quad x_0 = 0) \quad (3.8)$$

Thus, if the separation of the ends of the fiber occurs at $\sigma_f^* \leq \frac{4\mu G_t l_e}{d_f}$, then the contact zone remains along the fiber $0 \leq x \leq x_0$, and it disappears at $\sigma_f^* = \frac{4\mu G_t l_e}{d_f}$.

Let $\frac{4\mu G_t l_e}{d_f} \leq \sigma_f^* \leq \frac{8\mu G_t l_e}{d_f}$ (case b, Figure 3.4).

Before the start of separation along the fiber, the stress is distributed according to the law (Fig. 3.4).

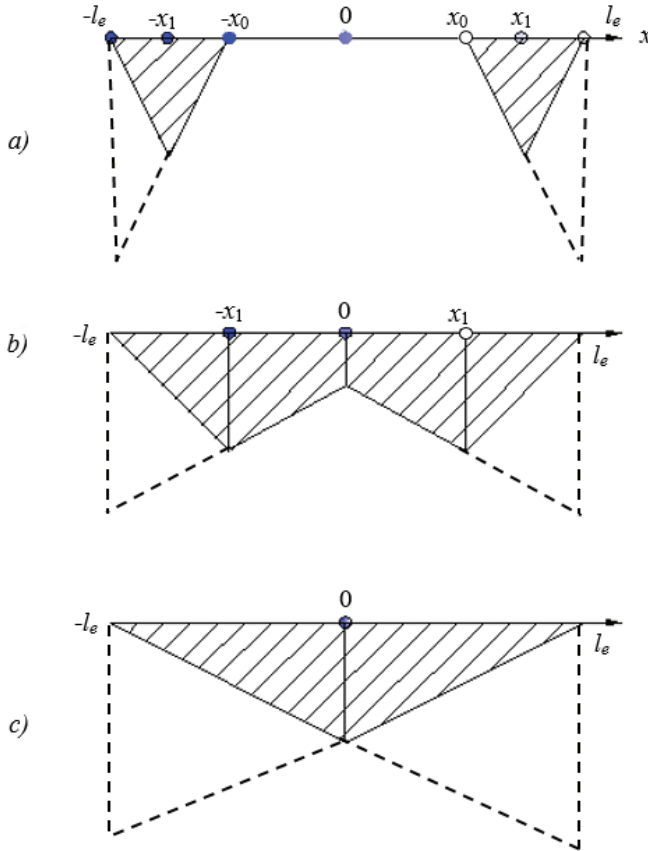


Fig. 3.4. Stress distribution diagram after unloading

$$\sigma = \sigma_1 = \sigma_f + \frac{4\mu}{d_f} G_t (x - l_e) \quad 0 \leq x \leq l_e \quad (3.9)$$

Let $\sigma_f = \sigma_f^* \leq \frac{8\mu G_t l_e}{d_f}$ the ends of the fiber detach from the matrix (Fig. 3.4 c).

Then, the stress along the fiber is determined by the formulas:

$$\begin{aligned}\sigma = \sigma_1 = \sigma_f^* + \frac{4\mu}{d_f} G_t(x - l_e) & \quad 0 \leq x \leq x_1, \\ \sigma = \sigma_2 = \frac{4\mu}{d_f} G_t(l_e - x) & \quad x_1 \leq x \leq l_e,\end{aligned}\tag{3.10}$$

$$x_1 = l - \frac{\sigma_f^* \cdot d}{8\mu G}.$$

Insofar, as $\frac{4\mu G l}{d} \leq \sigma_f^* \leq \frac{8\mu G l}{d}$, then $0 \leq x_1 \leq \frac{l_e}{2}$.

At $\sigma_f^* = \frac{4\mu G_t l_e}{d_f}$, it follows (Fig. 3.4):

$$\begin{aligned}\sigma = \sigma_1 = \sigma_f^* - \frac{4\mu}{d_f} G_t(l_e - x) & \quad \text{at} \quad 0 \leq x \leq \frac{l_e}{2}, \\ \sigma = \sigma_2 = \frac{4\mu}{d_f} G_t(l_e - x) & \quad \text{at} \quad \frac{l_e}{2} \leq x \leq l_e,\end{aligned}\tag{3.11}$$

which coincides with formulas (3.5) for $x_1 = \frac{l_e}{2}$, $x_0 = 0$.

At $\sigma_f^* = \frac{8\mu G_t l_e}{d_f}$, it follows ($x_1 = 0$):

$$\sigma = \sigma_2 = \frac{4\mu}{d_f} G_t(l_e - x) \quad 0 \leq x \leq l_e\tag{3.12}$$

Let $\sigma_f^* \geq \frac{8\mu G_t l_e}{d_f}$ (case ϵ in Fig. 3.4).

Before the start of separation (unloading) along the fiber, the stress is distributed according to the law:

$$\sigma = \sigma_1 = \sigma_f^* + \frac{4\mu G_t}{d_f} (x - l_e) \quad 0 \leq x \leq l_e.\tag{3.13}$$

After the separation of the fiber at $\sigma_f^* \geq \frac{8\mu G_t l_e}{d_f}$ and unloading:

$$\sigma = \sigma_2 = \frac{4\mu}{d_f} G_t(l_e - x) \quad 0 \leq x \leq l_e.\tag{3.14}$$

Thus, when the ends of the fiber are detached from the matrix, for $\sigma_f^* \geq \frac{8\mu G_t l_e}{d_f}$, all fibers are instantly unloaded, and a stress state is formed along it, determined by the formula (3.14), which does not depend on the voltage σ_f .

Using formulas (3.5–3.10), it is possible to find an expression for the average fiber stress as a function of σ_f , taking into account the presence of a zone of adhesion and slip.

1. Let $\sigma_f^* \leq \frac{4\mu G_t l_e}{d_f}$, then, at $0 \leq \sigma_f \leq \sigma_f^*$, the fibers are only stretched, and the average stress along the fibers will be:

$$\bar{\sigma}_{cp} = 2 \int_{1-\bar{\sigma}_f}^1 (\bar{\sigma}_f - 1 + \xi) d\xi = \bar{\sigma}_f^2 = \frac{\bar{\sigma}_f^2}{2}; \quad (3.15)$$

where $\bar{\sigma}_{cp} = \sigma_{cp} \frac{d_f}{4\mu G_t l_e}$; $\bar{\sigma}_f = \sigma_f \frac{d_f}{4\mu G_t l_e}$; $\bar{\sigma}_f^* = \sigma_f^* \frac{d_f}{4\mu G_t l_e}$;
 $0 \leq \bar{\sigma}_f \leq \bar{\sigma}_f^*$.

After unloading $\bar{\sigma}_f = \bar{\sigma}_f^* \leq 1$ ($\bar{\sigma}_f = \bar{\sigma}_f^* \leq 1$ (tearing off the ends of the fibers):

$$\bar{\sigma}_{cp} = 2 \int_{1-\bar{\sigma}_a^*}^{1-\bar{\sigma}_a^*/2} (\bar{\sigma}_f^* - 1 + \xi) d\xi + 2 \int_{1-\bar{\sigma}_f^*/2}^1 (1 - \xi) d\xi = \frac{\bar{\sigma}_f^{*2}}{2}; \quad (3.16)$$

where $\bar{\sigma}_f^* = \sigma_f^* \frac{d_f}{4\mu G_t l_e}$.

Thus, after pulling off, the average stress instantly drops from σ_f^{*2} to $\frac{\bar{\sigma}_f^{*2}}{2}$ (see Fig. 3.5).

2. Let $\frac{4\mu G_t l_e}{d_f} \leq \sigma_f^* \leq \frac{8\mu G_t l_e}{d_f}$. The average stress at $\frac{4\mu G_t l_e}{d_f} \leq \sigma_f \leq \sigma_f^*$ (before separation) has the following form:

$$\bar{\sigma}_{cp} = 2 \int_0^1 (\bar{\sigma}_a + \xi - 1) d\xi = 2\bar{\sigma}_f - 1. \quad (3.17)$$

After separation, it has the following form:

$$\bar{\sigma}_{cp} = 2 \left[\int_0^{1-\bar{\sigma}_f^*/2} (\bar{\sigma}_f^* + \xi - 1) d\xi + \int_{1-\bar{\sigma}_f^*/2}^1 (1 - \xi) d\xi \right] = 2\bar{\sigma}_f^* - \frac{\bar{\sigma}_f^{*2}}{2} - 1. \quad (3.18)$$

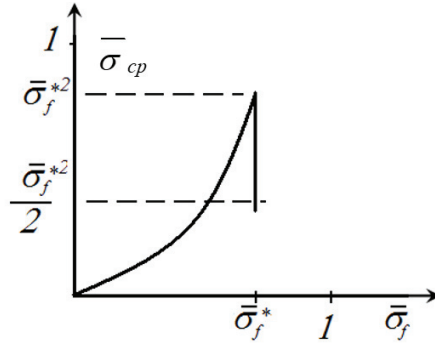


Fig. 3.5. Change in average fiber stress after separation from the bundle

As it can be seen from the graphs, voltage is variable. Thus, as a result of modeling the deformation of a small twist yarn, it has been found that the stress linearly depends on the location of the fiber in the bundle. If it is located in the contact zone, the voltage is constant; if the fiber leaves this zone and goes into the slip zone, the voltage becomes variable. When the end of the fiber breaks away from the bundle, the voltage goes to zero, and the yarn breaks. Thus, due to the mobility of the fibers, they are removed from the bundle, which is the reason for the breakage of the yarn as a whole. It follows from the analysis of the obtained formulas that the stress state of the fiber after breaking the contact of its ends with the bundle depends on the values of the initially applied tensile force F pressing it against the bundle pressure G_t , the friction coefficient μ , and the fiber diameter d_f .

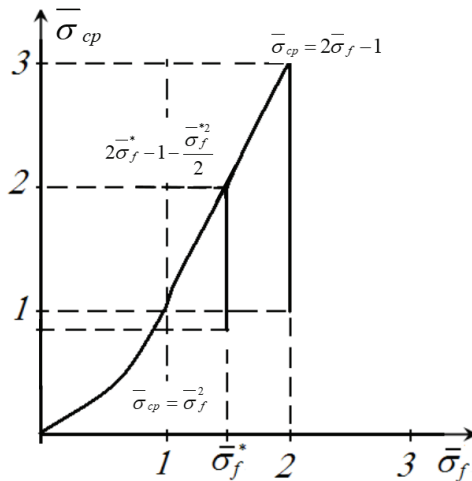


Fig. 3.6. Voltage change at the moment of separation of the fiber from the bundle

Thus, it can be concluded that by means of theoretical modeling of the deformation of a small twist yarn, the conditions for maintaining or violating its

integrity are determined, i.e., the yarn break conditions. More interesting is the consideration of the tensile and twisting behavior of the yarn.

Comparing formulas (3.17) and (3.18), it has been noticed that at the moment of fiber separation at $\sigma_f \geq \frac{4\mu G_t l_e}{d_f}$, voltage from $2\bar{\sigma}_f^* - 1$ (before separation) drops to the value $2\bar{\sigma}_f^* - 1 - \frac{\bar{\sigma}_f^2}{2}$ (Fig. 3.6).
 $\bar{\sigma}_{cp}$

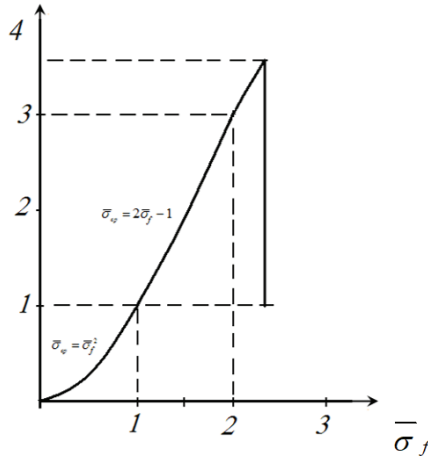


Fig. 3.7. Change in mean voltage in the case of $\sigma_f \geq \frac{8\mu G_t l_e}{d_f}$

3. Finally, considering the case $\sigma_f^* \geq \frac{8\mu G_t l_e}{d_f}$, before unloading the fiber, it has:

$$\bar{\sigma} = 2\bar{\sigma}_f - 1. \quad (3.19)$$

After unloading:

$$\bar{\sigma} = 1. \quad (3.20)$$

Thus, in case $\sigma_f \geq \frac{8\mu G_t l_e}{d_f}$, the average voltage $\bar{\sigma}$ from $2\bar{\sigma}_f - 1$ falls to $\bar{\sigma} = 1$ (Fig. 3.7).

Thus, on the basis of modeling the deformation of a small twist yarn, the conditions for maintaining or violating its integrity are determined, i.e., the yarn break conditions.

3.2. Analysis of the stress-strain state of the yarn based on the theory of elasticity

In order to assess the indicators of the mechanical characteristics of the yarn, it is necessary to analyze the stress-strain state of the yarn, taking into account its structure.

In order to do this, a yarn in the form of a cylinder, which is symmetric along the axis and is an anisotropic body, should be considered. The yarn is as well uniform along the axis; the fibers are very thin compared to the diameter of the yarn, and the fiber is isotropic in cross section. Thus, the yarn is considered in the form of a cylinder to carry out all calculations in the polar coordinates (r_p, θ_p, z_p) of the cylinder (Fig. 3.8). The yarn has an axis of symmetry, along which it is uniform. Therefore, stress and strain are functions of only the radial and longitudinal coordinates r_p and z_p .

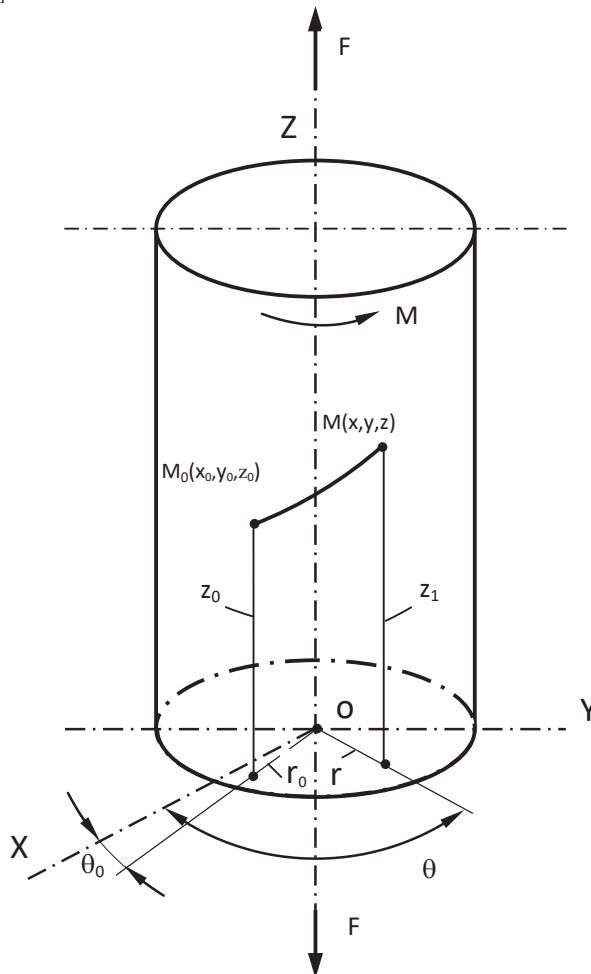


Fig. 3.8. Yarn deformation diagram

There was considered a yarn on the segment $z_p = l_y$, where the yarn is under the action of the external tensile force F and a torque M_t in the equilibrium position and displacement of an arbitrary point M (x, y, z) in directions along the axes of cylindrical coordinates $0r_p, 0\theta_p, 0z_p$ that are denoted through $U_r(r_p, z_p), U_\theta(r_p, z_p)$, and $U_z(r_p, z_p)$ (Fig. 3.8). Having designated the origin of the coordinates at point 0 , the $0z_p$ axis is directed upward.

The tensile deformation of the yarn along the axis will be denoted by ε_y and the orientation angle by θ , which is called differently in different sources, i.e., spiral angle [56], orientation angle [57], even ascent angle [58]. Regardless of its name, its value varies from zero at the center of the thread diameter to the value of the twist angle on its surface. Then, the displacements along the axes $0r_p, 0\theta_p$, and $0z_p$ can be written as a sum of the following form:

$$U_r = u_r(r_p) + A_1 r_p (z_p - l_y)^2, \quad U_\theta = u_\theta(r_p) + r_p \theta (z_p - l_y), \quad (3.21)$$

$$U_z = u_z(r_p) + \varepsilon_y (z_p - l_y) + \varepsilon_1 \frac{(z_p - l_y)^3}{3} + \varepsilon_y l_y + \varepsilon_1 \frac{l_y^3}{3}. \quad (3.22)$$

The first terms $u_\theta(r_p)$, $u_z(r_p)$ and $u_r(r_p)$ are displacements resulting from the non-linear deformation of the yarn. The yarn deformation, taking into account the displacements, is calculated using the formula [60].

$$\varepsilon_{11} = \varepsilon_{rr} = \frac{du}{dr_p} + \frac{1}{2} \left[\left(\frac{du_r}{dr_p} + A_1 (z_p - l_y)^2 \right)^2 + \left(\frac{du_\theta}{dr_p} + \theta_p z_p \right)^2 + \left(\frac{du_z}{dr_p} \right)^2 \right] \quad (3.23)$$

Tangential deformation along the 0θ axis is provided below.

$$\varepsilon_{22} = \varepsilon_{\theta\theta} = \frac{u_r}{r_p} + \frac{1}{2r_p^2} \left[u_r^2 + (u_\theta + r_p \theta_p)^2 \right] \quad (3.24)$$

$$\varepsilon_{33} = \varepsilon_{zz} = \varepsilon_y + \frac{1}{2} (\varepsilon_0^2 + r_p^2 \theta_p^2) + \varepsilon_1 (z_p - l_y)^2 \quad (3.25)$$

$$2\varepsilon_{11} = 2\varepsilon_{12} = 2\varepsilon_{r\theta} = \frac{du_\theta}{dr_p} - \frac{u_\theta}{r_p} + \frac{1}{r_p} \left\{ \left(\frac{du_\theta}{dr_p} + \theta_p z_p \right) u_r - \left[\frac{du_r}{dr_p} + A_1 (z_p - l_y)^2 \right] (u_\theta + r_p \theta_p (z_p - l_y)) \right\} \quad (3.26)$$

$$2\varepsilon_{31} = 2\varepsilon_{13} = 2\varepsilon_{zr} = 2\varepsilon_{rz} = \frac{du_z}{dr_p} (1 + \varepsilon_y) + A_1 r_p (z_p - l_y) \quad (3.27)$$

$$2\varepsilon_{23} = 2\varepsilon_{32} = 2\varepsilon_{\theta z} = 2\varepsilon_{z\theta} = \frac{du_{\theta}}{dz_p}(1+u_r) + r_p\theta_p \quad (3.28)$$

Using Hooke's law, the deformations and stress tensor components are determined:

$$\sigma_{rr} = b\varepsilon_{rr} + d\varepsilon_{\theta\theta} + a\varepsilon_{zz}, \quad \sigma_{\theta\theta} = d\varepsilon_{rr} + b\varepsilon_{\theta\theta} + a\varepsilon_{zz},$$

$$\sigma_{zz} = a\varepsilon_{rr} + a\varepsilon_{\theta\theta} + c\varepsilon_{zz}, \quad \sigma_{r\theta} = 2\varepsilon_{r\theta} \cdot G, \quad \sigma_{rz} = 2\varepsilon_{rz} \cdot G, \quad \sigma_{\theta z} = 2\varepsilon_{\theta z} \cdot G; \quad (3.29)$$

$$\text{where } a = \frac{\nu_{12}(\nu_{32}+1)}{E_1 E_2 \Delta}, \quad b = \frac{E_1 - \nu_{12}^2 E_2}{E_1^2 E_2 \Delta}, \quad c = \frac{1 - \nu_{32}}{E_2 \Delta}, \quad d = \frac{E_2 \nu_{12}^2 + \nu_{32} E_1}{E_1^2 E_2 \Delta},$$

$$\Delta = \frac{(1 + \nu_{32})}{E_1^2 E_2^2} [(1 - \nu_{32}) E_1 - 2\nu_{12}^2 E_2]; \quad (3.30)$$

where ν_{32} – Poisson's ratio, which determines the transverse deformation arising under the action of the tensile force along the θr_p and $\theta\theta_p$ axes.

Thus, the indicators of the mechanical properties of the yarn can be determined by five parameters: E_1 , E_2 , ν_{12} , ν_{23} , and G . The stresses σ_{ij} satisfy the following equilibrium equations:

$$\frac{\partial \sigma_{rr}}{\partial r_p} + \frac{\sigma_{rr} - \sigma_{\theta\theta}}{r_p} + \frac{\partial \sigma_{rz}}{\partial z_p} = 0, \quad (3.31)$$

$$\frac{2\sigma_{r\theta}}{r_p} + \frac{\partial \sigma_{r\theta}}{\partial r_p} + \frac{\partial \sigma_{\theta z}}{\partial z_p} = 0, \quad (3.32)$$

$$\frac{\sigma_{rz}}{r_p} + \frac{\partial \sigma_{zr}}{\partial r_p} + \frac{\partial \sigma_{zz}}{\partial z_p} = 0. \quad (3.33)$$

Substituting the values of σ_{ij} from formulas (3.29) and taking into account the deformations (3.23–3.26), a system of three nonlinear equations is formed, which in the general case cannot be solved analytically. Therefore, in order to obtain a solution to the equations, it is necessary to apply numerical methods. Let assume that $u_z(r_p) = 0$ and consider a particular case. Taking into account the influence of the orientation angle $\theta = \theta_0/l_y$ on the deformations ε_{rr} , $\varepsilon_{\theta\theta}$, ε_{zz} and using formulas (3.23–3.31), the deformations ε_{ij} will be obtained in the form:

$$\varepsilon_{rr} = \frac{du_r}{dr_p} + A_1(z_p - l_y)^2 + \frac{1}{2}\theta^2(z_p - l_y)^2,$$

$$\varepsilon_{\theta\theta} = \frac{u_r}{r_p} + \frac{1}{2}\theta^2(z_p - l_y)^2 + A_1(z_p - l_y)^2,$$

$$\varepsilon_{\alpha z} = \frac{r_p \theta}{2}, \quad \varepsilon_{rz} = A_1 r_p (z_p - l_y), \quad \varepsilon_{zz} = \varepsilon_y + \varepsilon_1 (z_p - l_y)^2, \quad \varepsilon_{r\theta} = 0. \quad (3.34)$$

where constants A_1 and ε_1 are determined from the conditions of transformation of equation (3.33) into identity, and the voltage σ_{rz} does not depend on z_p .

The stress tensor components (3.29) are determined according to Hooke's law.

$$\sigma_{rr} = d \frac{du_r}{dr_p} + \varepsilon \frac{u_r}{r_p} + \left[a \varepsilon_1 + (\varepsilon + d) \left(A_1 + \frac{1}{2} \theta^2 \right) \right] (z_p - l_y)^2 + a \varepsilon_y$$

$$\sigma_{\theta\theta} = \varepsilon \frac{du_r}{dr_p} + d \frac{u_r}{r_p} + \left[a \varepsilon_1 + (\varepsilon + d) \left(c A_1 + \frac{1}{2} \theta^2 \right) \right] (z_p - l_y)^2 + a \varepsilon_y$$

$$\sigma_{zz} = a \left(\frac{du_r}{dr_p} + \frac{u_r}{r_p} \right) + (\theta^2 + 2A_1 a + c \varepsilon_1) (z_p - l_y)^2 + c \varepsilon_y$$

$$\sigma_{rz} = A_1 r_p (z_p - l_y) G, \quad \sigma_{\alpha z} = \frac{E_2 \theta r_p}{2(1 + \nu_{32})}, \quad \sigma_{r\theta} = 0.$$

From the condition that the stress σ_{zz} is independent of the variable z_p , the following equation is obtained:

$$a \varepsilon_1 + (\varepsilon + d) \left(A_1 + \frac{1}{2} \theta^2 \right) = 0. \quad (3.35)$$

Substitute stresses σ_{rz} and σ_{zz} into equation (3.27):

$$4A_1 (z_p - l_y) G + 2(\theta^2 a + 2A_1 a + c \varepsilon_1) (z_p - l_y) = 0, \quad (3.36)$$

from this, the following equation is obtained:

$$2A_1 G + \theta^2 a + 2A_1 a + c \varepsilon_1 = 0. \quad (3.37)$$

From equations (3.30) and (3.31), the constants A_1 and ε_1 are found.

$$A_1 = -\theta^2 \frac{1}{2(1-2\beta)}, \quad \varepsilon_1 = \theta^2 \frac{\beta}{1-2\beta} \cdot \frac{1}{\nu_{12}}, \quad \beta = \frac{G}{E_1} \cdot \frac{\nu_{12}(1+\nu_{32})(1-\nu_{32}-2\nu_{12}^2 E_2)}{1-\nu_{32}-2\nu_{12}^2(1+\nu_{32}) \cdot E_2},$$

$$E_2 = \frac{E_2}{E_1}. \quad (3.38)$$

Thus, for the displacements U_r , U_θ , U_z , the following expressions are obtained:

$$U_r = u_r(r_p) - \theta^2 \frac{r_p (z_p - l_y)^2}{2(1-2\beta)},$$

$$U_\theta = r_p \theta (z_p - 1), \quad U_r = \xi_0 z_p + \frac{\theta^2 \beta}{3\nu_{12}(1-2\beta)} [(z_p - l_y)^3 + l_y^3]. \quad (3.39)$$

Similarly, for stresses, the formulas are obtained:

$$\begin{aligned} \sigma_{rr} &= d \frac{du_r}{ar_p} + \epsilon \frac{u_r}{r_p} + a\epsilon_y, & \sigma_{\theta\theta} &= \epsilon \frac{du_r}{ar_p} + d \frac{u_r}{r_p} + a\epsilon_y, \\ \sigma_{zz} &= \frac{\theta^2 G}{2(1-2\beta^2)} \cdot (z_p - l_y)^2 + a \left(\frac{du_r}{ar_p} + \frac{u_r}{r_p} \right) + c\epsilon_y, \\ \sigma_{\theta z} &= \frac{r_p \theta \cdot E_2}{2(1+\nu_{32})}, & \sigma_{rz} &= -\frac{\theta^2 \cdot r_p (z_p - l_y)}{1-2\beta} G, & \sigma_{r\theta} &= 0. \end{aligned} \quad (3.40)$$

The function $u_r(r_p)$ is defined as follows: $\frac{d^2 u_r}{ar_p^2} + \frac{1}{2} \frac{du_r}{ar_p} - \frac{u_r}{r_p^2} = 0$, for $u_r = 0$, $r_p = 0$, applying the conditions $\sigma_{rr} = 0$, $r_p = R$, it is found:

$$u_r = -\frac{a\epsilon_0 r_p}{a + \epsilon} = -\nu_{12} \cdot \epsilon_y r_p. \quad (3.41)$$

Thus, the following expressions can be written for U_r and σ_{zz} :

$$U_r = -\nu_{12} \epsilon_y r_p - \theta^2 \frac{r_p (z_p - l_y)^2}{2(1-2\beta)}, \quad \sigma_{zz} = \frac{\theta^2 \cdot G}{1-2\beta} (z_p - l_y)^2 + (c - 2a\nu_{12}) \epsilon_y. \quad (3.42)$$

In order to determine the angle of orientation θ and the tensile deformation of the yarn ϵ_y , the following conditions are used:

$$M_t = 2\pi \int_0^R r_p^2 \sigma_{\theta z} dr_p, \quad F = 2\pi \int_0^R r_p \sigma_{zz} |_{z=l} \cdot \quad (3.43)$$

Hence, θ and ϵ_y are determined:

$$\theta = \frac{4M_t(1+\nu_{32})}{\pi R^4 \cdot E}, \quad \epsilon_y = \frac{F}{\pi R^2 (c - 2a\nu_{12})}. \quad (3.44)$$

The total yarn deformation along the axis is determined using the formula:

$$\epsilon_{zz} = \frac{F\beta}{\pi R^2 E_1 \nu_{12}} + \theta^2 l_y^2 \cdot \frac{\beta}{1-2\beta} \left[1 - \left(\frac{z_p}{l_y} \right) \right]^2. \quad (3.45)$$

Fig. 3.9 shows changes in the deformation ϵ_{zz} along the yarn axis for different values of Young's modulus E_l and orientation angle θ . For the calculation, the

following parameter values were taken: $l_y = 1$ M, $E_2/E_1 \approx 0$, $G = 5 \cdot 10^{-4}$ H/MM², $\nu_{12} = \nu_{32} = 0.5$ [61–63].

From the analysis of the graphs obtained, it has been found that the tensile deformation of the yarn reaches the maximum at the attachment point, and at its other end, the deformation value is equal to ε_y . With an increase in Young's modulus, the deformation decreases proportionally, and with an increase in the orientation angle, the deformation of the yarn increases.

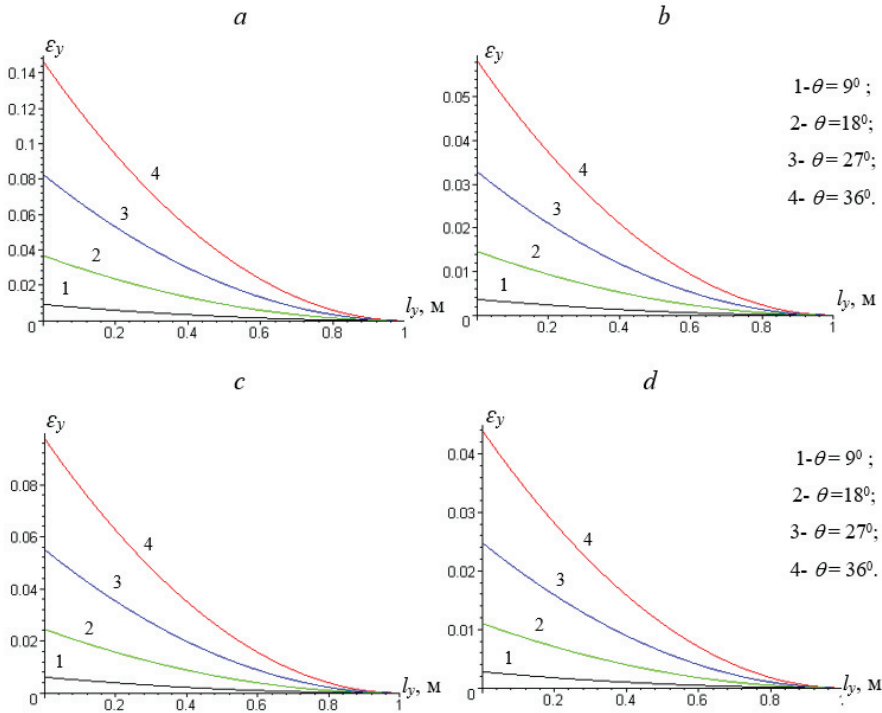


Fig. 3.9. Yarn deformations ε_y along its axis at different values of Young's modulus E_1 and orientation angle θ

$$(a - E_1 = 1200H / \text{MM}^2, b - E_1 = 1820H / \text{MM}^2, c - E_1 = 3020H / \text{MM}^2, d - E_1 = 4000H / \text{MM}^2)$$

Thus, the dependence of the total deformation along the yarn axis on its elastic properties has been established, and the influence of Young's modulus and the angle of orientation on the yarn deformation has been determined. In the future, in order to assess the indicators of the mechanical characteristics of the yarn, its deformation should be considered, taking into account the elastic and elastic-plastic deformation of the fibers.

3.3. Statistical analysis of the yarn deformation taking into account elastically and elastic-plastic deformation of cotton and other natural fibers

Experimental data show that the mechanical properties of the yarn significantly depend on the deformation of the individual fibers and the nature of the implementation of the contact forces of interaction between the fibers during torsion of the product [64–65]. If a yarn consisting of identical stretched fibers and located along helical lines with a constant pitch is considered, then, depending on the value of the twist angle and the value of the coefficient of friction between the fibers, a radial stress arises in the cross section of the product, determined by the formula (3.46):

$$\sigma_r = \sigma_f \cos^2 \beta \frac{(1 - \frac{\rho^2}{R^2}) \sin^2 \beta}{2 \left[\left(\frac{\rho}{R} \right)^2 \sin^2 \beta + \cos^2 \beta \right]}. \quad (3.46)$$

In formula (3.46), the stress σ_f is assumed to be the same for all fibers, while the mechanical property of each fiber is determined by its modulus of elasticity E_f . It is assumed that the product consists of many fibers with the same relative deformation ε_f , but different efforts due to their transition to the plastic state according to the Prandtl scheme [66]. Thus, there will be distinguished fibers for which Hooke's law is fulfilled:

$$\sigma_f = E_f \varepsilon_f; \quad (3.47)$$

where ε_f is the relative deformation of the fiber, and those fibers for which the relationship between stress and strain obeys the law:

$$\sigma_f = (E_f - E_{1f}) \varepsilon_s + E_{1f} \varepsilon_f. \quad (3.48)$$

The statistical method will be applied for an analytical description of the deformation process of a system with an unlimited number of fibers. Due to the difference in the law of deformation for different fibers, the stresses over the cross section of the product, if considered on very small areas, will be extremely unevenly distributed. This unevenness cannot be taken into account by the methods of the theory of elasticity and cannot be detected by the experimental methods. The main task of the theory of internal friction is to relate the value of the average stress to the values of stresses in individual fibers. The statistical average of the stress is calculated using an integral:

$$\bar{\sigma} = \int_0^{\infty} \sigma_f p(\alpha) d\alpha \quad (3.49)$$

where $p(\alpha)$ is the distribution function. It can be seen from the formula (3.49) that the average statistical value of the stress depends on the distribution of stress along the fibers. There should be considered a case when the dependence of stress on deformation in one part of the pulp obeys Hooke's law, and in the second part, it is determined according to the Prandtl scheme [67].

$$\sigma_f = E_f \varepsilon_f \quad \text{at} \quad 0 < \varepsilon_f < \alpha; \quad \sigma_f = (E_f - E_{1f})\alpha + E_{1f}\varepsilon_f \quad \text{at} \quad \varepsilon_f \geq \alpha.$$

In this case, the parameter α is determined through the initial stress σ_i and the proportionality limit $\sigma_s = E_f \varepsilon_s$ according to the formula $\alpha = (\sigma_s - \sigma_i) / E_f$. Thus, there, the voltage σ_s is of a random nature, as a result of which the parameter α has a statistical significance.

Then, the expression (3.49) is written in the following form:

$$\bar{\sigma} = \int_{\varepsilon_f}^{\infty} E_f \varepsilon_f p(\alpha) d\alpha + \int_0^{\varepsilon_f} [(E_f - E_{1f})\alpha + E_{1f}\varepsilon_f] p(\alpha) d\alpha. \quad (3.50)$$

Taking into account the equalities $\int_0^{\infty} p(\alpha) d\alpha = 1$, the last expression is brought to the form:

$$\bar{\sigma} = E_f \varepsilon_f - (E_f - E_{1f}) \int_0^{\varepsilon_f} (\varepsilon_f - \alpha) p(\alpha) d\alpha. \quad (3.51)$$

Expression (3.51) represents Hooke's law, complicated by the influence of plastically deformed fibers in the presence of initial stresses. If the dependences of $\sigma(\varepsilon_f)$ individual elements are represented by a Hooke diagram or a Prandtl diagram, the dependence for the model of the average statistical stress $\bar{\sigma}(\varepsilon_f)$ as a whole will already be depicted as a certain curve.

The specific form of the right-hand side of the expression (3.51) depends on the form of the function $p(\alpha)$. This function must have the following properties: it must have a maximum at some value $\alpha = \alpha_0$, which corresponds to the transition of the most of the fibers to the plastic state; at $\alpha = 0$, it should not vanish, since physically internal friction will exist even at low stress values; $p(\alpha) \rightarrow 0$ at $\alpha \rightarrow \infty$ because there is no infinite yield fiber in the product. There follows the consideration of fibers, for which the stresses do not reach the yield point. Considering the case of a normal distribution, according to which:

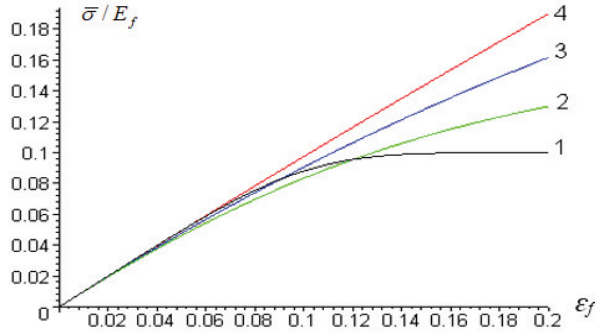
$$p(\alpha, a_2, D) = \frac{1}{\sqrt{2\pi}D} \exp\left(-\frac{(\alpha - a_2)^2}{2D^2}\right). \quad (3.52)$$

Formula (3.51), taking into account the adopted distribution law, takes the form:

$$\bar{\sigma} = E_f \varepsilon_f - (E_f - E_{1f}) \left\{ (\varepsilon_f - a_2) \Psi(\varepsilon_f, a_2, D) - D^2 [p(\varepsilon_f, a_2, D) - p(0, a_2, D)] \right\};$$

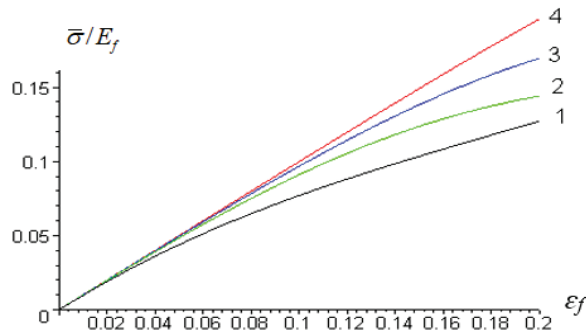
where

$$\Psi(\varepsilon_f, a_2, D) = \frac{1}{\sqrt{2\pi}} \left[\int_0^{\frac{a_2}{D}} \exp\left(-\frac{t^2}{2}\right) dt + \int_0^{\frac{\varepsilon_f - a_2}{D}} \exp\left\{-\frac{t^2}{2}\right\} dt \right]. \quad (3.53)$$



1 - $D = 0,03$; 2 - $D = 0,1$; 3 - $D = 0,2$; 4 - $D = 0,8$

Fig. 3.10. Dependences of the ratio $\bar{\sigma} / E_f$ on strain ε_f at $a_2 = 0,1$ and different values of dispersion



1 - $a_2 = 0,03$, 2 - $a_2 = 0,1$, 3 - $a_2 = 0,2$, 4 - $a_2 = 0,8$

Fig. 3.11. Dependences of the ratio $\bar{\sigma} / E_f$ on the strain ε_f at $D = 0,1$ and different values of the mathematical expectation

Figure 3.10 shows the dependence of the ratio $\sigma = \frac{\bar{\sigma}}{E_f}$ on the strain ε_f at $a_2 = 0,1$ and different values of the variance D . It can be seen that at low values of the variance, the dependence $\bar{\sigma} = f(\varepsilon_f)$ has a nonlinear character, and with increasing variance, this dependence becomes linear. Thus, the nonlinear properties of the yarn appear at the small scatter of the plastic properties of the fibers.

Figure 3.11 shows similar dependences at $D = 0,1$ and different values of the mathematical expectation of a_2 . It can be seen that the manifestation of the yarn nonlinearity is as well associated with low values of the mathematical expectation.

As a result of the analysis of the yarn deformation, taking into account the elastic and elastic-plastic deformation of the fibers, the dependence of the average stress of the yarn on the deformation of the fiber was established, which at low values of dispersion, has a nonlinear character, and with increasing dispersion, this dependence becomes linear. Thus, the nonlinear properties of the yarn appear at the small scatter of the plastic properties of the fibers, which must be taken into account when assessing the strength of the yarn.

3.4. The proposed mathematical model of the yarn

This section examines the issues of the occurrence of zones where the fibers slip relative to the yarn or where is no mutual displacement. In the absence of mutual displacement of a fiber located along the helical lines and passing through an arbitrary point of the yarn cross section, its deformation is determined by the formula proposed in the work [94]:

$$\varepsilon_f = \varepsilon_y (\cos^2 \theta - \nu_{12y} \sin^2 \theta), \quad (3.54)$$

$$\cos \theta = h / \sqrt{h^2 + 4\pi^2 \rho^2}. \quad (3.55)$$

Angle θ is variable and from zero at the center of the yarn to a twist angle of β at its surface. Let a stress σ_a in the axial direction and pressure (compressive stress) G_t act on the fiber. Under the action of these forces, the linear deformation of the fiber according to Hooke's law is determined by a formula (3.36).

$$\varepsilon_f = \frac{\sigma_a}{E_f} - \frac{2\nu_{12f}}{E_f} (-G_t) \quad (3.56)$$

Comparing formulas (3.54) and (3.56), a relationship has been established between stress $\sigma_a = \sigma \cdot E_f \varepsilon_y$ and pressure $G_t = g E_f \varepsilon_y$.

$$\sigma = \cos^2 \theta - \nu_{12} \sin^2 \theta - 2\nu_{12f} g; \quad (3.57)$$

where $\sigma = \frac{\sigma_a}{\sigma_f}$, $g = \frac{G_t}{\sigma_f}$. Function g is the solution of differential equation for the equilibrium of a fiber in a matrix and has the form:

$$g = \frac{1 + \nu_{12}}{(1 + 2\nu_{12f})} \frac{c^2}{u^2} (1 - u^{1+2\nu_{12f}}) - \nu_{12} \frac{1 - u^{2\nu_{12f}-1}}{(2\nu_{12f} - 1)}; \quad (3.58)$$

where $u = c / \cos\theta$, $c = \cos\beta$.

In this work, it is proposed to express the compressive stress (pressure) G_t in the accepted notation by using the formula proposed in the work [94].

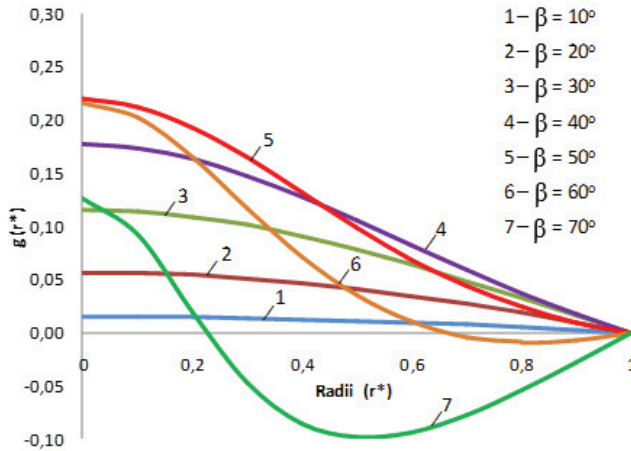
$$G_t = E_f \varepsilon_f \frac{(R^2 - \rho^2) \cos^2 \beta \sin^2 \beta}{2(\rho^2 \sin^2 \beta + R^2 \cos^2 \beta)} \quad (3.59)$$

Substituting the expression G_t from (3.57) into (3.59), it is obtained:

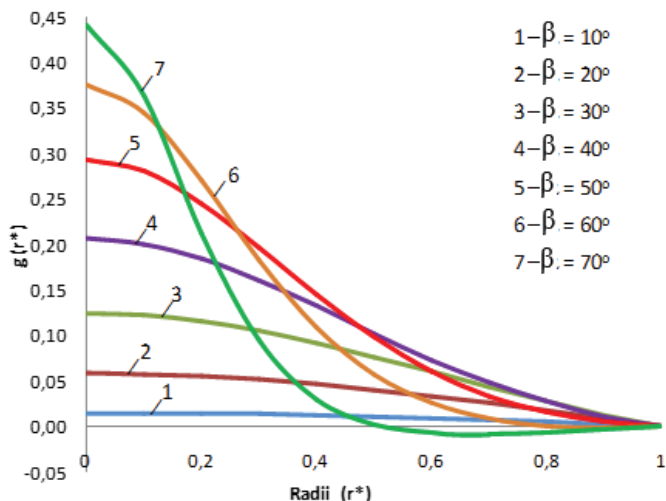
$$\varepsilon_f = \frac{\sigma_a}{E_f} + \nu_{12f} \varepsilon_f \frac{(R^2 - \rho^2) \cos^2 \beta \sin^2 \beta}{(\rho^2 \sin^2 \beta + R^2 \cos^2 \beta)}. \quad (3.60)$$

From the last expression, ε_f is found and taking into account formula (3.57):

$$\sigma = (\cos^2 \theta - \nu_{12f} \sin^2 \theta) \left[1 - \nu_{12f} \frac{(R^2 - \rho^2) \cos^2 \beta \sin^2 \beta}{\rho^2 \sin^2 \beta + R^2 \cos^2 \beta} \right]. \quad (2.61)$$



a) Modeled after J.W.S. Hearle



b) According to the proposed model

Fig. 3.12. Distribution curves of the compressive fiber reduced stress $g = G_t / E_f \varepsilon_y$ along the radius $r^* = \rho / R$ for different values of the angle of torsion β

Figure 3.12 shows the dependence curves of the function $g = G / E_f \varepsilon_y$ (where G_t is determined by a formula (3.59)) on the ratio $r^* = \rho / R$ for various values of the torsion angle β . It can be seen that the force (pressure) compressing the fibers in the center of the yarn takes on a maximum value, which increases significantly with an increase in the angle β . An increase in the angle of torsion leads to an uneven distribution of pressure along the radius of the yarn. This pattern is most clearly seen for angle $\beta > 40^\circ$.

Comparing the curves obtained by the J.W.S. Hearle model (see Figure 3.12 a) and the proposed model (see Figure 3.12 b), it is easy to see that the J.W.S. Hearle model is acceptable up to the value of the torsion angle $\beta = 50^\circ$. It means that the existing model does not take into account the technological regimes of high speed spinning machines. Due to these regimes, the changes in the yarn structure occur.

3.5. Conclusions of the chapter

Based on the study of change in the structure of the yarn during its stretching and torsion, the mechanical characteristics of the yarn were evaluated, and it has been found that the stressed state of the fiber at the moment of breaking the contact of its ends with the bundle depends on the values of the initially applied tensile force pressing it to the pressure bundle, the coefficient of friction of the fiber, and fiber diameter.

It has been established that the tensile strain of the yarn reaches its maximum at the attachment point, and at its other end, the strain value is zero, and with an increase in the Young's modulus, the yarn strain proportionally decreases, and with an increase in the twisting angle, the yarn strain increases.

As a result of comparing the solutions of the J.W.S. Hearle model and the proposed model of the radial reduced stress, it has been found that the J.W.S. Hearle model is acceptable up to a torsion angle of 50° , and the proposed model is acceptable for all cases, which confirms the validity of the proposed model.

It has been established that the radial stress in the yarn cross section increases with an increase in twist and an increase in the coefficient of friction as well as an increase in the proportion of longer fibers, which explains the possibility of reducing the number of yarn twists.

As a result of the analysis of the yarn deformation, taking into account the elastic and elastic-plastic deformation of the fibers, the dependence of the average yarn stress on the fiber deformation was established, which, at small values of dispersion, has a nonlinear character, and with increasing dispersion, this dependence becomes linear.

The non-linear properties of the yarn manifest themselves with small spreads in the plastic properties of the fibers, which must be taken into account when assessing the mechanical characteristics of the yarn, i.e., to study the non-stationary processes in yarn, taking into account its structural formation of yarn and nonlinear deformation.

4. EXPERIMENTAL RESEARCH

Experimental yarn samples were obtained on a BD 330 spinning machine installed in the experimental laboratory. The indicators of the physical and mechanical properties of the yarn were determined on the test devices in the accredited certification center at TITLI “CentexUz” as well as on the devices in the laboratories of the enterprise “Gurlanteks” and JV LLC “BF Textile”. When processing the results of the experimental studies to determine the indicators of the physical and mechanical properties of the yarn, the Windows XP operating system and special programs: AutoCAD, Maple, Inventor Pro, were used.

Ring and pneumomechanical spinning methods are most common and widely used in cotton spinning. Therefore, these two methods were chosen for further research.

A method is proposed where two rovings of cotton fiber with a linear density of 0.132–0.154 tex and length of 35–40 mm are used to produce yarn, which are separately fed into the exhaust device of the spinning machine. After drawing, both fibrous ribbons exit the drawing device in parallel at a distance of 1–3 mm from one another. Further, after the preliminary twisting of each ribbon, they are connected and twisted into a yarn. From the resulting yarn, a knitted fabric is produced, which is softer than average in comparison with the fabric made from ordinary twisted yarn [136]. To conclude, the yarn was obtained in a duplicated way (Sirospin). In some cases, the yarn in two additions, as noted in [137], can be replaced with single-strand yarn.

SLG Textile AG is reported to be one of the top five producers of elastic cotton yarn in Europe. The company created two new types of yarn. One of them is formed from bamboo fibers, has a linear density of 8.33–100 tex and has high hygienic, antistatic, and antibacterial properties, a soft neck, and good absorbency. The yarn is used to produce knitwear, bed linen. Another yarn with a linear density of 11.7–100 tex was obtained from long-staple cotton and is similar to cashmere yarn in its softness and structure [138].

The general trends in the production of yarn for the manufacture of knitted fabrics, the potential of the fine yarn market and its development trends are considered. The comparison of the classical alternative spinning methods is carried out according to various technical parameters and properties of the resulting yarn. The boundaries of the application of spinning methods in the manufacture of fine and very fine yarn have been established.

Thus, as a result of the analysis of the existing classification of spinning methods, its shortcomings were identified, and an improved classification was proposed. A brief analysis of the current state of spinning technology, features of technological processes of various spinning methods was carried out, and it was established that the improvement of technology is carried out in the direction of increasing the productivity of machines with a simultaneous improvement in the physical and mechanical properties of the yarn. It should be noted that it is the spinning method and the technological processes carried out according to it that

contribute to the formation of a structural formation of the yarn, on which the mechanical characteristics of properties, unevenness, neps are the indicators of yarn properties according to the international standard “Uster Statistics 2018” [14].

4.1. Influence of spinning parameters on the structural formation of the yarn and physical and mechanical properties of the blended yarn

The main spinning parameters in a ring spinning machine are the spindle speed, the number of turns, and the amount of tension, which affect the structural formation of the yarn and physical and mechanical properties of the yarn. As the speed of rotation of the spindle increases, the tension of the thread in the ball increases, and its properties change. The tension of the rope reaching the torsion triangle has an effect corresponding to the state of the fiber. The ends of the fibers that do not reach the yarn are flattened under the influence of tension. Thus, under the influence of tension of the rope in the torsion triangle, there is a partial straightening without moving them, and therefore, a partial elongation of the output.

As a result, the product is elongated due to the partial straightening of the fibers with a constant amount of fiber in the cross section of the resulting line; therefore, the linear density of the yarn is partially reduced. An increase in yarn tension leads to flattening and even greater deformation of the fibers in the bending triangle. This can be attributed to a number of positive phenomena, as the straightening of the fibers results in their denser placement and an increase in both radial and axial stresses in the yarn structure. However, in the process of flattening and increasing the tension of the fibers, they may as well shift relative to each other. As a result, additional structural unevenness occurs. These phenomena are usually considered digitally on a ring spinning machine. According to the manufacturer's recommendations, the spindle speed can reach 25,000 m⁻¹.

As noted in literature, an increase in the spindle speed results in an increase in thread breakage. This means that the positive effect of the spindle rotation speed should be maintained, and the negative effect avoided, i.e., the optimal values of the spinning speed parameters should be determined, which helps to improve the structural integrity, physical and mechanical properties of the yarn.

4.1.1. Investigation of the physical and mechanical properties of the yarn

In order to test the above-presented theoretical premises, the experiments were carried out. On a Saurer Zinser 350 ring spinning machine at a spindle speed of 11,000, 12,000, 13,000, 14,000 and 15,000 m⁻¹, the prototypes of yarn with a linear density of 20 tex with various twists from 740 to 860 rpm were obtained. Yarn parameters, i.e., linear density, twist, unevenness, were tested according to the standard method, and it has been found that the linear density of the yarn does change under the influence of the spindle speed. Figure 4.1 shows graphs of changes in the linear density of the yarn depending on the frequency of rotation of the spindle.

As it can be seen from the graphs, in all four values of the twist, the linear density of the yarn with an increase in the spindle speed decreases to 2.5%. This means that the linear density of the yarn becomes less than the nominal by 2.5%.

This situation does not satisfy everyone, since the limits in the difference in linear density are determined by the consumer.

In order to prevent such a negative phenomenon, the yarn must be very flat, i.e., the unevenness of the yarn should be as small as possible. On the new generation ring spinning machines, this phenomenon is taken into account, and the production at all preparatory passes is leveled, for which the linear density regulators and corresponding sensors are installed.

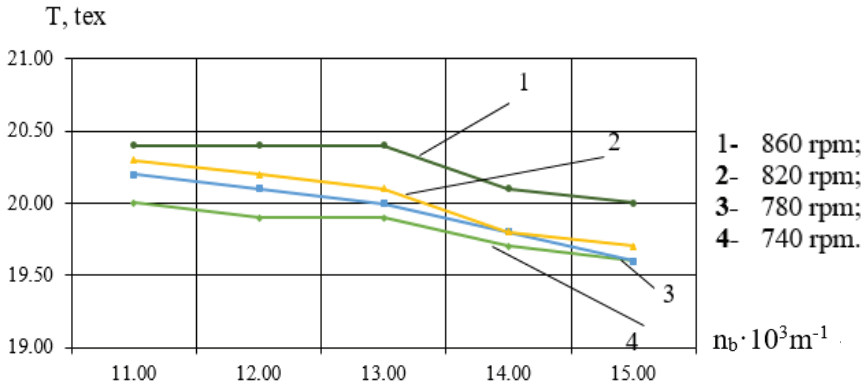


Fig. 4.1. The influence of the spindle speed on the yarn linear density at different twists

Since the rotational speed of the spindle affects the linear density of the yarn, it naturally as well affects the number of twists per unit length [139].

Therefore, as shown, the loss of twist compared to the nominal torsion in the study range is from 3.5% to 8.3%, which is shown in Fig. 4.2 and Fig. 4.3.

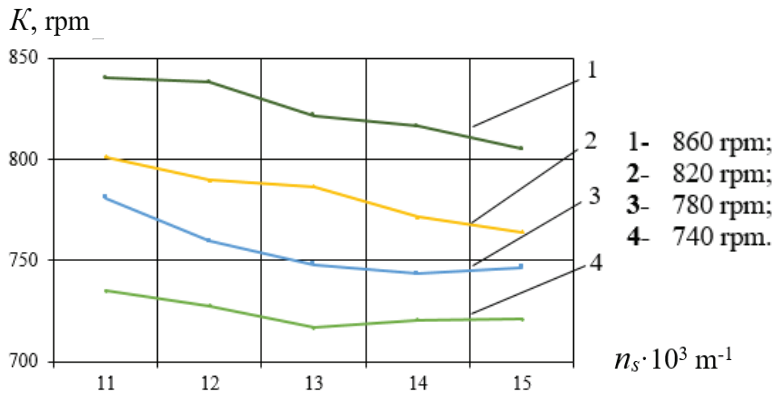


Fig. 4.2. The influence of the spindle speed on the number of twists

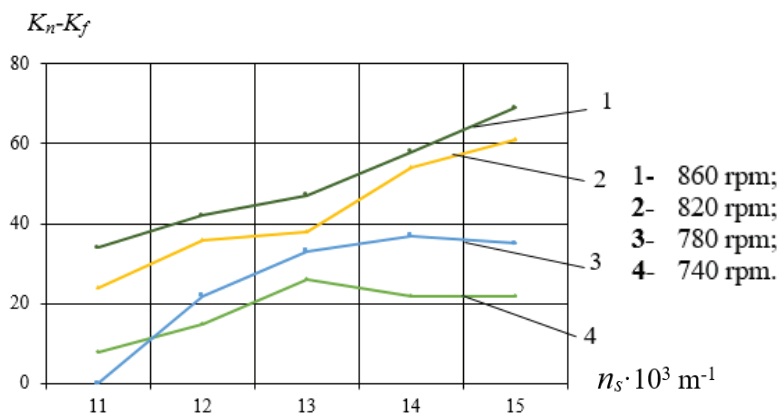


Fig. 4.3. The influence of the spindle speed on the difference between the nominal and actual twists

Due to the loss of twist by 3.5% at low torsion (740 rpm) and 8.3% at high torsion (860 rpm), naturally, the phenomenon is negative, because at the same time, the coefficient of energy use is reduced. In order to study the influence of the spinning speed on the indicators of the mechanical properties of the yarn, the graphs of influence of the spindle speed on the specific breaking load of the yarn were built (Fig. 4.4).

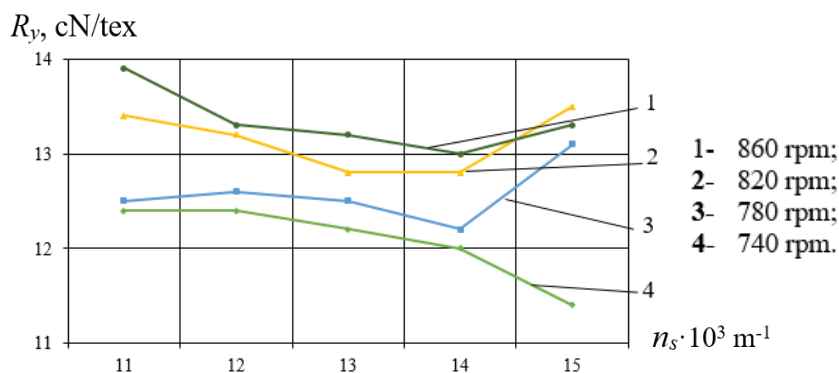


Fig. 4.4. The influence of the spindle speed on the specific breaking load of the yarn

As the graphs show, at the lowest (740 rpm) and the highest (860 rpm) twist at a low spindle frequency, the breaking load of the yarn is higher, and at a high rotational speed, it is relatively lower. With another low and high number of twists (780 rpm, 820 rpm), the presence of an extremum is clearly visible. This means that it is difficult to conclude from these graphs whether the effect is different for different values of the twist. Therefore, for the evaluation of mechanical characteristics of the yarn, it was necessary to compare the tensile curves of the above-presented samples.

In order to analyze this phenomenon, the tensile curves of the yarn samples with a minimum (740 rpm) and maximum twist (780 rpm) were constructed at different spindle speed (Fig. 4.5 and Fig. 4.6).

The tensile curves of the yarn produced with the lowest twist (740 rpm) and at five levels of the spindle speed show that the yarn has a different breaking load, the largest of which was obtained at a spindle speed of 13,000 min^{-1} .

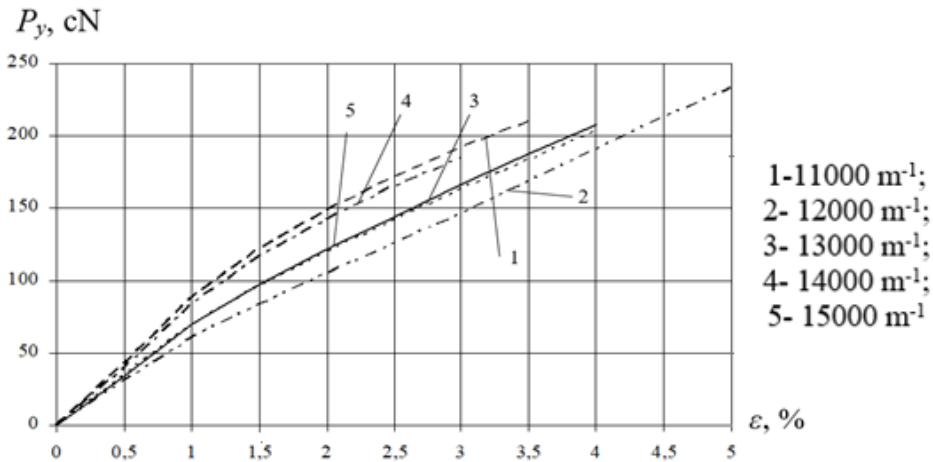


Fig. 4.5. The influence of the spindle speed on the yarn tension force at a torsion number of 740 rpm

Its lowest value corresponds to the yarn obtained at a spindle speed of 15,000 min^{-1} . Another characteristic of the mechanical properties of the yarn is that the tensile force to break is distributed differently. For example, the tensile curve of a yarn sample with the maximum breaking load (curve 1) is shown in the lowest curve. The sample of the yarn with a high tensile force to break refers to the yarn obtained at the highest spindle speed (curve 5). The tensile curves of the yarn samples diverge with increasing spindle speed, which is the evidence of influence of the spinning speed on the mechanical properties of the yarn. In this case, as noted above, with an increase in the spindle speed, the axial stress of the yarn increases, i.e., the indicators of additional breaking mechanical characteristics of the yarn increase.

At the maximum twist in the study range (780 rpm), the tensile graphs of the yarn samples are divided into two groups, where the 1st, 2nd, and 3rd lines are very close to each other and make up the first group, and the second group is 4th and 5th lines, which almost overlap each other (Figure 4.6). This suggests that the variation interval must be chosen wider, which was taken into account in the experiments carried out on the Zinser-351 spinning machine. It must be assumed that in this case, the tension curves were influenced, along with the spindle rotation frequency, by an increase in the twist value.

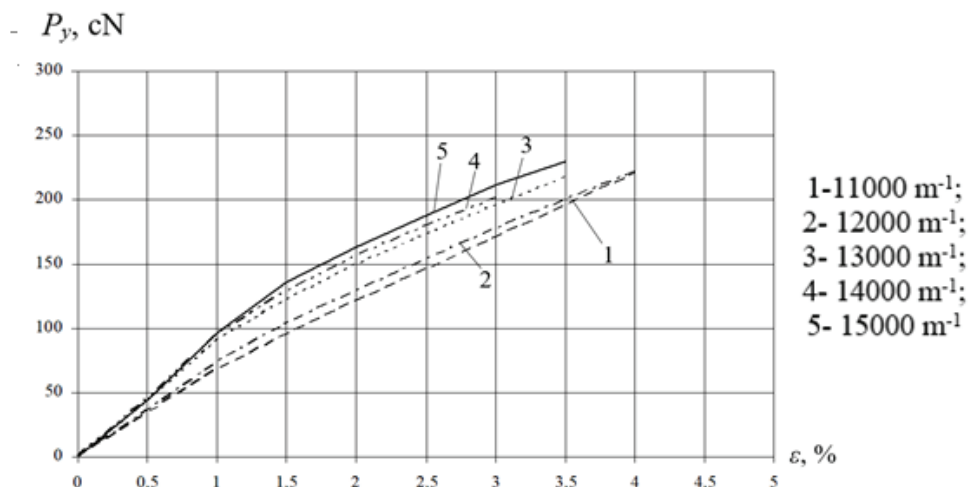
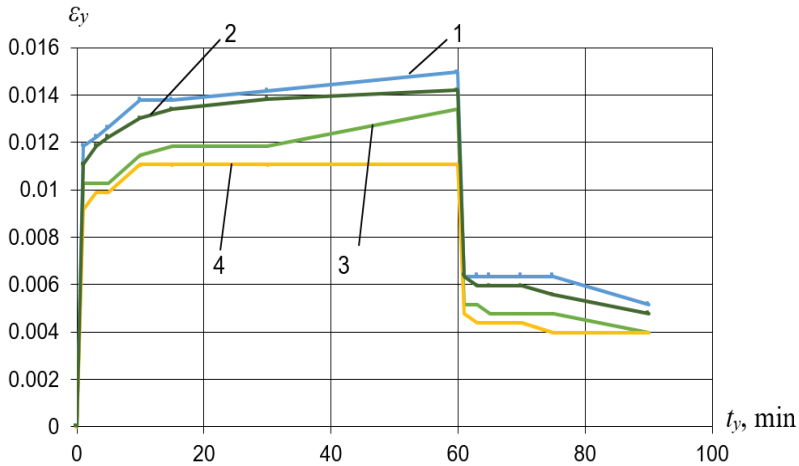


Fig. 4.6. The influence of the spindle speed on the yarn tension force at a torsion number of 780 rpm

Thus, the results of the experimental studies carried out on a ring spinning machine showed that the spindle speed and the number of twists (twists), as discussed theoretically in Chapter III (3.2., 3.3.), do change the structural formation of the yarn, and therefore, the indicators of the mechanical characteristics of the yarn. This must be taken into account when adjusting and setting the operating parameters of the ring spinning machine. With an increase in the spindle speed, the additional breaking performance of the yarn increases. In order to analyze this change in the yarn structure, it is recommended to study single-cycle mechanical characteristics, i.e., the deformation properties of the yarn.

In order to determine the influence of the spindle speed on the structure and properties, as noted in 4.2., an experiment was carried out to produce a yarn with a linear density of 20 tex with varying the spindle speed from 11,000 m^{-1} to 15,000 m^{-1} . The study of changes in the structural formation of the yarn was carried out by determining the single-cycle characteristics according to the method described in [140].

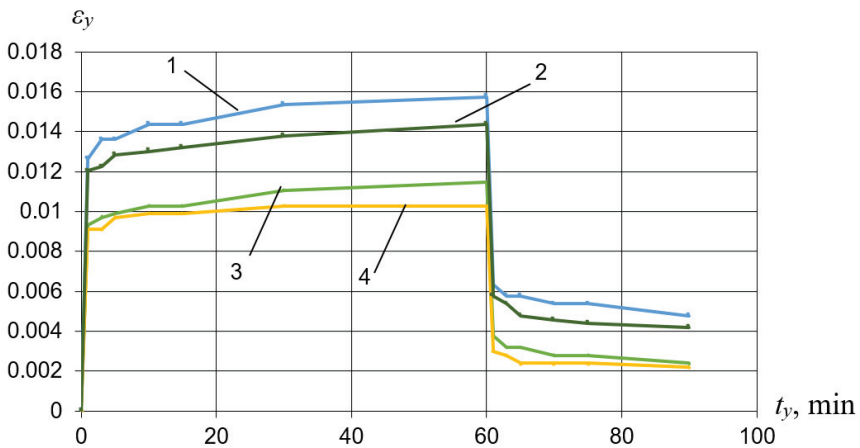
The values of the deformation of the yarn lengths 250 mm and 500 mm were recorded, which were loaded with a load weighing 50 g for 60 minutes. After that, the samples were unloaded and were in the rest mode for 30 min. Based on the results of the experiments, the corresponding graphs were built (Fig. 4.7 and Fig. 4.8). In order to compare the results, the dimensionless strain values are shown on the ordinate axes.



1 – 740 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$; 2 – 860 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$;
 3 – 740 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$; 4 – 860 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$.

Fig. 4.7. Change of deformation in time of segments (250 mm) of carded yarn

It is easy to see that the resulting graphs are identical. Curves 1 and 3 show yarn deformations with minimum twist (740 rpm), and curves 2 and 4 show yarn deformations with maximum twist (860 rpm). As it can be seen, the deformations of the small twist yarn at both levels of the spindle speed are higher compared to the deformation of the yarn with maximum twist.



1 – 740 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$; 2 – 860 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$;
 3 – 740 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$; 4 – 860 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$.

Fig. 4.8. Change of deformation in time of segments (500 mm) carded yarn linear density 20 tex

It should be noted that the yarn samples were produced taking into account the values of the minimum (740 rpm) and maximum (860 rpm) twist for knitted yarn and based on the technical capabilities of the spinning machine; the spindle speed was selected in the range from 11,000 m^{-1} to 15,000 m^{-1} .

It should be noted that the deformation of the yarn obtained at the minimum rotational speed of the spindle (11,000 m^{-1}) is higher compared to the deformation of the yarn obtained at the maximum rotational speed of the spindle (15,000 m^{-1}). As noted in 2.1., under the influence of a tensile force, the tensile deformation of the yarn reaches the maximum at the attachment point, and at its other end, the deformation value is zero. The theoretical conclusion is confirmed by the results of a study of the single-cycle mechanical characteristics of yarns of various twists, produced at minimum and maximum twists. This is due to the fact that with an increase in the spindle speed, the tension of the yarn in the balloon increases. The tension created by the slider following the spindle extends from it along the thread to the torsion triangle.

The increasing tension reaches the torsion triangle, and the fibers contained in it, undergoing deformation, are partially straightened. Thus, with increasing tension, the degree of straightening of the fibers in the torsion triangle partially increases, and the fibers enter the yarn structure more straightened. As a result, the deformation of the yarn is reduced by the greater number of straightened fibers, and with an increase in the number of torsions, as noted in 2.2., the number of fibers that resist stretching increases, due to which the deformation of the yarn is reduced. The same picture can be observed when comparing permanent deformations. Thus, the residual deformations of yarns obtained at the maximum spindle speed are less compared to the yarns obtained at the minimum spindle speed.

Thus, with an increase in the rotational speed of the spindle, there is a change in the structural formation of yarn, and consequently, a change in the mechanical characteristics of the yarn. This is one of the advantages of high speed ring spinning machines to guarantee the production of competitive yarns. It should be noted as well that the spindle speed changes during the production of one full bobbin. When working on the nest and spout of the cob, the spindle rotates at a lower frequency than when winding the body. Any change in the speed of the spindle, as it is seen from the information presented above, can lead to changes in the structure, and consequently, in the properties of the yarn, in particular, its internal roughness in mechanical characteristics increases.

Therefore, it is considered advisable to conduct a study on the mechanical properties of the yarn from different parts of the same cob. As a result of the study, it has been found that with an increase in the rotational speed of the spindle, the tension of the thread in the balloon increases, the degree of straightening of the fibers in the torsion triangle increases, and the fibers enter the structure of the yarn more straightened. As a result of this, the deformation of the yarn under the action of the tensile force, due to the greater number of straightened fibers, is reduced.

4.2. Investigation of physic and mechanical behavior of yarn made from fiber waste

The need to improve the quality of the finished product requires that the yarn is smooth, clean, durable, and elastic.

The quality of the spun yarn, the stability of technological processes depends on the composition of the fiber mixture as well as the rational organization of the process of mixing components in many respects.

The natural fibers in one or more samples differ in their properties. For example, the fibers obtained from a single cotton ball differ from each other in their length, linear density, toughness, and other properties. In order to give more examples, wool fibers obtained from a single skin differ in length and structure [141].

Fiber compounds found in nature do not have the same properties. However, the difference between such natural compounds and mixtures consisting of several components obtained in an enterprise can be very large.

Physico-mechanical parameters of recycled waste silk fibers N1 and N2, separated from the spinning mills of silk spinning mills, are shown in Table 4.1.

Table 4.1. Physical and mechanical properties of recycled silk waste

№	Indicators	Number of secondary waste	
		N1	N2
1	Contaminants from the sponge, %	0.54	1.57
2	Fiber length, mm		
	Average	34.1	30.4
	Modal	30.7	28.7
	Staple	46.0	43.8
3	Interruption force, cN	6.3	5.25
4	Elongation at break, %	5.9	10.2
5	Linear density, tex	0.109	0.102
6	Relative tensile strength, cN/tex	0.58	0.52

The natural blend blends relatively well with different fibers. If a sample of a certain amount of cotton fiber is taken and spun, it could be seen that the cotton fiber is different in certain small pieces of yarn, which in turn indicates a natural mixture.

Addition and mixing of cocoons are carried out on the cocooning machines. The distribution of components in the resulting crude product is uniform and constant, but the mixed wicks are separated after stretching. The process of adding and stretching is repeated to overcome this shortcoming. In artificial mixtures, however, a mixture of several components is obtained, and the fibers do not form a smooth mixture as mentioned above.

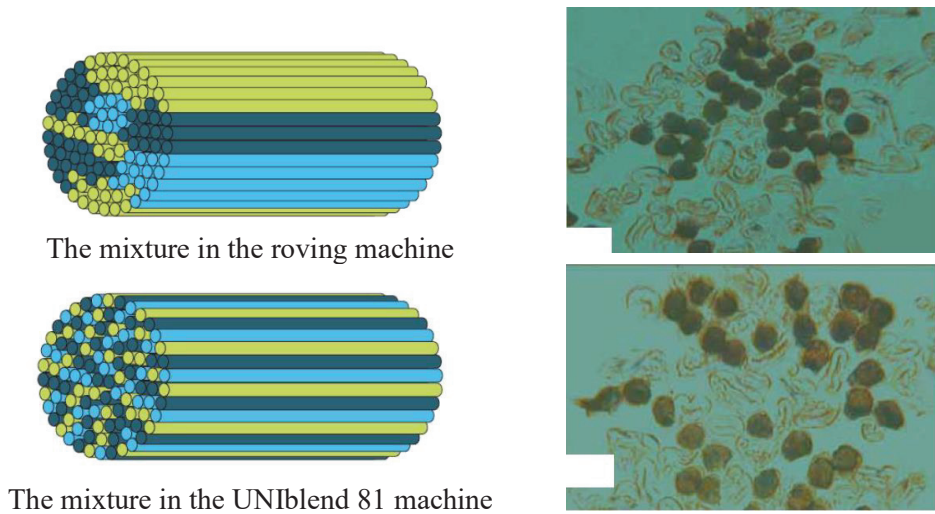


Fig. 4.9. Fiber mixing processes in REETER machines

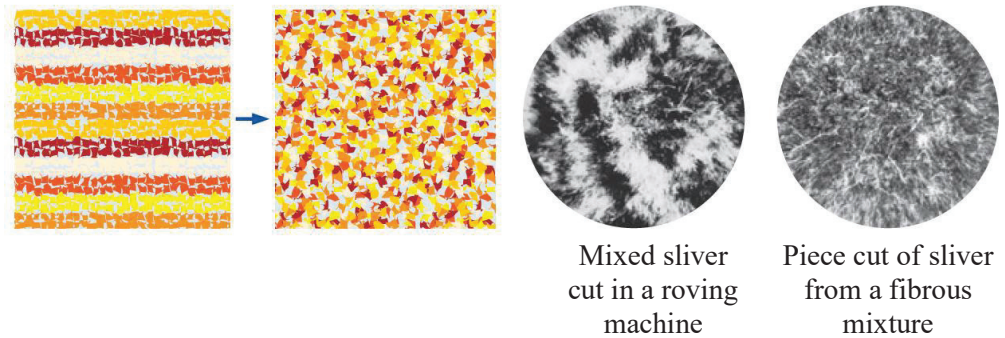


Fig. 4.10. Fiber mixing processes in TRUETZSCHLER machines

Table 4.2. Experimental results in the production of yarn from blended fibers

№	Indicators	87.5-cotton 12.5-silk	75-cotton 25-silk	62.5-cotton 32.5-silk	50-cotton 50-silk
1	linear density, tex	5,000	4,989	4,994	5,004
2	coefficient of variation in linear density, %	0.54	0.59	0.52	0.58

In each compound, the components are presented as fragments, and in these fragments, the fibers are of different sizes, and these fibers do not mix with other

fiber fragments. It is only possible to achieve mixing by separating all the particles into completely separate fibers [142].

The repetition of the components, first separately and then evenly distributed in the composition of the mixture, indicates the intensity of the mixing process (Table 4.2). The efficiency of the mixing process is directly related to the mixing intensity. High efficiency can be achieved by increasing the mixing intensity [143].

Thus, in the alternative, the cotton fiber in the mixture was 62.5 percent, and the silk fiber waste was 37.5 percent.

The results of the experiment showed that compared to the initial mixture, the final product contained 29.6% of silk fiber, and cotton fiber was 70.4%. In spinning yarn, the extent to which the composition of the samples changed from the machines obtained by the processes of spinning and mixing, cleaning, scraping, spinning and spinning was determined by chemical means.

4.3. Comparative assessment of quality indicators of cotton-silk yarn

The quality of textile products largely depends on the quality level of the yarn. The yarns are defined in their place by their strength, unevenness, and coefficient of variation in shear mass.

A number of other parameters affect the properties of the product during processing. They are indicators, such as thickness, thinness, defects, such as knots, swelling, appearance, smoothness, flexibility, elongation, and hairiness.

In fact, 100% cotton yarn (option 1) and cotton-silk blend yarn (option 2) were obtained according to the sequential spinning plan on a Zinser 350 spinning machine in the technological mode set to produce yarn with a linear density of 20 tex.

In both options, the average results of the main physico-mechanical properties of yarns were obtained. The test work was carried out on the USTER TENSORAPID instrument to determine the tensile strength of the thread and related parameters.

Table 4.3. The main physico-mechanical properties of yarn

№	Indicator name	100% Cotton yarn				Cotton-silk blend yarn			
		1	2	3	Average	1	2	3	Average
1	linear density of the yarn, tex	20.2	20.0	20.1	20.1	20.2	20.0	20.0	20.06
2	coefficient of variation in linear density, %	1.8	1.4	1.6	1.6	1.6	1.4	1.5	1.5
3	breaking force, cN	233	280.3	280.2	281.2	341.4	337.8	338.4	339.4
4	coefficient of variation in breaking load, %	10.1	9.7	9.6	9.8	8.9	8.6	8.3	8.6
5	specific	14.0	13.8	14.1	13.9	16.9	16.89	16.92	16.9

	breaking strength, cN/tex								
6	quality indicator	1.38	1.42	1.46	1.42	1.64	1.7	1.77	1.7
7	elongation to break, %	3.98	3.92	3.9	3.93	5.9	6.1	6.0	6.0
8	number of interruptions 1000 int/s	52	57	53	54	50	48	49	49

Uster Statistic 2018 was used for checking the obtained results, and the existing Spinning method was used. In order to get the experimental data, it has been done min 100 tests for each type and number of yarns.

The same 20 tex linear density of cotton spun yarn and cotton-silk yarn have different coefficients of variation: in cotton yarn, in three cases higher than blended yarn. The breaking force is higher for the blended yarn. It shows 339.4 cN, but cotton yarn has 281.2 cN. The coefficient of variation in breaking strength of the blended yarn is less than cotton yarn by 1.2 times. Specific breaking strength for blended yarn is as well higher than the cotton yarn. It shows 16.9 cN/tex, but cotton has 13.9cN/tex. The elongation in break for blended yarn is 6%, but for cotton, it is 3.93%.

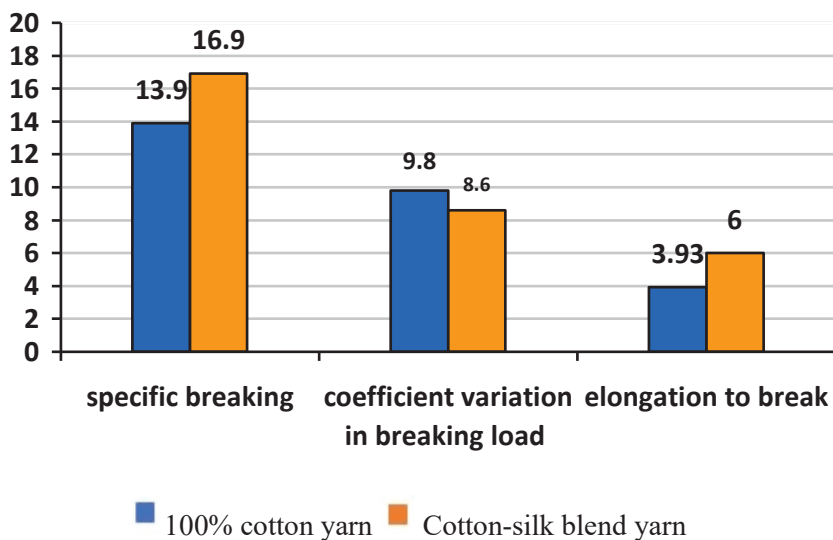


Fig. 4.11. The main physical and mechanical properties of the yarn

The breaking time for both spun yarns are different as well: the regular yarn in both cases has less time, i.e., 20 tex has 0.31 sec, but the experimental, 0.36 sec, and for the spun yarn with 40 tex, has 0.6 sec, but the experimental one has 0.38 sec.

Physico-mechanical parameters of 100% cotton yarn and bicomponent yarn with 37.5% silk secondary waste are presented in Figure 4.11.

During the monitoring of the number of outages, it showed an average decrease of 54 outages per 1,000 int/s and 49 outages per 1,000 int/s, which is equal to 9.3%.

In both options, the unevenness of the thread and its appearance defects were detected on the RREMIER measuring equipment. The test results of linear density 20 tex yarn are presented in Table 4.3 and Figure 4.11.

Table 4.4. Appearance defects of yarns

№	Indicator name	Options	
		100 percent cotton fiber	Cotton and silk blend
1	Unevenness of the cross section, %		
	- linear, U_m	10.9	10.72
	- coefficient of variation, C_m	13.84	13.58
2	The proportion U_m/C_m	1.27	1.266
3	Thin areas (-50%), corresponding to 1 km	5	2
4	Bold areas (+50%), corresponding to 1 km	66	48
5	Small defects (neps +280%), corresponding to 1 km	50	28
6	Total defects, corresponding to 1 km	121	78

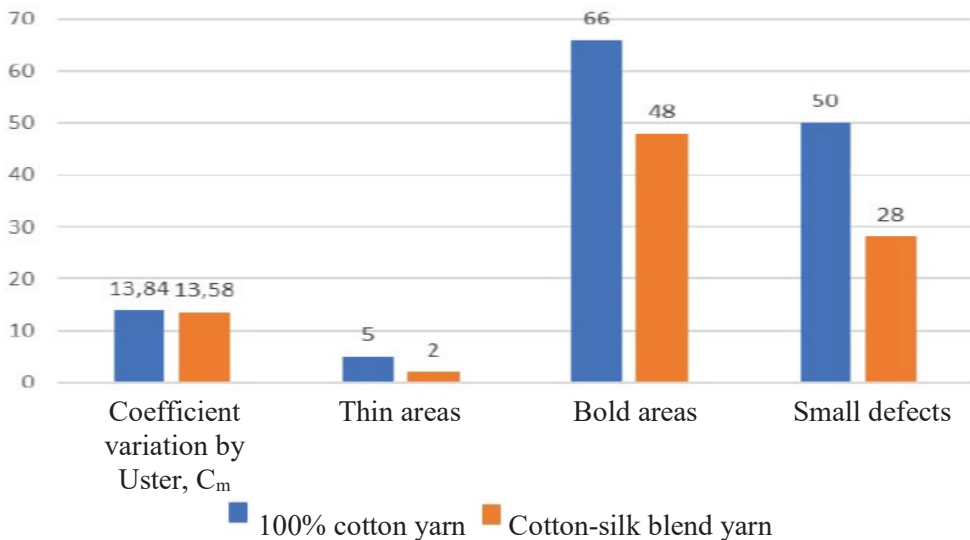


Fig. 4.12. Defects in the appearance of the yarn

As it can be seen from Table 4.4 and Figure 4.12, compared to 100% cotton fiber yarn, cotton-silk blend yarn has less cross-sectional unevenness and appearance defects than cotton-silk blend yarn. It is known that the tension of the thread

increases by 36–40 percent due to the effect of the fiber complex or special fibers. This process increases the probability of thread breakage.

Such fibers are easily removed from the thread with the help of clamps; they do not participate in the formation of the strength of the thread, make it soft, do not maintain resistance to friction, and as a result of some weighting, its appearance deteriorates. Fibers protruding from the thread mix with adjacent threads cause an increase in the number of breaks in weaving and knitting machines.

The hairiness depends on the internal structure of the yarn as well as the geometric dimensions of the fibers that make it up, their length distribution in the cross-section, the spinning method, and technical indicators in the production of semi-finished products. Hairiness can be assessed by the number of bristles, their length and shape. Hairiness can be evaluated by the number of hairs on the surface of the yarn as well as the average length of the hairs or its weight.

As it can be seen in Figure 4.5, the degree of hairiness in the yarn spun from cotton fiber was 4.39 cm, and in the bicomponent yarn with the addition of silk waste, it was 3.34 cm. In this case, it can be seen that the hairiness and the content of the spun yarn with the addition of silk waste is reduced compared to the yarn made of 100% cotton fiber. In fact, 84–87% of bicomponent yarn obtained from silk fiber waste is 3 mm long bristles, and 4 mm bristles make up 11.5–15.5 percent, 5 mm bristles 1–2 percent, and 6 mm bristles 0.1–0.36 percent.

Table 4.5. The degree of hairiness

Indicators	Recheck							
	1	2	3	Average	1	2	3	Average
Options	cotton fiber	cotton fiber	cotton fiber		silk waste	silk waste	silk waste	
The degree of hairiness, cm	4.06	4.78	4.34	4.39	3.48	3.34	3.22	3.34
The number of hairs in 100 m of yarn	298.4	316.2	286.3	300.3	290.4	346.2	297.8	311.5
The length of the bristles:								
3 mm	249.5	262.1	249.3	253.6	241.8	289.2	249.6	260.2
4 mm	42.6	48.7	33	41.4	44.2	50.4	43.4	46.0
5 mm	4.5	4.4	3	4	4.2	6.2	4.4	4.9
6 mm	1.1	1.0	1.0	1.1	0.2	0.4	0.4	0.33
7 mm	-	-	-	-	-	-	-	-
8 mm	-	-	-	-	-	-	-	-

4.4. Theoretical and experimental assessment of physical and mechanical properties of bicomponent yarn

New assortments of bicomponent yarns mixed with raw silk and other natural fibers are being created as well as knitted fabrics, fabrics and dresses made from

them. In addition, taking into account the physical and mechanical properties of cotton-silk yarn, carpets, bedclothes, socks, various household items, and sewing threads are produced as well.

The testing and research work was carried out on the technological equipment of companies "Truetzschler", "Zinser" (Germany) in the production conditions of the stretching device and yarn conductors of the JV "SUNTEX" LLC spinning enterprise [144].

A yarn with a linear density of 20 tex was produced from a cotton-silk mixture on a Zinser-350 ring spinning machine.

Table 4.5 and Figure 4.13 show the physical and mechanical properties of the yarn obtained in the experiment. The physical-mechanical parameters of the linear density 20 tex yarn are presented below.

Table 4.6. Physical and mechanical property indicators of yarn

	Indicators	Unit of measure	Options	
			Cotton yarn	Cotton-silk blend yarn
1	Linear density of yarn	<i>tex</i>	20.0	20.2
2	Coefficient of variation in linear density	%	1.6	1.4
3	Tensile strength	<i>cN</i>	282	290.4
4	Coefficient of variation in tensile strength	%	10.2	9.3
5	Relative breaking strength	<i>cN/tex</i>	14.0	14.4
6	Quality indicator	1.37	1.55	1.37
7	Elongation	%	3.92	4.22
8	The number of twists in the yarn	<i>twist/m</i>	796	811
9	Number of interruptions	<i>inter/s:</i>	64	52

It can be seen from the table that the yarn obtained from the cotton-silk blend has a higher level of tensile strength, and the relative tensile strength is close in both variants. One of the main classifications of the thread is its quality indicator. As it can be seen from the table, it is 1.55 in cotton-silk blend yarn, and this indicator corresponds to type I yarn.

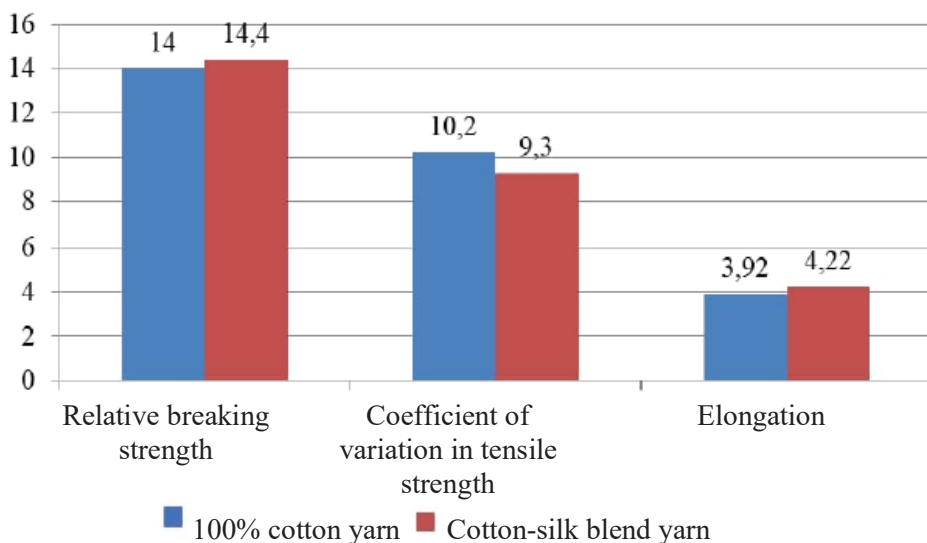


Fig. 4.13. Physical and mechanical property indicators of yarn

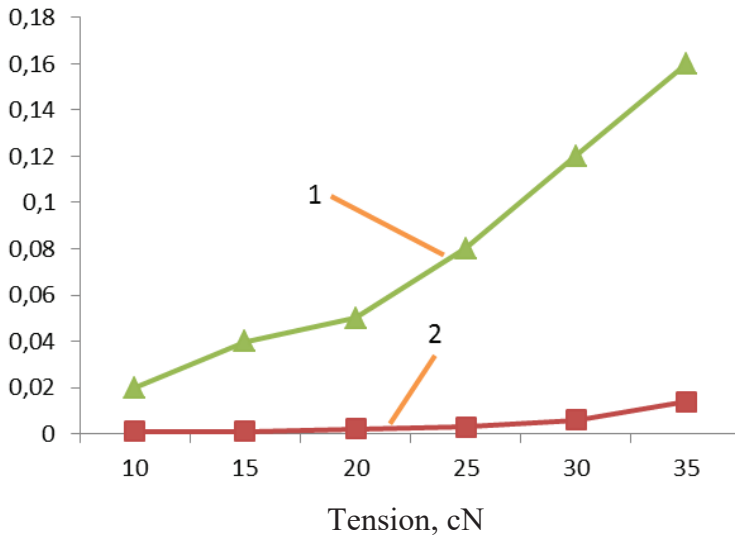
It is worth noting that the experiments were carried out mainly according to the technological regulations for the cotton fiber processing. The technological experiments that were carried out in this research show that the yarn obtained from the cotton-silk mixture has good quality indicators, and it has been proved that the yarn obtained from these mixtures can be spun in the equipment designed for the processing of cotton fiber.

4.5. Production of textile fabrics from bicomponent yarn

Bicomponent yarn was used in the production of textiles, including woven and knitted fabrics. The bicomponent yarn was used as weft yarn in canvas weaving. In the weaving and knitting laboratory of the Tashkent Institute of Textile and Light Industry, a new cotton-silk blended fabric with $T = 20$ tex and a surface density of 110 g/m^2 was made. During the production of fabric, a sharp decrease in the number of yarn breaks was observed. This situation can be explained by the high strength of the resulting bicomponent yarn. The high degree of strength of the yarn made it possible to use it in looms without a shuttle.

It is known that in the process of weaving on a loom, the breakage of the body and warp yarns directly affects the quality of the fabric, the productivity of the loom, and the cocktail, and there is a constant effort to reduce it during the process. The number of thread breaks depends on many technological factors, the main of which is the tension of the body and warp yarn [145]. Yarn tension is an important factor in fabric formation, which affects the consumption of raw materials, fabric structure, its quality. In order to study the effect of the obtained bicomponent yarn on the amount of yarn breaks with changes in tension in the weaving process, a study was conducted on the relationship between the warp yarn tension and yarn breaks on the STB loom.

Number of breakage, breakage/1m



1 – Warp direction, 2 – Weft direction

Fig. 4.14. The relationship between back tension and warp breakage

Figure 4.14 shows a graph of relationship between the back tension and thread breakage. It can be seen from the analysis of the obtained results that the number of thread breaks increased with increasing tension. The number of thread breaks can be explained by the fact that the tension of the backing yarn is high when the backing tension is high, under the influence of the forces during the throwing of the backing yarn on the loom. The studies have shown that bicomponent yarn can be used in the production of various textiles from a technological point of view. The number of thread breaks was found to be less than the fabric norm belonging to the bias group.

The experimental results on the physical and mechanical properties of the fabric samples are given in Table 4.7.

According to the results, the physical and mechanical properties of the fabric samples produced on the loom are close to those obtained on the loom, and the difference in tensile strength is due to the difference in the density of the fabric on the weft and warp.

The research was conducted at ZENITH TEXTILES in Bangalore, India, and at CHAMUNDI TEXTILES in Karnataka at the SOMET (Italy) looms to test the technological factors of yarn in high-speed looms in the production of different densities of the yarn.

The created bicomponent yarn was used as a backing, and fabric was produced in 5 different variants (5 samples). Polyester yarns of 100% different linear densities were used as warp yarns in the weaving process. Fabric technological settling factors are given in Table 4.8.

Table 4.7. Mechanical properties of plain pattern fabric samples with density of 110 g/m²

№	Indicators	Unit of measurement	Quantity AT-100	Quantity STB-180
1	Fabric thickness	<i>mm</i>	0.34	0.38
2	Breaking force Warp (cotton yarn) Weft (cotton-silk yarn)	<i>cN</i>	293.0 443.1	314.5 287.6
3	Air permeability	<i>sm³/sm².sek</i>	80.7	87.5
4	Friction resistance	<i>cycle</i>	11,200	10,300
5	Surface density	<i>gr/m²</i>	111.1	102.5
6	Do not wrinkle Warp Weft	<i>%</i>	44	47
7	Capillary	<i>mm/hours</i>	30	40
8	Hygroscopicity	<i>%</i>	3	5
9	Water swelling resistance	<i>sm</i>	10	11

Table 4.8. Factors of technological settling of fabrics

№	Indicators	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	Linear density of warp yarn, tex (den)	8.33 (50)	8.33 (75)	5.55 (50)	3.33 (30)	3.33 (30)
2	Linear density of weft yarn, tex	20	20	20	20	20
3	Fabric density, yarn/dm Warp Weft	350 500	300 560	330 580	300 340 x 2	300 200 x 4
4	Fabric surface density, g/m ²	84.5	138.0	113.5	90.0	86.5

The obtained fabrics were studied in the testing and certification laboratory TITLI "Cantexuz" as well as in the international research laboratory "TESTING CENTER" in Bangalore, India, testing their physical-mechanical and hygienic properties. The results of the study are presented in Table 4.9 below.

Based on the results of the study, the following analyzes can be made on the examined fabrics. The air permeability of the fabric was directly related to its surface density and thickness, which was lower in the second sample (9.93 sm³/sm².sek.) and higher in the fourth sample (87.5 sm³/sm².sek.). Although the first and fourth samples are close in surface density and thickness, the sharp difference in air permeability is due to the difference in the number of threads on the body and back. The almost uniformity of all fabric samples in terms of non-shrinkage can be explained by the high number of artificial yarns in the texture. Quantitatively consistent changes in the structural factors of the fabric in terms of friction, rupture

(on the warp, weft), hygroscopic and water resistance of the obtained samples indicate that they can be used to obtain different assortments.

Table 4.9. Results of the research on physical-mechanical and hygienic properties of newly obtained fabrics

№	Indicators	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	Fabric thickness, <i>mm</i>	0.25	0.35	0.25	0.25	0.35
2	Breaking force, <i>cN</i> Warp (cotton thread) Weft (cotton-silk thread)	289 (6) 291 (21)	1,003 (12) 365 (7)	717 (45) 317 (6)	357 (38) 313 (6)	334 (50) 306 (6)
3	Air permeability, <i>sm³/sm².sek</i>	39.3	9.93	38.44	87.5	100.9
4	Friction resistance, <i>cycle</i>	4,500	21,500	19,000	17,400	19,000
5	Do not wrinkle, % Warp Weft	44.4 45.1	51.6 49.3	50.9 48.8	48.6 47.7	50.8 48.6
6	Capillary, <i>mm/hours</i>	70	70	94	117	35
7	Hygroscopicity, %	7.69	3.17	5.71	6.22	6.05
8	Water swelling resistance, <i>sm</i>	7	7	9.4	11.7	3.5

Thus, the yarn obtained from a mixture of cotton fiber with secondary fiber waste of the proposed silk can be used in the production of textile products, i.e., in the knitting industry, to expand the range of fabrics, reduce production costs, and develop waste-free technologies. According to the examples shown in the following case, it is possible to produce yarn spun at a linear density of 10–100 tex in mixture ratios. For example, knitted tops made of cotton-silk yarn are distinguished by their high air permeability (982.0 sm^3/sm^2) and hygroscopicity of 15–25%. Compared with pure cotton yarn, its strength has almost doubled, and the shape retention of fabrics has improved by 2.5 times.

A structural change of yarns occurs as a result of changes in the technological processes and spinning operating modes. This leads to a change in the mechanical properties of the yarn itself. After manufacturing the spun yarn and comparison of two types of yarn with the same linear density, the results are presented in Table 4.10.

Table 4.10. Comparative table of obtained experimental results

№	Yarn indicators	Yarn options			
		Ordinary		Experienced	
1	Linear density of the yarn, tex	20	40	20	40
2	Breaking load, cN	237	492	237	516

3	Breaking load unevenness, %	6.7	5.7	2.5	5.7
4	Breaking elongation, %	5.13	5.92	6.0	6.25
5	The unevenness in specific breaking load, %	6.5	6.3	1.8	5.0
6	Specific breaking load, cN/tex	12.07	12.56	12.08	13.16
7	Irregularity in specific breaking load, %	6.7	5.7	2.5	5.7
8	Work of a gap, cN*sm	348	782	384	858
9	Unevenness in work breaking, %	12.2	10.1	4.1	9.3
10	Breaking time, sec	0.31	0.36	0.36	0.38
11	Roughness according to Uster, %	14.73	12.58	14.03	12.40
12	Thin spots -50%, pcs/km	35	1.0	40.0	1.3
13	Thick spots +50%, pcs/km	66.3	17.5	85.0	8.8
14	Number of neps, pcs/km	421.3	47.5	386.3	40.0

4.6. Economic efficiency calculation

The following efficiencies have been achieved in the production of spun bicomponent yarn by adding secondary waste of silk with cotton fiber.

1. The high strength of silk fiber relative to cotton fiber leads to high quality of the obtained bicomponent yarn.

2. Recycling of secondary waste used in the silk will improve the economic situation in silk spinning mills.

3. Cheaper silk fiber waste compared to the expensive cotton fiber reduces the body cost of bicomponent spun yarn.

The price of a ton of cotton fiber is €4,910.

The cost of a ton of silk secondary waste is €2,420.

In the production of one ton of bicomponent yarn, 62.5% of cotton fiber and 37.5% of silk secondary fiber waste were used.

The economic efficiency can be calculated using the following formula:

$$C_e = [H - (aH_1 + bH_2) - F_x];$$

where C_e – cost-effectiveness;

H – the price of the product sold;

H_1 – price of cotton fiber;

H_2 – price of silk fiber;

a, b – share of components;

F_x – share of the total cost of the factory (shop costs, labor costs, and other costs) in the output.

The profit from the production and sale of one ton of bicomponent yarn is in EURO.

$$C_e = [H - (aH_1 + bH_2) - \Phi_x] = [67.0 - (0.625 * 54.0 + 0.375 * 26.6) - 10] = 1,300 \text{ Euro}$$

Thus, in the production of one ton of bicomponent yarn, with the addition of cocoons derived from cotton fiber and silk fiber waste, the estimated share of factory

costs was €910, and the expected net profit from the sale of finished yarn was €1,300.

4.7. Conclusions of the chapter

The experimental studies that were carried out on the Zinser-350 ring spinning machine have shown that the structure and properties of the yarn are affected by the frequency of rotation of the spindle and the number of twists (twist) of the yarn. With an increase in the spindle speed, the pre-breaking load of the yarn increases.

The results of the analysis of single-cycle yarn deformations show that with an increase in the frequency of rotation of the spindle, the fibers in the torsion triangle under the influence of tension straighten out and enter the yarn structure more straightened, due to which the strain of the yarn during stretching decreases.

It has been experimentally established that the tensile curves of the yarn samples from the nest, body, and spout of one cob do not match, which is the source of yarn unevenness in terms of the mechanical characteristics, i.e., the unevenness in the stress-strain state of the yarn of one cob.

As a result of the compaction and parallel arrangement of the fibers in the compacting zone of the mechanical compact device, the tension of the fibers included in the yarn structure is equalized, due to which the stretching curves of the samples from different sections of the cob are combined; therefore, a decrease in internal unevenness has been achieved.

Thus, in practice, the possibility of producing yarn with minimal unevenness in the mechanical characteristics of the ring yarn has been proven.

As a result of research, it has been proved that the air permeability of fabrics made by mixing chemical yarn, i.e., polyester, in tan yarns, and cotton-silk yarn from natural fibers in warp yarns is 30% higher than that of pure polyester yarns.

The application of advanced technology for the production of mixed fiber spun yarns allows for the efficient and full use of secondary fiber waste from silk in the textile industry.

In the production of one ton of bicomponent yarn, 62.5% cotton, 37.5% silk, with the addition of secondary waste fibers, the estimated share of factory costs was €910, and the expected net profit from the sale of the finished yarn was €1,300.

5. CONCLUSIONS

1. The analysis of literature sources show that the prediction of the mechanical properties of yarn requires taking into account the condition of its formation, the mechanism of which significantly depends on the method of spinning and speed modes of spinning machines:

- At the moment of application of force in the structure of the yarn, the process of straightening the fibers and their convergence, the nature of which depends on the degree of yarn torsion, occurs. As a result, the value of the radial stress in the cross section of the yarn gradually increases, which increases the tensile stiffness of the product.

- The strength of the fibers located along the helical lines increases with increasing angle of inclination, and after a while, it reaches the maximum value, after which, it gradually begins to decrease.

- At the same time, the heterogeneity of the yarn microstructure and the wide range of changes in some values that are characteristic to the deformation of a given yarn (for example, breaking load) makes it possible to represent a real yarn as a combination of a large number of elements that have the simplest laws of deformation but with different constants. In the initial stages of loading, viscous properties are more pronounced, and then, with increasing force, these properties pass from single to a compact system of fibers with a high modulus of elasticity and a lower viscous parameter.

2. The analysis of the known models for assessing the characteristics of mechanical properties, in particular, the deformation of textile yarns, certainly shows their acceptability for assessing the mechanical properties, but they have certain disadvantages:

- The model of J.W.S. Hearle does not take into account the coordinates of the location of the fiber in the yarn cross section,

- T model of G.I. Chistoborodov does not take into account the axial stress of the yarn that occurs when the product is twisted,

- Both models do not take into account the change in the proportions of torn and slipping fibers under the influence of torsion and tension. All these phenomena are related with spinning regimes and speed.

3. A new mathematical model that determines the deformation of the yarn under the action of tensile force and torque, taking into account the variability and anisotropy of the mechanical properties of the yarn, using the theory of elasticity, was developed, and new kinds of yarns from cotton and silk waste fibers were manufactured by them.

4. A structural change of yarns occurs as a result of changes in the technological processes and spinning operating modes. This leads to a change in the mechanical properties of the yarn itself. After manufacturing, the spun yarn and comparison of two types of yarn with the same linear density, it has been determined:

- A breaking load for 40 tex spun yarn increased by 4.8%. The breaking load for regular spun yarn with 40 tex is 492 cN, but for the new one, it is 516

cN. It means that due to the arrangements of fibers in the new spun yarn, they are more parallel compared with regular yarn. The unevenness in breaking load shows that the experimental spun yarn with 20 tex has unevenness in breaking load less than the regular one. The regular yarn has 6.7%, when the experimental one has 2.5%.

- An elongation in break of regular yarn with 20 tex has 5.13%, but the experimental one has 6.0%, and the regular yarn with 40 tex has 5.92%, the experimental yarn has 6.0%. The unevenness of elongation in break of the regular yarn with 20 tex has 6.5%, but the experimental one has 1.8%, which means 2.6 times less. The regular yarn with 40 tex has more or less 1.3 times less, i.e., the regular yarn has 6.3%, but the experimental yarn has 5.0%.

- A specific breaking load of the regular spun yarn with 20 tex has 12.07 cN/tex, but the experimental one has 12.08 cN/tex. The regular spun yarn with 40 tex has 12.56 cN/tex when the experimental one has 13.16 cN/tex, which means 4.7 times higher compared with the regular spun yarn. The unevenness in specific breaking load of the regular yarn with 20 tex has 6.7%, but the experimental one with same tex has 2.5%, while the regular and experimental spun yarn with same 40 tex have the same result, i.e., 5.7%.

- A work gap of the regular yarn with 20 tex has 348 cN*cm, but the experimental yarn has 384 cN*cm. The regular yarn with 40 tex has 782 cN*cm, when the experimental yarn has 858 cN*cm. It means that in order to break fibers, it takes more work in time. The experimental yarns have better quality. The unevenness in the work gap as well shows different results: the regular yarn with 20 tex has 12.2%, but the experimental one has 4.1%, and the regular yarn with 40 tex has 10.1%, but the experimental one has 9.3%. It means that the more fibers there are, the smaller is the indicator.

- A breaking time for both spun yarns are different as well: the regular yarn in both cases has less time, i.e., 20 tex has 0.31 sec, but the experimental 0.36 sec, and the spun yarn with 40 tex has 0.6 sec, but the experimental one has 0.38 sec.

- The same 20 tex linear density of cotton spun yarn and cotton-silk yarn have different coefficients of variation: in cotton yarn, it is three cases higher than in the blended yarn. The breaking force is higher for the blended yarn. It shows 339.4 cN, but cotton yarn has 281.2 cN. The coefficient of variation in breaking strength of the blended yarn is less than the cotton yarn by 1.2 times. Specific breaking strength for blended yarn is higher than the cotton yarn as well. It shows 16.9 cN/tex, but cotton has 13.9cN/tex. The elongation in break for blended yarn is 6%, but for cotton, it is 3.93%.

5. All determined differences in bicomponent yarn show that the structure of yarn plays the main role in the mechanical and physical characteristics of any type of yarns. Higher parallel location fibers in the yarn gives more strength in break, elongation in break. Using mixed fibers, especially silk waste fibers, gives more strength and better properties.

6. The usage of silk waste fibers gives positive influence on the sustainability and circular economy as well as properties and economic benefit.

6. SANTRAUKA

IVADAS. Pasaulinėje šilko pramonėje svarbią vietą užima kokonų auginimo, šilko žaliavos ir šilko gaminių gamybos procesai bei jų atliekų perdirbimas. Šioje srityje pirmaujančios šalys – tai Kinija, Indija, Uzbekistanas, Iranas, Tailandas, Vietnamas, Šiaurės Korėja, Brazilija ir Prancūzija.

Šiandien pasaulio mokslo pasiekimų panaudojimas yra svarbus veiksnys vystant visas visuomenės ir valstybės gyvenimo sritis, kuriant ir užtikrinant gerą šalies ateitį. Ekonomikos plėtra, pritraukiant investicijas, yra vienas iš šilko pramonės augimo prioritetų. Pasinaudojant investicinėmis programomis bei taikant modernią techniką ir šiuolaikines technologijas, planuojama statyti, modernizuoti ir pertvarkyti naujas šilko gamybos įmones.

Visos kokonų auginimo ir šilko žaliavos gamybos procese susidaranti pluoštinės atliekos yra naudojamos šilko verpalų gamyboje. Tai yra pagrindinė ir vertinga šilko gamybos žaliava. Šilko verpyklose šilko pluošto atliekų perdirbimo metu susidaro skirtingų savybių antrinės pluošto atliekos. Tokios trumpo pluošto atliekos nėra panaudojamos tekstilės pramonėje, nors jų fizikiniai ir mechaniniai savybių rodikliai yra reikiamo lygio. Tokias pluoštines atliekas galima maišyti su medvilnės pluoštu ir gauti dvikomponenčius medvilnės ir šilko siūlus. Iš šių verpalų galima gaminti audinius ir mezginius, leidžiančius išplėsti tekstilės gaminių asortimentą. Todėl, remiantis išsamiau antrinių šilko pluošto atliekų savybių tyrimu, būtina skubiai tobulinti dvikomponenčių verpalų gamybos technologiją, maišant šilko pluoštą su medvilnės pluoštu.

Pasaulyje imamas plataus masto priemonių šilko pramonės modernizavimui, vietinių žaliavų perdirbimui, kokybiškų, konkurencingų ir eksportui skirtų gatavų gaminių gamybos didinimui. Šioje srityje jau yra pasiekta tam tikrų rezultatų.

Uzbekistanas turi pasaulio mastu išvystytą mokslinę bazę šilko pramonėje, leidžiančią auginti aukštos kokybės kokonus, žaliavinį šilką ir šilko audinius, galinčius konkuruoti su kitomis šalimis. Daugelis mokslininkų užsiima antrinių trumpųjų pluoštų atskyrimu ir šilko verpalų gamybos bei apdorojimo metu susidariusiomis pluoštinėmis atliekomis. Vyksta verpalų gamybos iš perdirbtų pluoštinių atliekų bandymai. Užsienio mokslininkai M. A. Becker, N. Tuross, A. K. Gupta, M. L. Gulrajani, Rajkhowa (Indija), Y. Hsia, C. Vierra (JAV), R. Kothari, W. E. Hearle (Anglija), S. Nakamura, J. Magoshi, Y. Magoshi, M. Babu, M. Tsukada, G. Freddi, M. Nagura, H. Ishikawa, N. Kasai (Japonija), K. Sen (Kinija), A. B. Ishmatov (Tadžikistanas) ir kt. atlieka ir tęsia tyrimus šioje srityje.

Uzbekistane ir kitose šalyse nemažai mokslininkų atlieka teorinius ir praktinius tyrimus, siekdami ištirti kokybiškos šilko žaliavos gavimo technologinius procesus, sukurti, patobulinti ir padidinti šilko pluošto atliekų perdirbimo efektyvumą. V. A. Usenko, E. B. Rubinov, G. K. Kukin, X. A. Alimova, I. Z. Burnašev, A. I. Isajev, L. A. Amzajev, J. E. Ergašev, A. J. Raksimov, A. E. Gulamov, A. D. Daminov, O. Axunbabayev, G. N. Ilayev, S. A. Yusupovs reikšmingais moksliniais tyrimais prisidėjo prie pramonės plėtos.

Tyrimo tikslas. Sukurti aukštos kokybės dvikomponenčius siūlus pridedant prie medvilnės pluošto šilko pluošto atliekas iš šilko verpimo įmonių ir pagerinti verpimo, maišant medvilnės pluoštą ir šilko pluošto atliekas, technologiją.

Tyrimo uždaviniai. Atsižvelgiant į tyrimo tikslą, buvo nustatyti šie uždaviniai:

- Išanalizuoti siūlų gamybos iš šilko pluošto atliekų galimybes;
- Išanalizuoti ir ištirti pirminio ir antrinio apdorojimo šilko pluošto atliekų savybes;
- Sukurti dvikomponenčių medvilnės ir šilko verpalų gamybos technologiją, sumaišant medvilnės pluoštą su antrinėmis šilko pluošto gamybos atliekomis;
- Išanalizuoti sukurtų audinių iš medvilnės ir šilko siūlų kokybę;
- Išanalizuoti sukurtos technologijos ekonomiškumą gamyboje.

Mokslinio tyrimo objektas. Medvilnės pluoštas, šilko pluošto atliekos, jų maišymo būdas, dvikomponenčiai verpalai, audiniai.

Mokslinis tyrimas. Medvilnės ir šilko mišrių pluoštų verpalų gamybos technologija, audinių savybės, šių procesų metodai ir priemonės.

Tyrimo metodai. Tyrimu metu buvo naudojami verpalų apdorojimo mechaniniai tyrimai, eksperimentinė analizė ir matematinė statistika, kompiuterinė programinė įranga, standartiniai ir nestandartiniai šilko verpalų kokybės nustatymo metodai.

Tyrimo mokslinis naujumas

Nustatytos šilko ir medvilnės pluošto mišinio kiekybinių frakcijų alternatyviosios vertės;

Sukurta pluošto pridėjimo verpimo metu technologija;

Pagrįsta galimybė verpti siūlus, įmaišant į medvilnės pluoštą antrinio šilko pluošto atliekas;

Sukurta pažangi dvikomponenčio medvilnės ir šilko pluošto verpimo technologija.

Mokslinė ir praktinė tyrimų rezultatų reikšmė. Mokslinė tyrimų rezultatų reikšmė paaiškinama pažangios verpalų iš mišrių pluoštų gamybos technologijos sukūrimu.

Praktinė mokslinių tyrimų rezultatų reikšmė –gamyboje naudojamų verpalų kiekio ir audinių asortimento padidėjimas.

Naujausių Lietuvoje ir užsienyje atliktų tyrimų disertacijos tema apžvalga. Natūralus šilkas yra viena svarbiausių pasaulio tekstilės pramonės žaliavų. Šilkas yra vertingas natūralus pluoštas, pasižymintis įvairiomis naudingomis savybėmis ir šalia kitų pluoštų pasižymintis dideliu tvirtumu, drėgmės sugėrimu (higroskopishumu), bakterijų naikinimu (antibakterinėmis savybėmis), krūvio nekaupimu (antistatiškumu), blizgesiu ir elastingumu.

Šiuo metu mokslininkai atlieka tyrimus, skirtus naujoms aukštos kokybės vietinių šilkverpių veislėms ir hibridams kurti. Naujai sukurtų veislių šilkverpio kokono apvalkalus galima suskirstyti į regionus pagal klimato sąlygas ir didelį šilkverpių gyvybingumą. Visuose regionuose jų gyvybingumas sudaro daugiau kaip

56 proc. Tai rodo, kad iš aukštos kokybės kokonų ir šilko gaminama visus standartinius reikalavimus atitinkanti šilko žaliava.

Pagrindinės priežastys, dėl kurių neįmanomas tinkamas pluoštinių atliekų panaudojimas, tai sericino (natūralių šilko klijų) kiekis, ilgio ir ilginio tankio nevienodumas žaliavoje. Šilko pluošto atliekų perdirbimo technologija reikalauja nuolatinio tobulinimo. Šilko pluošto verpimo pramonėje, be anksčiau minėtų produktų, susidaro antrinės trumpos pluošto atliekos, kurios praktiškai nėra naudojamos tekstilės pramonėje. Todėl antrinių atliekų, susidarančių šilko verpimo metu, perdirbimo technologijos sukūrimas yra neatidėliotinas ir labai svarbus.

Šilkverpių kokonų šilko pluoštas yra sudarytas iš sericino ir fibroino baltyminių medžiagų, kuriose sericino kiekis sudaro 20–30 %. Siekiant padidinti pluošto apdorojimo lygį tolesniuose technologiniuose procesuose, taip pat sumažinti elektros krūvį, būtinas minimalus sericino kiekis, t. y. 0,5 % riebalų, 2 % sericino. Norint tai padaryti, šilko pluošto atliekos turi pereiti technologinį riebalų šalinimo ir nuriebalinimo procesą. Šis technologinis procesas atliekamas priklausomai nuo sericino ir riebalų kiekio žaliavoje, kuriame natūralaus šilko pluošto atliekos yra skirstomos į 3 grupes.

6.1 lentelė. Sericino sudėtis ir riebalų kiekis žaliavoje

Nr.	Grupės	Kiekiai
1	1 grupė	Daug sericino turinčios žaliavos: žiedai, sėklų kokonų apvalkalai, nupjautų kokonų apvalkalai, seriplaniniai siūlai ir kontroliniai siūlai, kuriuose sericino yra iki 24–27 %, o riebalų mažiau nei 0,5 %.
2	2 grupė	Verpimo žaliavos, turinčios vidutinį sericino kiekį: kokonai, mazgeliai; neišvyniotų kokonų apvalkale sericino yra 23–24 %, riebalų – apie 0,5 %.
3	3 grupė	Mažai sericino turi: kaznakai, I ir II apdorojimo audiniai, taip pat grįžtamasis sericinas – 19–22 %, riebalų kiekis 1,5 %.

Šios nematomos atliekos pasižymi vertingomis naudojimo savybėmis, bet šiandien nėra jų surinkimo ir tolesnio jų panaudojimo būdų. Ši problema reikalauja greito sprendimo ir mokslinių tyrimų.

Šilko pluošto atliekos gali būti šlapios, sausos, drėgnos, o, vertinant pagal išvaizdą, – reikalaujančios perdirbimo. Išvirta žaliava pirmiausia nuplaunama, išdžiovinama, susmulkinama, tada kuriam laikui paliekama. Po riebalų šalinimo ir nuriebalinimo proceso pluoštinėse atliekose, t. y. kokonuose, mazguose ir pjūviuose, riebalų yra iki 0,5 %, o kokono apvalkale – 0,8 %.

Kadangi nėra alternatyvių technologijų, kaip iš pluoštinių atliekų gaminti aukštos kokybės šilko verpalus, iš žaliavų gaunamo produkto kiekis neviršija 50 procentų. Taip yra dėl to, kad šilko verpimo technologijos proceso metu gaunamas mažas produkto kiekis, taip pat dėl atliekų, kurių pobūdis skiriasi, ir negalima perdirbti pagal vieną technologinį procesą.

Pluošto savybės mišrių verpalų gamyboje ir tyrimų metodikos formavimas. Disertaciniame darbe analizuojant technologinių procesų ypatumus, verpalų struktūrą ir mechanines savybes, pluoštinių medžiagų verpimo procesus ir verpalų mechanines savybes, buvo naudota matematinė statistika ir gauti atitinkami rezultatai bei pateiktos išvados. Eksperimentiniai verpalų pavyzdžiai buvo pagaminti eksperimentinėje laboratorijoje esama verpimo mašina BD 330. Verpalų fizikinių ir mechaninių savybių rodikliai buvo nustatyti TITLP (Taškento, Uzbekija) akredituotame sertifikavimo centre „CentexUz“ bei įmonės „Gurlanteks“ ir BĮ UAB „BF Textile“ laboratorijose esančiais prietaisais. Apdorojant eksperimentinių tyrimų rezultatus verpalų fizikinių ir mechaninių savybių rodikliams nustatyti buvo naudota „Windows XP“ operacinė sistema ir specialios „AutoCAD“, „Maple“, „Inventor Pro“ programos.

Atsižvelgiant į pirmiau pateiktą pluošto atliekų apibrėžimą ir tipą, buvo pasirenkami verpimo proceso režimai. Kadangi šių žaliavų pluošto ilgis, storis, stiprumas, elastingumas ir kitos technologinės savybės skiriasi, jų apdorojimo technologija tampa sudėtingesnė. Žinomos trys šilko pluošto apdorojimo sistemos. Pirmoji iš jų yra senasis klasikinis būdas, kai pluoštai atskiriami pagal ilgį, pereina per keturias šukavimo mašinų eigas, po to pluošto verpimo technologinius procesus. Šiuos procesus sudaro daugiau kaip 40 etapų, todėl ši technologija šilko verpimo įmonėse šiandien visiškai nenaudojama.

Antrąjį metodą sudaro karšimo procesai, pagrįsti kuokštelinių pluoštų apdorojimu, šukuojant šilko pluošto atliekas daugybe karšimo mašinų.

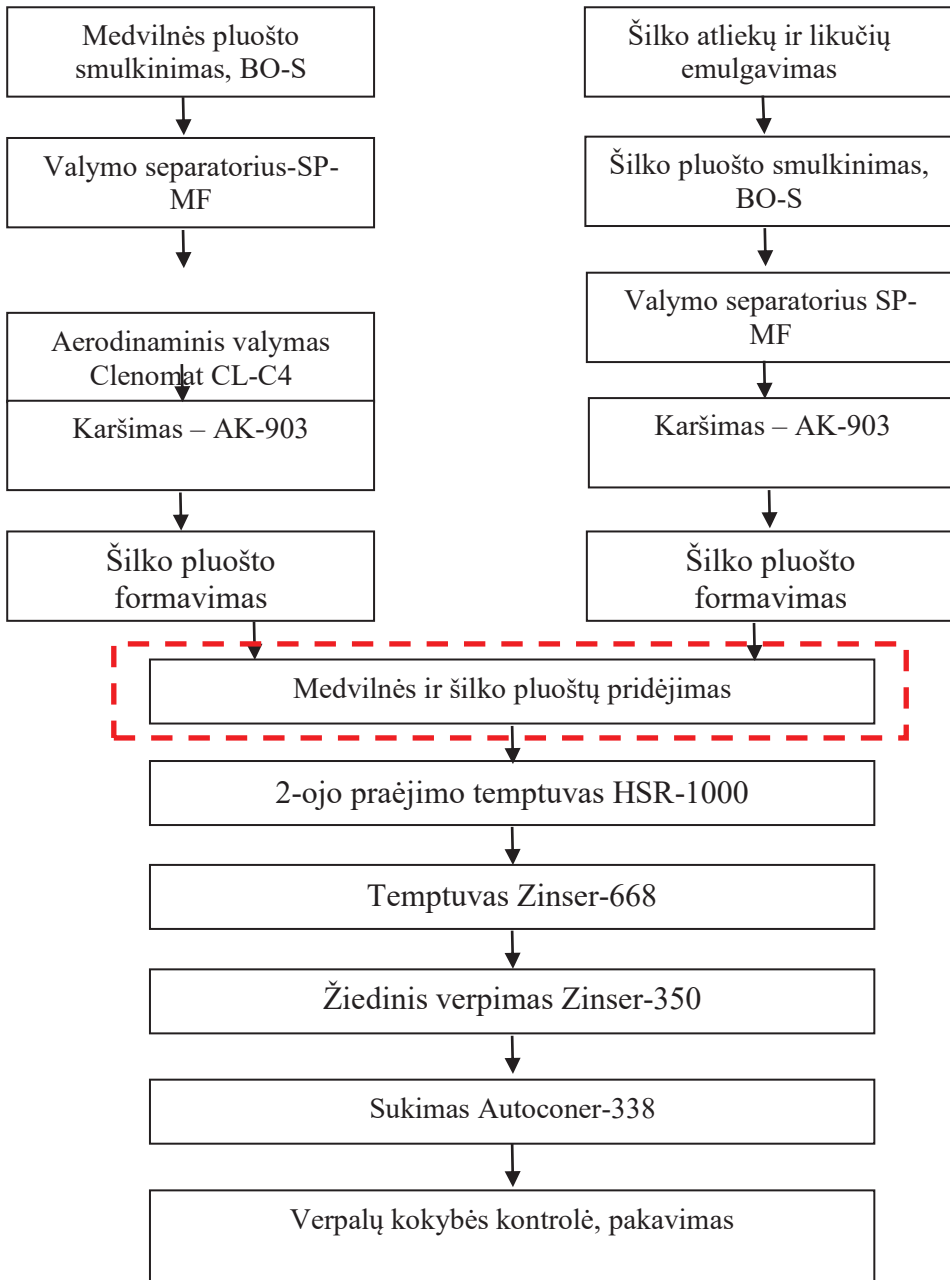
Trečiasis metodas yra šukavimo metodas, pagrįstas kuokštelinio pluošto ilgio ir pjovimo giljotininėmis apdorojimo mašinomis, derinant su nuosekliu šukavimu veleninėmis ir karšimo mašinomis.

Neįmanoma efektyviai panaudoti natūralaus šilko pluošto atliekų be išsamios natūralaus šilko pluošto atliekų technologinių savybių analizės audimo pramonėje, neatsižvelgiant į jų fizines ir mechanines savybes ruošiant jas verpti ir perdirbti.

Šilko gamybos technologijoje atliekos skirstomos į pluoštines ir nepluoštines grupes. Savo ruožtu pluoštinės atliekos skirstomos į daug ir mažai pluošto turinčias grupes.

Daug pluošto turinčios žaliavų atliekos yra medvilnės pūkai, kokonų pūkai, virveliniai pūkai, žiedai, kontrolinės pagalvėlės, žiedai ant seriplano plokščių, kokonų sėklų luobelės, pervyniojimo ir pjovimo proceso metu susidarę žiedai, pjovimo atliekos. Mažai pluošto turinčioms grupėms priskiriamos pluoštinės atliekos, kuriose yra pluoštai ir jų likučiai.

Šilko verpyklose verpiami įvairūs šilko siūlai. Jie yra 20, 25, 100 ir 125 tex, priklausomai nuo naudojimo paskirties pridėdant 2 po 5, 10, 7, 14 tex. Iš jų gaminami audiniai kaklaraiščiams, marškiniams ir plunksnos „Dukhobor“. Suverpti šilko siūlai plačiai naudojami audimo, mezgimo ir kitose pramonės šakose. Jie taip pat naudojami tam tikrų siūlų gamybai, derinant verptus šilko siūlus su dirbtiniais ir cheminiais siūlais, taip pat įvairių tinklų ir mezginių gamybai.



6.1 pav. Patobulinta dvikomponenčių verpalų iš mišrių pluoštų gamybos technologinė schema

Technologijų, kurias taikant neliktų atliekų po pirminio kokonų apdorojimo ir šilko žaliavos gamybos procesų tobulinimas yra viena iš svarbiausių problemų, su kuria susiduria viso pasaulio mokslininkai. Atsižvelgiant į natūralaus šilko gaminių ypatumus ir panaudojimo ateityje perspektyvas, naujų rūšių asortimentų plėtra, įvairių gaminių gamyba efektyviai panaudojant atskirtas pluoštines atliekas taip pat yra aktualios šiandienos pramonės problemos.

Pjovimo proceso metu atskirti trumpi pluoštai yra antrinės šilko pluošto verpimo atliekos. Tai vertingos šilko pluošto atliekos, susidarančios pirmojo ir antrojo verpimo metu, naudojant klasikinę šilko verpimo sistemą. Mokslinių tyrimų, skirtų verpalų gamybai iš sudėtinių pluoštų, analizė rodo, kad daugiausia yra orientuojamasi į kombinuotą natūralių ir cheminių pluoštų naudojimą.

Pasirinkus antrinio šilko pluošto atliekų pluošto ilgį, prilygstantį medvilnės pluošto ilgiui (29–35) mm, įprastomis medvilnės verpimo pramonės mašinomis galima gauti medvilnės ir šilko verpalus.

Perdirbant antrines šilko atliekas, pirmiausia jas reikia emulguoti arba sudrėkinti muilo tirpalu, kuriame yra 8 % muilo ir 92 % vandens. Emulgavus pluoštines atliekas, tirpalas turėtų būti paliktas laboratorijoje mažiausiai 72 valandas tolygiai įsigerti.

Atliekami kiekvieno šilko ir medvilnės pluošto varianto tyrimai. Dėl plačios pluoštų ilgių amplitudės (nuo 1 mm iki 70 mm), siekiant paruošti antrines trumpas atliekas maišymui, atrankos procesas atliekamas pagal šilko verpimo ir verpimo sistemą.

Buvo sukurtas verpalų gavimo būdas maišant medvilnės ir šilko pluoštus ir atsižvelgiant į kai kurių rūšių natūralaus šilko pluošto atliekų struktūrą, savybes ir mokslinių tyrimų rezultatus. Remiantis medvilnės ir šilko (perdirbtų atliekų) pluoštų kuokšto ilgio eksperimentiniais tyrimais, taip pat tiriant šiuolaikinę medvilnės verpimo karšimo sistemos technologinę grandinę, buvo nuspręsta, kad medvilnės ir šilko verpalus tikslinga gauti pagal šią technologiją.

Teoriniai tyrimai. Siūlų struktūra ir jų įtaka verpalų fizikinėms ir mechaninėms savybėms tiriama nuo XX a. šeštojo dešimtmečio. Šia kryptimi atliktus tyrimus apžvelgė ir apibendrino indų mokslininkas A. Basu. Tyrimuose analizuojamas ryšys tarp verpalų netolygumo charakteristikų ir jų struktūros, ypač mechaninių savybių, t. y. verpalų netolygumo charakteristikų priklausomybė nuo jų su(si)sukimo, tankio ir pluoštų slinkimo išilgai gaminio. Pažymima, kad verpalų struktūra taip pat priklauso nuo išilginio radialinio pluoštų išsidėstymo ir nuo pluoštų išsidėstymo verpalų skerspjuvyje, priklausančio nuo pluošto savybių, verpalų našumo ir verpimo procesų dinamikos.

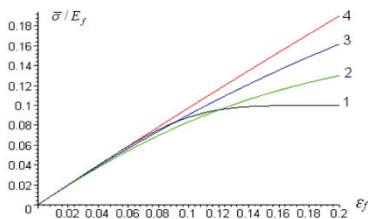
Verpimas atliekamas verpimo mašinomis, veikiančiomis įvairiais būdais. Verpimo mašinoje atliekamų procesų pagrindinis reikalavimas yra ištempti tiekiamą pusfabrikatį (sluoksną arba pusverpalį) iki tam tikro ilginio tankio, suteikti gaminiui tam tikrą struktūrą ir reikiamą stiprumą, susukti ir suformuoti verpalą. Taigi, verpalai formuojami tempimo, sukimo ir vyniojimo procesuose. Verpalų formavimas taip pat gali būti atliekamas be susukimo, o jų sutvirtinimas gali būti atliekamas suklijuojant verpalų pluoštus. Todėl verpimo būdą daugiausia lemia

verpalų formavimo būdas, t. y. verpalų struktūros formavimo būdas ir būdas, kuriuo verpalams suteikiamas atsparumas tempimui. Įvairiose šalyse verpimo būdai klasifikuojami skirtingai. Klasifikavimo pagrindas yra verpimo skirstymas pagal verpalų sutvirtinimo būdą ir priemones.

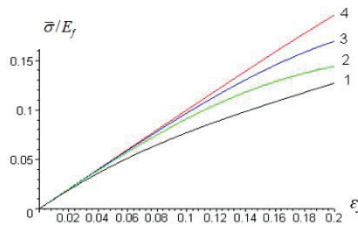
Išanalizavus mechaninių savybių tyrimo būdus aprašančius literatūros šaltinius, buvo nustatyta, kad jų charakteristikos labiau priklauso nuo verpalų struktūros ir formavimo sąlygų. Pastaruoju metu šia kryptimi atliktų tyrimų rezultatų galima rasti periodinėje spaudoje. Čia, atsižvelgiant į pluoštų išsidėstymą (orientaciją) verpalų struktūroje, nagrinėjama verpalų deformacija. Toliau pateikiamas pluoštų elgsenos audinio struktūroje (pluoštas, matrica) prieš verpalų formavimą, t. y. prieš su(su)kimo procesą, tyrimas. Siekiant įvertinti pluošto struktūros įtaką jo mechaninėms savybėms, nagrinėjama nestipriai susuktų verpalų deformacija.

Eksperimentiniai duomenys rodo, kad verpalų mechaninės savybės priklauso nuo atskirų pluoštų deformacijos ir pluoštų tarpusavio sąveikos jėgų pobūdžio gaminio sukimo metu. Teigiant, kad verpalai sudaryti iš vienodai ištemptų pluoštų, išsidėsčiusių išilgai spiralinių linijų su pastoviu žingsniu, priklausomai nuo sukimo kampo vertės ir trinties koeficiento tarp pluoštų vertės, gaminio skerspjuvyje atsiranda radialinis įtempimas, nustatomas pagal formulę:

$$\sigma_r = \sigma_f \cos^2 \beta \frac{(1 - \frac{\rho^2}{R^2}) \sin^2 \beta}{2 \left[\left(\frac{\rho}{R} \right)^2 \sin^2 \beta + \cos^2 \beta \right]} \quad (1)$$



6.2 pav. Santykio $\bar{\sigma} / E_f$ priklausomybė nuo įtempimo ϵ_f , kai $a_2 = 0,1$ ir dispersijos vertės yra skirtingos



6.3 pav. Santykio $\bar{\sigma} / E_f$ priklausomybė nuo įtempimo ϵ_f , kai $D = 0,1$ ir matematinės tikimybės vertės yra skirtingos

6.2 paveiksle parodyta santykio $\sigma = \frac{\bar{\sigma}}{E_f}$ priklausomybė nuo deformacijos ϵ_f , kai $a_2 = 0,1$ ir skirtingų dispersijos reikšmių D . Matyti, kad, esant mažoms dispersijos reikšmėms, priklausomybė $\bar{\sigma} = f(\epsilon_f)$ yra netiesinė, o, didėjant dispersijai, ši priklausomybė tampa tiesinė. Taigi, netiesinės verpalų savybės atsiranda esant nedidelei pluošto plastinių savybių sklaidai.

6.3 paveiksle pavaizduotos panašios priklausomybės, kai $D = 0,1$ esant skirtingoms a_2 matematinio lūkesčio reikšmėms. Matyti, kad verpalų netiesiškumas čia taip pat susijęs su mažomis matematinės tikimybės vertėmis.

Atlikus verpalų deformacijos analizę, atsižvelgiant į tampriąsias ir tampriąsias bei plastines pluoštų deformacijas, nustatyta verpalų vidutinio įtempio priklausomybė nuo pluošto deformacijos, kuri, esant mažoms dispersijos vertėms, yra netiesinio pobūdžio, o, didėjant dispersijai, ši priklausomybė tampa tiesinė. Taigi, esant nedidelei pluoštų plastinių savybių sklaidai, pasireiškia netiesinės verpalų savybės, į kurias reikia atsižvelgti, vertinant verpalų stiprumą.

Eksperimentiniai tyrimai. Eksperimentiniai verpalų pavyzdžiai buvo gauti eksperimentinėje laboratorijoje esančia verpimo mašina BD 330. Verpalų fizikinių ir mechaninių savybių rodikliai buvo nustatyti TITLP akredituotame sertifikavimo centre „CentexUz“, taip pat įmonės „Gurlanteks“ ir BĮ UAB „BF Textile“ laboratorijose esančiais prietaisais. Apdorojant eksperimentinių tyrimų rezultatus verpalų fizikinių ir mechaninių savybių rodikliams nustatyti, buvo naudojama „Windows XP“ operacinė sistema ir specialios programos „AutoCAD“, „Maple“, „Inventor Pro“.

Karštuvų verpimo sistema verpia siūlus, kurių vidutinis ilginis tankis yra nuo 15,4 iki 33,3 tex. Eksperimentiniam procesui, atsižvelgiant į šilko atliekų iš šilko verpimo antrųjų šukavimo mašinų suderinamumą ir maišomos žaliavos plaukelių ilgį, sukurta rekomenduojama dvikomponenčių medvilnės ir šilko verpalų gamybos technologinė grandinė.

Viename ar keliuose mėginiuose esantys natūralūs pluoštai skiriasi savo savybėmis. Pavyzdžiui, iš vienos medvilnės dėžutės gauti pluoštai skiriasi vienas nuo kito savo ilgiu, ilginiu tankiu, tvirtumu ir kitomis savybėmis. Pateiksime daugiau pavyzdžių: vilnos pluoštai, gauti iš vieno plako, skiriasi ne tik ilgiu, bet ir struktūra.

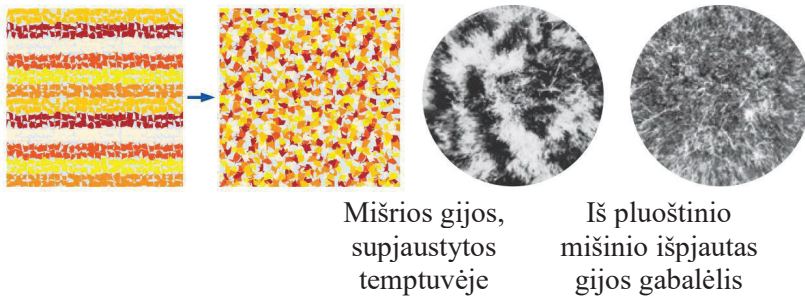
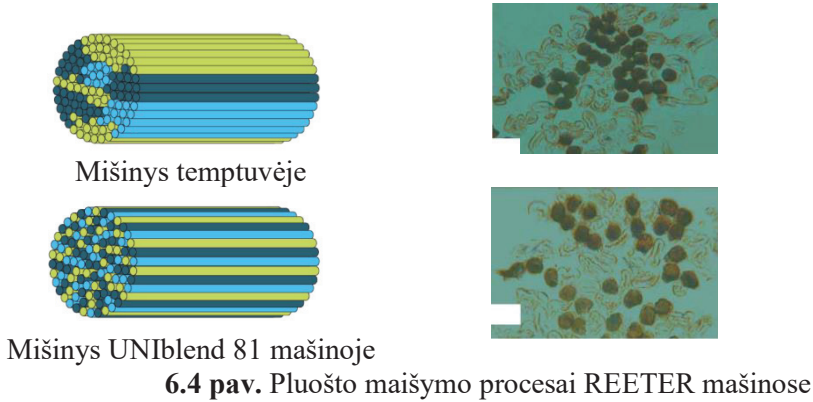
6.2 lentelė. Perdirbtų šilko atliekų fizinės ir mechaninės savybės

Nr.	Indikatoriai	Antrinių atliekų skaičius	
		N1	N2
1	Teršalai iš pinties, %	0,54	1,57
2	Pluošto ilgis, mm		
	Vidutinis	34,1	30,4
	Modalinis	30,7	28,7
	Kuokštelinis	46,0	43,8
3	Trūkimo jėga, cN	6,3	5,25
4	Pailgėjimas nutrūkimo metu, %	5,9	10,2
5	Ilginis tankis, tex	0,109	0,102
6	Santykinis tempimo stipris, cN/tex	0,58	0,52

Gamtoje randami pluoštiniai junginiai neturi tų pačių savybių. Tačiau skirtumas tarp tokių natūralių junginių ir įmonėje gaunamų iš kelių komponentų susidedančių mišinių gali būti labai didelis.

N1 ir N2 numerio perdirbtų šilko pluoštų atliekų, atskirtų nuo šilko verpimo įrenginių, fizikiniai ir mechaniniai parametrai pateikti 6.2 lentelėje.

Natūralus mišinys palyginti gerai dera su įvairiais pluoštais. Paėmę tam tikro kiekio medvilnės pluošto mėginį ir jį suverpę, pamatysime, kad medvilnės pluoštas tam tikruose mažuose siūlų gabalėliuose skiriasi, o tai savo ruožtu rodo natūralų mišinį.



Kokonų pridėjimas ir maišymas atliekamas kokonų ir kokonų maišymo mašinomis. Komponentų pasiskirstymas gautame neapdorotame produkte yra tolygus ir pastovus, tačiau sumaišytos vytelių dalys po ištempimo atskiriamos. Šiam trūkumui pašalinti kartojamas gretinimo ir tempimo procesas. Tačiau dirbtiniuose mišiniuose gaunamas kelių komponentų mišinys, o pluoštai, kaip minėta, nesudaro tolygaus mišinio.

Kiekviename junginyje sudedamosios dalys yra pateikiamos fragmentų pavidalu. Fragmentuose esantys pluoštai yra skirtingo dydžio, ir jie nesusimaišo su kitais pluošto fragmentais. Susimaišymą galima pasiekti tik atskyrus visas daleles į visiškai atskirus pluoštus.

6.3 lentelė. Verpalų iš mišrių pluoštų eksperimentiniai gamybos rezultatai

Nr.	Indikatoriai	87,5 – medvilnė 12,5 – šilkas	75 – medvilnė 25 – šilkas	62,5 – medvilnė 32,5 – šilkas	50 – medvilnė 50 – šilkas
1	Ilginis tankis	5000	4989	4994	5004
2	Ilginio tankio variacijos koeficientas	0,54	0,59	0,52	0,58

Komponentų pasikartojimas, iš pradžių atskirai, o paskui tolygiai pasiskirstęs mišinio sudėtyje, rodo maišymo proceso intensyvumą (6.2 ir 6.3 lentelės). Maišymo proceso efektyvumas yra tiesiogiai susijęs su maišymo intensyvumu. Didinant maišymo intensyvumą, galima pasiekti didelį efektyvumą.

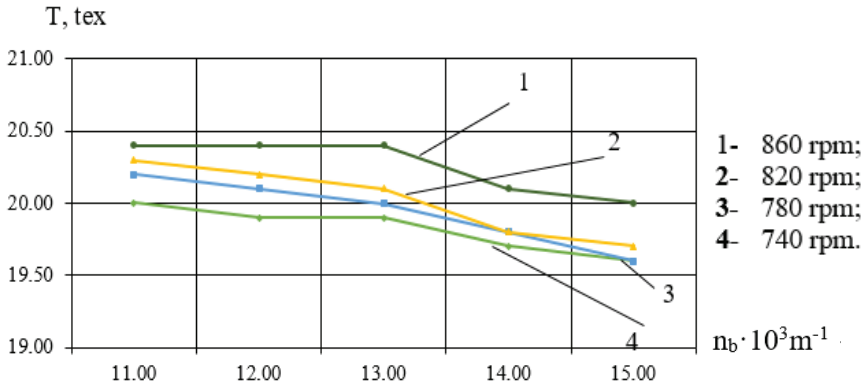
Žiedinis ir pneumomechaninis verpimo būdai yra labiausiai paplitę ir plačiai naudojami verpiant medvilnę. Todėl šie du metodai buvo pasirinkti tolesniems tyrimams.

Verpstės greitis, apsisukimų skaičius ir įtempimo dydis yra pagrindiniai žiedinio verpimo mašinos verpimo parametrai, turintys įtakos verpalų struktūrai ir fizinėms bei mechaninėms savybėms. Didėjant verpstės sukimosi greičiui, didėja siūlų įtempimas kamuolyje ir keičiasi jų savybės. Siūlo įtempimas, pasiekiantis sukimo trikampį, turi poveikį, atitinkantį pluošto būseną. Įtempimo veikiami pluošto galai, nepasiekiantys siūlo, suplonėja. Taigi, siūlo įtempimui veikiant sukimo trikampį, vyksta dalinis jų ištiesinimas nejudinant, todėl gaunama iš dalies pailgėjusi išeiiga.

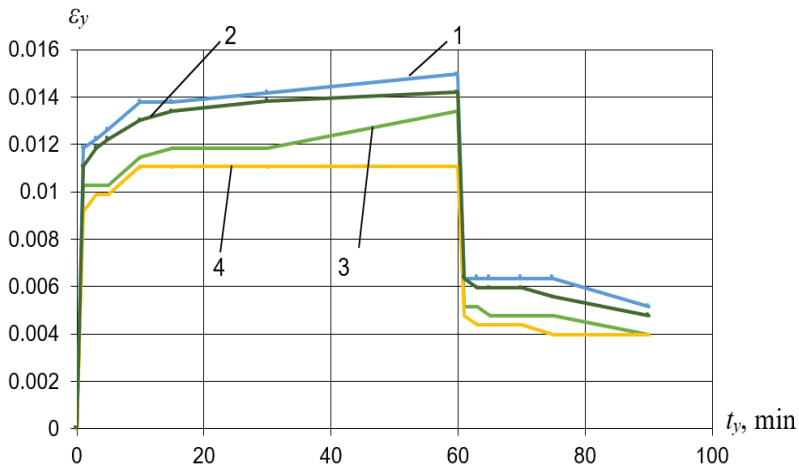
Verpalų fizikinių ir mechaninių savybių tyrimas. Siekiant patikrinti minėtas teorines prielaidas buvo atlikti eksperimentai. Žiedinėmis verpimo staklėmis „Saurer Zinser 350“, esant 11000, 12000, 13000, 13000, 14000 ir 15000 m^{-1} sukimosi greičiui, buvo gauti 20 tex ilginio tankio ir įvairių sukrumų nuo 740 iki 860 m^{-1} verpalų prototipai. Verpalų parametrai (ilginis tankis, sukrumas, netolygumas) buvo tiriami standartiniu metodu ir nustatyta, kad ilginis verpalų tankis kinta priklausomai nuo verpstės greičio. 6.6 paveiksle pavaizduoti verpalų ilginio tankio kitimo priklausomai nuo verpstės sukimosi dažnio grafikai.

Verpstės greičio įtakos struktūrai ir savybių nustatymui, kaip nurodyta 4.2. punkte, buvo atliktas eksperimentas, kurio metu, keičiant verpstės greitį nuo 11 000 min^{-1} iki 15000 min^{-1} , buvo pagaminti 20 tex ilginio tankio verpalai. Struktūros pokyčių tyrimas buvo atliktas nustatant vieno ciklo tempimo charakteristikas pagal aprašytą metodą.

Buvo užregistruotos 250 mm ir 500 mm ilgio verpalų deformacijos vertės, 60 minučių juos apkrovus 50 g svorio apkrova. Po to svoris buvo nuimtas ir 30 min. verpalai buvo ramybės būsenos. Remiantis eksperimentų rezultatais buvo sudaryti atitinkami grafikai (6.7 pav. ir 6.8 pav.). Rezultatams palyginti ordinačių ašyse pateiktos bedimensės deformacijų vertės.



6.6 pav. Verpstės sukimosi greičio įtaka verpalų ilginiam tankiui esant skirtingiems sukrumams

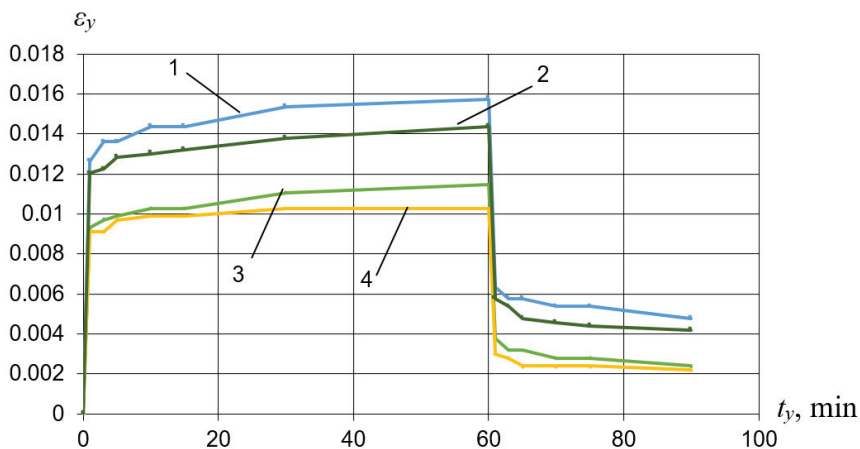


1 – 740 rpm, $n_s = 11 \cdot 10^3 m^{-1}$; 2 – 860 rpm, $n_s = 11 \cdot 10^3 m^{-1}$;
 3 – 740 rpm, $n_s = 15 \cdot 10^3 m^{-1}$; 4 – 860 rpm, $n_s = 15 \cdot 10^3 m^{-1}$.

6.7 pav. Sukarštų verpalų segmentų (250 mm) deformacijos kitimas laike

Nesunku pastebėti, kad gauti grafikai yra identiški. 1 ir 3 kreivės rodo verpalų deformacijas esant mažiausiam sukrumui (740 rpm), o 2 ir 4 kreivės – verpalų deformacijas esant didžiausiam sukrumui (860 rpm). Kaip matyti, mažo sukrumo verpalų deformacijos abiejuose verpstės sukimosi greičio lygiuose yra didesnės, palyginti su didžiausio sukrumo verpalų deformacijomis.

Pažymėtina, kad verpalų pavyzdžiai buvo gaminami atsižvelgiant į minimalaus (740 rpm) ir maksimalaus (860 rpm) mezgimo verpalų sukrumo vertes ir atsižvelgiant į verpimo mašinos technines galimybes. Verpimo greitis buvo parinktas nuo $11000 m^{-1}$ iki $15000 m^{-1}$.



1 – 740 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$; 2 – 860 rpm, $n_s = 11 \cdot 10^3 \text{ m}^{-1}$;
 3 – 740 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$; 4 – 860 rpm, $n_s = 15 \cdot 10^3 \text{ m}^{-1}$.

6.8 pav. Sukarštų 20 tex ilginio tankio verpalų segmentų (500 mm) deformacijos kitimas laike

Taigi verpalai, gauti iš medvilnės pluošto mišinio su antrinėmis siūlomo šilko pluošto atliekomis, siekiant išplėsti audinių asortimentą, sumažinti gamybos sąnaudas ir sukurti beatliekines technologijas, gali būti naudojami tekstilės gaminių gamyboje, t. y. audimo ir mezgimo pramonėje. Remiantis toliau pateiktais pavyzdžiais, galima pagaminti 10–100 tex ilginio tankio mišinio verpalus. Pavyzdžiui, iš medvilninių ir šilkinųjų verpalų pagamintos viršutinės drabužių dalys išsiskiria dideliu oro pralaidumu ($982,0 \text{ sm}^3/\text{sm}^2$) ir 15–25 % higroskopiskumu. Palyginti su grynos medvilnės verpalais, jų stiprumas padidėjo beveik dvigubai, o audinių formos išlaikymas pagerėjo 2,5 karto.

Ekonominio efektyvumo apskaičiavimas. Gaminant dvikomponenčius verpalus, į medvilnės pluoštą pridodant antrinių šilko pluošto atliekų, buvo pasiektas toliau pateiktas efektyvumas.

1. Didelis šilko pluošto stiprumas, palyginti su medvilnės pluoštu, lemia aukštą gautų dvikomponenčių verpalų kokybę.

2. Šilko gamyboje naudojamų antrinių šilko atliekų perdirbimas pagerins ekonominę šilko verpyklų padėtį.

3. Pigesnės šilko pluošto atliekos, palyginti su brangesniu medvilnės pluoštu, sumažina dvikomponenčių verpalų kainą.

Medvilnės pluošto tonos kaina yra 4 910 eurų.

Šilko antrinių atliekų tonos kaina yra 2 420 eurų.

Vienai tonai dvikomponenčių verpalų pagaminti sunaudojama 62,5% medvilnės pluošto ir 37,5 % antrinio šilko pluošto atliekų.

Ekonominių efektyvumą galima apskaičiuoti pagal šią formulę:

$$C_e = [H - (aH_1 + bH_2) - F_x], \quad (2)$$

čia C_e – ekonominis efektyvumas;

H – parduodamo produkto kaina;

H_1 – medvilnės pluošto kaina;

H_2 – šilko pluošto kaina;

a, b – komponentų dalys;

F_x – bendrųjų gamyklos sąnaudų (parduotuvės sąnaudų, darbo sąnaudų ir kitų sąnaudų) dalis produkcijoje.

Pelnas, gautas pagaminus ir pardavus vieną toną dvikomponenčių verpalų, nurodomas eurai:

$$C_e = [H - (aH_1 + bH_2) - F_x] = [67,0 - (0,625 * 54,0 + 0,375 * 26,6) - 10] = 1300 \text{ EUR}$$

Taigi, gaminant vieną toną dvikomponenčių verpalų, pridėdant medvilnės pluošto ir šilko pluošto atliekų kokonus, numatoma gamyklinių sąnaudų dalis buvo 910 EUR, o tikėtinas grynasis pelnas, gautas pardavus gatavus verpalus, buvo 1300 EUR.

IŠVADOS

1. Literatūros šaltinių analizė rodo, kad verpalų mechaninėms savybėms prognozuoti būtina atsižvelgti į jų formavimosi būklę, kurios mechanizmas labai priklauso nuo verpimo būdo ir verpimo įrenginių greičio režimų:

- Jėgos poveikio siūlų struktūroje momentu vyksta pluoštų tiesinimo ir jų konvergencijos procesas, kurio pobūdis priklauso nuo siūlų sukimo laipsnio. Dėl to palaiptinui didėja siūlų skerspjuvio radialinio įtempio vertė, o tai padidina gaminio tempimo standumą.

- Pluoštų, išsidėsčiusių išilgai spiralinių linijų, stiprumas didėja didėjant pasvirimo kampui ir po kurio laiko pasiekia maksimalią reikšmę, tada palaiptinui pradeda mažėti.

- Siūlų mikrostruktūros nevienalytiškumas ir platus kai kurių verčių, būdingų tam tikro verpalų deformacijai, pokyčių diapazonas (pavyzdžiui, trūkimo apkrova) leidžia vaizduoti tikrą siūlą kaip didelį pluošto elementų derinį, turinčių paprasčiausius deformacijos dėsnius, tačiau turinčių skirtingą konstantų skaičių. Pradinėse apkrovos stadijose klampumo savybės yra ryškesnės, o vėliau, didėjant jėgai, šios savybės pereina iš viengubo į kompaktišką pluoštų sistemą, turinčią didelį elastingumo modulį ir mažesnį klampumo parametą.

2. Žinomų modelių, skirtų mechaninėms savybėms įvertinti, ypač tekstilės siūlų deformacijai, analizė neabejotinai parodo jų priimtinumą mechaninėms savybėms įvertinti, tačiau jie turi tam tikrą trūkumą:

- J. W. S. Hearle modelyje neatsižvelgiama į pluošto vietos siūlų skerspjuvyje koordinatas,

- T modelyje G.I. Chistoborodov neatsižvelgia į ašinį siūlų įtempimą, kuris atsiranda gaminiui sukant.

- Abiejuose modeliuose neatsižvelgiama į suplyšusių ir slystančių pluoštų proporcijų pasikeitimą, veikiant sukimui ir įtempimui. Visi šie reiškiniai yra susiję su sukimosi režimais ir greičiu.

3 Sukurtas naujas matematinis modelis, nustatantis siūlų deformaciją veikiant tempimo jėgai ir sukimo momentui, atsižvelgiant į siūlų mechaninių savybių kintamumą ir anizotropiją, naudojant tamprumo teoriją, bei naujų rūšių siūlai iš medvilnės ir šilko atliekų pluoštų.

4 Pasikeitus technologiniams procesams ir verpimo darbo režimams, atsiranda siūlų struktūrinis pokytis. Dėl to pasikeičia paties verpalo mechaninės savybės. Pagaminus verpalus ir palyginus dviejų rūšių verpalus, kurių ilginis tankis 20 tex ir 40 tex, nustatyta:

- 40 tex verpalų trūkimo apkrova padidėjo 4,8%. Įprastų 40 tex verpalų trūkimo apkrova yra 492 cN, o naujų – 516 cN. Tai reiškia, kad pluoštų išsidėstymas naujame verptame siūle lygiagretesnis, palyginti su įprastais siūlais. Trūkimo apkrovos netolygumai rodo, kad eksperimentinis verptas siūlas su 20 tex turi mažesnę trūkimo apkrovos netolygumą nei įprastas. Įprasti siūlai turi 6,7%, o eksperimentiniai – 2,5%.

- Įprastų 20 tex verpalų trūkio pailgėjimas yra 5,13%, eksperimentinio – 6,0%; įprastų 40 tex – 5,92%, eksperimentinio – 6,0%. Įprasto 20 tex verpalo trūkimo pailgėjimo netolygumas yra 6,5%, o eksperimentinio – 1,8%, tai yra 2,6 karto mažiau. Įprasti verpalai su 40 tex turi apytiksliai 1,3 karto mažesnę vertę, t. y. įprasti siūlai turi 6,3%, o eksperimentiniai siūlai – 5,0%.

- Įprasto 20 tex verpalo savitoji trūkimo jėga yra 12,07 cN/tex, o eksperimentinio – 12,08 cN/tex. Įprasti verpti verpalai su 40 tex turi 12,56 cN/tex, o eksperimentiniai – 13,16 cN/tex, o tai reiškia 4,7 karto daugiau, palyginti su įprastais verptais verpalais. Įprasto 20 tex verpalo savitosios trūkimo apkrovos netolygumas yra 6,7%, o eksperimentinio esant tam pačiam ilginiam tankiui – 2,5%; įprasto ir eksperimentinio verpto verpalo esant tam pačiam 40 tex rezultatas yra toks pat, t. y. 5,7%.

- Įprasto 20 tex verpalo darbas yra 348 cN*cm, o eksperimentinio – 384 cN*cm. Įprasti verpalai su 40 tex turi 782 cN*cm, o eksperimentiniai siūlai 858 cN*cm. Tai reiškia, kad, norint nutraukti siūlą, reikia didesnės energijos. Eksperimentiniai siūlai yra geresnės kokybės. Darbo verčių netolygumai taip pat rodo skirtingus rezultatus: įprastiniai 20 tex siūlai turi 12,2%, eksperimentiniai – 4,1%, įprastiniai 40 tex – 10,1%, o eksperimentiniai – 9,3%. Tai reiškia, kad kuo daugiau plaukelių, tuo mažesnė vertė.

- Verpalų trūkimo laikas taip pat skiriasi – įprastas siūlas abiem atvejais turi mažesnę trūkimo laiką, t. y. 20 tex turi 0,31 s, bet eksperimentinis 0,36 s; verptų verpalų su 40 tex – 0,6 sek, o eksperimentinis – 0,38 sek.

- To paties 20 tex ilginio tankio medvilnės verpalų ir medvilnės ir šilko verpalų variacijos koeficientai skiriasi: medvilnės verpalai trimis atvejais yra didesni nei mišrių verpalų. Dvikomponenčių verpalų trūkimo jėga didesnė – 339,4 cN, o medvilniniai verpalai turi 281,2 cN. Dvikomponenčių verpalų trūkimo stiprumo

kitimo koeficientas yra 1,2 karto mažesnis nei medvilnės. Specifinis mišraus verpalų stiprumas taip pat didesnis nei medvilninių – 16,9 cN/tex, o medvilnės 13,9 cN/tex. Dvikomponenčių verpalų pailgėjimas trūkstant yra 6%, o medvilnės – 3,93%.

5. Visi nustatyti mišrių siūlų skirtumai rodo, kad siūlų struktūra vaidina pagrindinį vaidmenį bet kokio tipo siūlų mechaninėms ir fizikinėms savybėms. Didesnės lygiagrečios orientacijos pluoštai verpaluose suteikia daugiau stiprumo trūkimo metu bei pailgėjimą. Naudojant mišrų pluoštą, ypač šilko atliekų pluoštą, taip pat suteikiama daugiau stiprumo ir geresnių savybių.

6. Šilko atliekų pluoštų naudojimas daro teigiamą įtaką ne tik tvarumui ir žiedinei ekonomikai, bet ir savybėms bei ekonominei naudai.

Moksliniai darbai, susiję su disertacijos tema:

1. [S1; PL; OA] **Shukhratov, Sharof;** Milašius, Rimvydas; Gafurov, Kabuljon; Maksudov, R.; Gafurov, Jakhongir; Tojimirzaev, Sanjar. Improvement in the design and methods of calculation of parameters of vibration multifaceted gridirons of natural fibre cleaners // *Fibres & textiles in Eastern Europe*. Łódź : Institute of biopolymers and chemical fibres. ISSN 1230-3666. eISSN 2300-7354. 2021, vol. 29, iss. 5, p. 29-33.
2. [S1; PL; OA] **Shukhratov, Sh.;** Milašius, R.; Gafurov, K.; Gafurov, J. Investigation of twist waves distribution along structurally nonuniform yarn // *Autex research journal*. Warsaw : Sciendo. ISSN 1470-9589. eISSN 2300-0929. 2021, vol. 00, p. 1-5.
3. [S1; PL; OA] **Shukhratov, Sharof;** Milasius, Rimvydas; Gafurov, Jakhongir; Mardonov, Batir; Gafurov, Kabuljon; Repon, Md Reazuddin. Investigation of open end yarn tension using an elastic yarn-guide // *Fibres & textiles in Eastern Europe*. Łódź : Institute of Biopolymers and Chemical Fibres. ISSN 1230-3666. 2021, vol. 29, iss. 4, p. 43-47.

Mokslinės konferencijos:

1. [T2; PT] Shukhratov, Sharof; Milašius, Rimvydas; Gafurov, Jakhongir; Gafurov, Kabuljon; Mardonov, Batir. Features of the formation and torsion of OE yarn // *AUTEX 2021 - Unfolding the future: 20th world textile conference*, 5-9 September 2021, Guimarães, Portugal. p. 37-38.
2. [T1e; LT] Shukhratov, Sharof; Milašius, Rimvydas; Ochilov, Tulkin. Influence of silk wastes indicators on silk-raws roughness // *Advanced materials and technologies: book of abstracts of 23rd international conference school*, 23-27 August 2021, Palanga, Lithuania. Kaunas. 2021, A-P3, p. 32.
3. [T1e; PT] Shukhratov, Sharof; Milašius, Rimvydas; Makhudov, Ravshan; Gafurov, Kabul; Gafurov, Jakhongir. The formation of a fibrous ribbon of dense structure // *ICNF 2021: 5th international conference on natural fibers - materials of the future*, 17-19 May 2021, online, Portugal. p. 37-38. [M.kr.: T 008]
4. [T1e; LT] Shukhratov, Sharof; Yusupkhodjaeva, Gulnoz; Milašius, Rimvydas. Research of methods to improve properties of blended fibres from waste of natural fibres // *Advanced materials and technologies: book of abstracts of 22nd international conference - school*, 24-28 August 2020, Palanga, Lithuania. Kaunas. ISSN 1822-7759. 2020, B-P125, p. 154. [M.kr.: T 008]
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145. M. El Messiry, Design of multilayer filters; study the effect of nanofibre structures application, *Autex 2011 World Textile Conference*, June 8–10, 2011, Mulhouse, France.

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Areas of research interests

Textile industry, bicomponent yarns, naturel fibers, mechanical engineering, production engineering, textile technology, cotton and silk industry, materials engineering, etc.

LIST OF PUBLICATIONS

Scientific papers related to the topic of dissertation

1. [S1; PL; OA] **Shukhratov, Sharof**; Milašius, Rimvydas; Gafurov, Kabuljon; Maksudov, R.; Gafurov, Jakhongir; Tojimirzaev, Sanjar. Improvement in the design and methods of calculation of parameters of vibration multifaceted gridirons of natural fibre cleaners // *Fibres & textiles in Eastern Europe*. Łódź : Institute of biopolymers and chemical fibres. ISSN 1230-3666. eISSN 2300-7354. 2021, vol. 29, iss. 5, p. 29-33. DOI: 10.5604/01.3001.0014.9292. [Science Citation Index Expanded (Web of Science); Scopus] [IF: 1,045; AIF: 3,042; IF/AIF: 0,343; Q3 (2020, InCites JCR SCIE)] [CiteScore: 1,40; SNIP: 0,770; SJR: 0,304; Q2 (2020, Scopus Sources)] [M.kr.: T 008] [Indélis: 0,085]
2. [S1; PL; OA] **Shukhratov, Sh.**; Milašius, R.; Gafurov, K.; Gafurov, J. Investigation of twist waves distribution along structurally nonuniform yarn // *Autex research journal*. Warsaw : Sciendo. ISSN 1470-9589. eISSN 2300-0929. 2021, vol. 00, p. 1-5. DOI: 10.2478/aut-2021-0040. [Science Citation Index Expanded (Web of Science); Scopus; DOAJ] [IF: 1,375; AIF: 3,042; IF/AIF: 0,452; Q3 (2020, InCites JCR SCIE)] [CiteScore: 1,80; SNIP: 1,090; SJR: 0,353; Q3 (2020, Scopus Sources)] [FOR: T 008] [Input: 0,250]
3. [S1; PL; OA] **Shukhratov, Sharof**; Milasius, Rimvydas; Gafurov, Jakhongir; Mardonov, Batir; Gafurov, Kabuljon; Repon, Md Reazuddin. Investigation of open end yarn tension using an elastic yarn-guide // *Fibres & textiles in Eastern Europe*. Łódź : Institute of Biopolymers and Chemical Fibres. ISSN 1230-3666. 2021, vol. 29, iss. 4, p. 43-47. DOI: 10.5604/01.3001.0014.8230. [Science Citation Index Expanded (Web of Science); Scopus] [IF: 1,045; AIF: 3,042; IF/AIF: 0,343; Q3 (2020, InCites JCR SCIE)] [CiteScore: 1,40; SNIP: 0,770; SJR: 0,304; Q2 (2020, Scopus Sources)] [M.kr.: T 008] [Indélis: 0,085]

Scientific conferences

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2. [T1e; LT] Shukhratov, Sharof; Milašius, Rimvydas; Ochilov, Tulkin. Influence of silk wastes indicators on silk-raws roughness // *Advanced materials and technologies: book of abstracts of 23rd international conference school*, 23-27 August 2021, Palanga, Lithuania. Kaunas: Kaunas University of Technology. ISSN 2669-1930. 2021, A-P3, p. 32. [M.kr.: T 008]
3. [T1e; PT] Shukhratov, Sharof; Milašius, Rimvydas; Makhsudov, Ravshan; Gafurov, Kabul; Gafurov, Jakhongir. The formation of a fibrous ribbon of dense structure // *ICNF 2021: 5th international conference on natural fibers - materials*

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4. [T1e; LT] Shukhratov, Sharof; Yusupkhodjaeva, Gulnoz; Milašius, Rimvydas. Research of methods to improve properties of blended fibres from waste of natural fibres // Advanced materials and technologies: book of abstracts of 22nd international conference - school, 24-28 August 2020, Palanga, Lithuania. Kaunas: Kaunas University of Technology. ISSN 1822-7759. 2020, B-P125, p. 154. [M.kr.: T 008]
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