DEPENDENCE OF HYDROPHOBIC PROPERTIES OF TEXTILE MATERIAL ON THE ANATOMICAL STRUCTURE OF HEMP FIBERS IN ITS BASIS

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Abstract: The article examines the actual problems of the production of textile shoes from domestic Ukrainian bast fiber raw materials. Hemp raw materials have all the necessary consumer properties to be used for the upper fabric of textile shoes. In order to study all the qualitative properties of this fiber and determine the possibility of application in shoe production, scientists of the Kherson National Technical University conducted a number of experimental studies. Research was aimed at determining not only the physical and mechanical properties of hemp fiber, but also considered the anatomical structure of this type of fiber. In the course of research, it was established that at full maturity of the stalks of industrial hemp, after their mechanical processing using the combing process, the chaff is completely freed from the woody part: phloem, xylem, parenchyma, and a cuticle remains on the outside of the fibers, which gives the fibers hydrophobic properties. To confirm this result, an experiment was conducted on the wettability of hemp cotinine after steaming in order to identify the hydrophobic properties of future raw materials for the shoe industry. According to the results of this experiment, it was confirmed that the presence of cutins on hemp fibers reduces moisture permeability, which is a positive indicator in the use of this raw material for shoe upper fabric. The use of this fiber for the production of raw fabric without processing makes it possible to create textile shoes with water-repellent properties. Further research in this field should be aimed at obtaining mixed yarn based on the fibers of technical hemp, fabric using of it. The final stage of this work is obtaining shoes with upper fabric based on this fiber.

Keywords: technical hemp; fibers; anatomical structure; cutins; hydrophobicity; hygroscopicity; footwear.

1 Introduction

Shoes are one of the integral parts of our life. Currently, there are thousands of shoe options in the world, from simple flip flops to extravagant high heels.

In the era of such diversity, one needs to understand when and what kind of shoes to wear in order not to harm health and feel comfortable in any place. The wardrobe of every inhabitant of the planet must have light, comfortable, textile shoes. For the manufacture of such shoes, fibers of vegetable origin, animal, artificial, and even mineral materials are used. The main thing is that this textile has high-quality environmental and operational properties.

Scientists of the Kherson National Technical University are conducting research on the use of Ukrainian domestic textile raw materials of technical hemp fibers in shoe production. After all, this textile raw material has many quality properties that have a positive effect on the production of shoes. The lightness and strength of such textile shoes contribute to its demand among the population. In such a dynamic pace of life, one needs to be able to move quickly and painlessly [4]. The physical properties of natural textiles allow air to move freely from the inside to the outside, which means that foots in it will not sweat and will not have damage from walking. Thanks to this, natural textiles are an ideal choice for hot weather. Also, natural textiles made from hemp plant fibers do not cause allergies, irritation, or other dermatological disorders.

Among all indicators of the quality of textile footwear, reliability is the main indicator that summarizes various physical and mechanical properties. Even the most fashionable, most necessary shoes will not be purchased if the consumer has doubts about their reliability. The concepts of reliability and durability are closely related, but by no means identical. Reliability means complete, failure-free, repair-free preservation of the properties of shoes during the period of operation, which is determined by a certain calendar period [3].

Despite all the positive aspects, Ukrainian scientists proved that this natural textile has negative factors affecting the performance properties of shoes, which can negatively affect the reliability of this product. The conducted studies proved that due to the high rate of relative tensile elongation of technical hemp fibers, which were used in the fabric of the shoe upper, the shape stability of this shoe was lost over time.

Scientists have carried out fundamental work on preserving the operational properties of shoes with upper fabric based on technical hemp [2]. Also, anatomical studies of technical hemp fibers were conducted in order to determine the hydrophobic properties of this raw material. After all, the use of this fiber in fabrics for the upper of textile sports shoes requires the use of special solutions, sprays or treatments to give the fabric a protective effect against the passage of water, and this fact can harm the naturalness and environmental friendliness of the product. This work is based on the creation of textile eco-shoes with high quality properties.

2 Materials and Method

During the implementation of this scientific work in the conditions of the laboratory of the Kherson National Technical University, a study of the anatomical structure of fibers of technical hemp of the Glyana variety, which are proposed to be used for the production of textile shoe uppers, was conducted.

In the production of hemp fabric for use in footwear products, hemp cotinine is produced using the stem decortication technology followed by mechanical modification of the fiber.

It is known that fibers with a linear density of 0.16 – 0.33 tex and cross-sectional dimensions of 15 - 19 microns are used on the equipment of cotton processing enterprises using the carded spinning system. The obtained hemp cotinine according to the traditional technology has a linear density of 6.8 tex, which is 20 times higher than the standard cotton cotinine. Thus, the hemp cotonin obtained using mechanical modification technology does not correspond to the similar parameters of medium-fiber cotton in terms of thickness, therefore it cannot be used for obtaining thin and soft yarn [1].

Analyzing the strength of hemp cotinine fibers, which is one of the most important indicators of its quality, it can be concluded that the breaking load of cotinine is 0.039 daN greater than the maximum value of the breaking load of medium fiber cotton, which is 0.003 daN. Therefore, hemp cotinine fibers exceed cotton fibers by 93% in terms of breaking load. The relative breaking elongation of hemp cotinine is 17.2%, and with such an indicator, one hundred percent use of this raw material in yarn for the production of form-resistant products is not recommended. To reduce this indicator, it is necessary to select mixtures with other fibers or use different types of processing of hemp cotinine fiber.

For this purpose, raw materials were steamed in a laboratory autoclave. The following modes were used for steaming the material:

- Pressure: heating, cooking – 1.2 – 7.1 kgf/cm^2; steaming - 1.8 - 2.3 kgf/cm^2; washing – 0 kgf/cm^2;
- Temperature: heating, cooking – 90 – 160 ^{o}C; steaming - 140 - 121 ^{o}C; washing - 40 ^{o}C;
- Operation duration: heating, cooking – 30 min.; steaming - 20 min.; washing – 10 min.

After steaming, repeated studies of physical and mechanical parameters of hemp fiber were carried out. After steaming, a significant decrease in absolute and relative elongation at break was observed. The decrease was by half - from 10.6 to 5.3 mm, from 17.2 to 9.3% respectively. This happens due to a change in the chemical composition of cotinine, namely a decrease in the content of fatty waxes to 1.0-1.2%. In addition, there is also a decrease in the linear density of hemp cotinine, which also has a positive effect on the quality of the final textile product [5]. As a result of the conducted research, it was revealed that due to the steaming of hemp cotinine, a mechanical method of modification, under certain conditions, it is possible to ensure a decrease in elongation during stretching, which improves the dimensional stability of future footwear products during their use.

The preservation of hemp cotinine with improved mechanical and geometric properties cannot be the only prerequisite for the use of this fiber in the production of footwear products. Other properties of fibers, in particular physical, are important to ensure the quality of the fabric used to make shoes. The physical properties of hemp fibers include hygroscopicity. A property of footwear products is hygroscopicity. This indicator is characteristic of the properties that determine the convenience of a particular material when using it in footwear products. Thus, in order to determine the hydrophobic properties of technical hemp fibers, a study of their anatomical structure by light microscopy was conducted.

Light microscopy of cross-sections of technical hemp fibers was carried out according to the method of V.A. Arkhangelsky with the use of metal plates on which there are small holes for forming slices. According to this method, a thin bundle of the investigated fibers is previously slightly twisted and pulled through a loop of sewing thread via a small round hole in a thin metal plate. As a result, the bundle of fibers is clamped in the hole perpendicular to the plate. The protruding ends of the bundle are cut with a blade on both sides at the level of the plate. The plate is placed in a microscope to study the cross-section in reflected light [9].

Research is carried out on a biological microscope designed for the study of transparent objects in transmitted light. For a comparative assessment of the degree of splitting of fibers obtained using different methods of mechanical and physical-chemical processing, one should use the methodology developed by N. A. Ordina [11]. According to this technique, 30 handfuls of compared batches of fiber, selected from different places, are separated by a small spinning wheel. Cross sections are made from the fiber of each spinning wheel. The number of single elementary fibers and fibers in groups of all technical fibers is counted under a microscope. Next, the total number of fibers in groups up to 5 (including single ones), from 6 to 10, from 11 to 15, from 16 to 20, from 21 to 25, from 26 to 30, from 31 to 35 and more than 35 or fibers in groups of more than 25 are combined together. The total number of fibers is then counted and the percentage of each group is determined from the total number of fibers. According to the results of the calculations, a graphic image of the distribution of fibers by groups is built for each batch. On the basis of obtained curves, a conclusion is made about the degree and nature of fiber grinding under different processing modes [13].

The next stage of checking the hygroscopic properties of this fiber was based on determining the percentage of moisture absorbed by the fiber at certain intervals of time. For this, the so-called wetting of technical hemp fibers was carried out in the conditions of the laboratory of the Kherson National Technical University. To determine the wettability, 15 g of air-dry cotinine, selected from the average sample, is weighed with an error of no more than 0.1 g and a sample is formed on the table according to the size of an aluminum cylinder, which was previously made according to the drawing [7]. The fiber is placed in a pre-weighed cylinder and compacted to the inner mark of 50 mm.

During the formation of the sample, the dust that has spilled out is collected and placed in the cylinder together with the fiber.

Distilled water with a temperature of 20 ± 0.5 ℃ is poured into the crystallization cup to a level no lower than 20 mm from the edge. After that, an aluminum cylinder is lowered into it to the level of the outer lower mark of the cylinder. After 30 s, the aluminum cylinder with the moistened mass of fibers is removed from the water and weighed with an error of no more than 0.1 g. Wettability X_2, g is calculated according to the formula:

$$X_2 = m_1 - (m_2 + m), \qquad (1)$$

where

m – mass of air-dry cotinine, g;

m_1 – mass of the cylinder with cotinine after the test, g;

m_2 – mass of the empty cylinder, g

The result of the test is taken as the arithmetic average of five parallel tests rounded to a whole number, the permissible difference between which does not exceed 10% relative to the average value. All research results are the basis for the production of high-quality textile eco-shoes with upper fabric based on technical hemp fibers.

3 Results and Discussion

Increased air and body temperature leads to profuse sweating, which, in turn, creates tangible discomfort for a person. The high breathability and heat generation of the fabric allow getting rid of excess moisture. These physical properties are important for the production of comfortable shoes. As evidenced by the results of the research of famous Ukrainian domestic scientists N. P. Lyalina, N. I. Rezvyh, O. O. Horash, the above-mentioned fiber quality indicators of bast crops depend on their anatomical structure. As it was already studied earlier, hemp fiber has a large channel that allows the required amount of air and heat to pass through well [7; 10; 12].

It is known that fabrics for the upper of textile shoes are usually treated with special solutions in order to retain moisture coming from the outside (rain, puddles, water). If we are talking about the production of high-quality eco-shoes, then treatment with special preparations, sprays or waxes will be superfluous in this product. Thus, further study of the physical parameters of the obtained hemp cotinine is a very urgent task.

Scientists of the Department of Commodity Science, Standardization and Certification of the Kherson National Technical University conducted similar studies of the qualitative characteristics of the fiber of another bast culture oil flax. O. O. Horach conducted a thorough study of the anatomical structure of linseed fibers in order to find out the reasons for their low wettability and found that this indicator depends on the presence of a cuticle on the surface of the fiber, which delays the absorption of moisture [8]. Taking into account the results of this scientific work, it was decided to investigate the wettability of technical hemp fibers, because, as it is known, they also have a cuticular layer on the surface (Figures 1 and 2). The general characteristics of the anatomical structure of the stem of this culture are given in Table. 1.

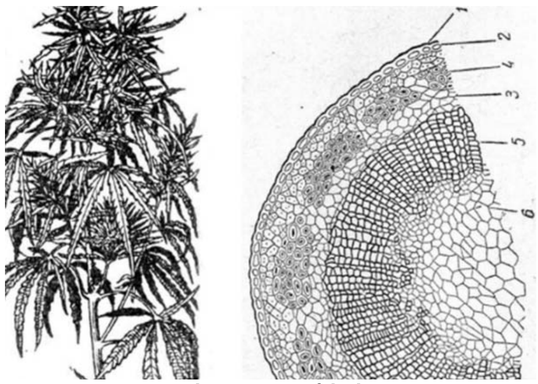

Figure 1. The structure of the hemp stem:

a) the appearance of the plant;
b) cross-section of a hemp stem:
1 – cuticle; 2 – covering fabric; 3 – bundles of fibers; 4 – parenchyma; 5 – wood; 6 – core

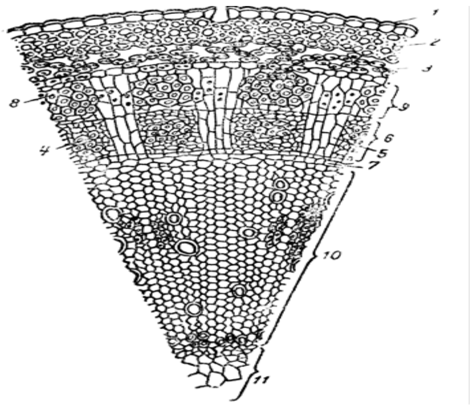

Figure 2. Diagram of the anatomical structure of the hemp stem:

1 – epidermis with cuticle; 2 – collenchyma; 3 – cortical parenchyma; 4 – secondary bast fibers; 5 – bark parenchyma; 6 – phloem; 7 – cambium; 8 – primary bast fibers; 9 – cells of perecyclic parenchyma; 10 – wood; 11 – core

Table 1: Characteristics of the structure of the hemp stem

Part stems	**Tissue name**	**Tissue structure**	**Tissue functions**
1	2	3	4
Fibrous part	Cover part	It consists of a skin - the epidermis (1), which is one or more layers of tightly closed cells, not separated by an intercellular space, with a cellulose membrane and externally covered with a film - a cuticle. The cuticle is impregnated with the fatty substance cutin, which does not allow moisture to pass through.	Protects hemp plants from harmful evaporation of moisture, from adverse environmental conditions, carries out water and gas exchange
	Main, or fabrics primary cortex	It consists of three layers: - collenchyma (2), which is a tissue of the parenchymal type, cells have a cellulose shell of uneven thickness; - cortical parenchyma (3), consisting of thin-walled cells separated from each other by an intercellular space; - the endodermis, which forms the inner boundary of the primary cortex, cells are arranged in one layer and contain starch grains. Behind the primary bark is a hard bark, which consists of thin-layered pericyclic parenchyma cells (9) and thick-walled prosenchymal cells of primary bark fibers (8).	Collenchyma is a mechanical tissue that gives the stem strength and stability. Cortical parenchyma performs the function of carbon dioxide assimilation and is often filled with nutrients (starch, sugar, etc.). The endodermis accumulates nutrients necessary for the restoration of plant vegetation. Primary bast fibers perform the function of mechanical fabric
	Conductive or phloem (6)	It consists of sieve tubes, secondary bast fibers (4) and bast parenchyma (5). Sieve-like tubes are capillaries with transversely perforated walls. Secondary bark fibers and bark parenchyma are formed from the cambium (7). Behind the parenchyma of the bark is a narrow strip of cambium, which separates the bark (hard bark, primary bark, integument tissue) and wood tissue consisting of thin, dividing cells.	Sieve-like tubes allow nutrients to easily pass through them into nearby living tissues.
Wooden part	Parenchyma, mechanical, vascular	Wood (10) consists of three groups of tissues: parenchyma, mechanical, and vascular. Wood parenchyma is poorly developed and consists of thin-walled, lignified cells. Wood fibers are thick-walled lignified elongated cells with pointed ends. Vessels in the form of tubes are dead cells. In the radial direction, the wood is divided by core rays.	In the wood parenchyma, there is an accumulation of nutrients and their movement in a horizontal direction. Wood fibers give the stem strength and stability in the vertical direction. Vessels are conductive tissue, along which the soil solution moves along the plant.
Core		Core (11) is the last inner tissue of the stem. The cells of this tissue are parenchymal, large, thinly layered	

As a result of the study of the anatomical structure of the hemp stem, it was revealed that the primary fiber lies in the bark in one layer in the form of a cylinder along the entire stem. At the same time, the height of secondary fiber formation in the stem is very different, since depending on the growing conditions of hemp, it can develop from one to several layers of fibers. Primary and secondary fibers are anatomically heterogeneous. Cells of primary elementary fibers have isodiametric (round or close to round), elliptical and oval shapes. The variability of the shape of the cells largely depends on the force of their pressure on each other during the compaction of the fibrous layer [6]. Fibers with thinner sheaths change shape significantly more than fibers with thicker sheaths. The diameter of the cells ranges from 5 to 55 μm, and the length - from 0,61 to 7.5 mm. Fiber with an isodiametric shape of cells has high quality, with elliptical or oval cells - medium, and fiber from "crumpled" cells is characterized by the lowest quality. The sheath of primary elementary fibers is multi-layered. Its thickness varies from 7.5 to 15.7 microns. As the wall thickness increases, the channel (cavity) of the cell decreases.

The secondary elements of the fiber, together with the primary ones, have a more rounded shape, a lower degree of wall stratification, that is, a thin cell shell, but a larger channel in relation to the number of cells. Their length does not exceed 4 mm, and the diameter is 10.0 - 19.8 microns. They are less compactly arranged in bundles, and the bundles are in the fibrous layer. High-quality hemp fiber is obtained if the fiber elements are correctly formed and have an isodiametric shape, a small cell diameter, and a rounded sheath contour (without zigzags).

At the full maturity of the straw stalks of industrial hemp, after their mechanical processing using the combing process, the husk is completely freed from the woody part: phloem, xylem, parenchyma, and a cuticle remains on the outside of the fibers, which gives the fibers hydrophobic properties. The cuticle is a solid, structureless transparent film, which in the form of hairs enters between the fibers. The cuticle consists of substances called cutins. As was proved in the work of N.A. Ordina, cutins are high-molecular fatty acids, oxyacids, waxes, and fats [11]. They are resistant to the action of strong chemical reagents, such as concentrated acids and alkalis. Cutins are insoluble in sulfuric and chromic acids and even in copper-ammonia solution, in which cellulose dissolves. The presence of cutins on the surface of technical hemp is the reason for its low wettability. After the mechanical processing of the straw stems, which was carried out on the decorticator, and the modification of the fibers, the cuticle still remained on the fiber. This is evidenced by the analysis of a micrograph of a cross-section of technical hemp fibers (Figure 3).

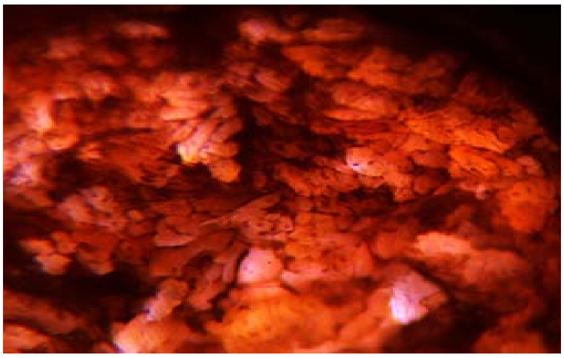

Figure 3. Photomicrograph of a cross-section of fibers of technical hemp of the Glyana variety

After a detailed study of the microstructure of technical hemp fibers and the detection of cutins on their surface, a study of the wettability of hemp cotinine after steaming was conducted in order to identify the hydrophobic properties of future raw materials for the shoe industry. The results of studies on the determination of the wettability of hemp cotinine after steaming are shown in Table 2.

Table 2: Indicators of wettability of hemp cotinine

Test number	Wettability, g	Absolute deviation, Δ	Relative deviation, %
1	74.2	3.9	5.55
2	79.3	9.0	12.80
3	62.8	7.5	10.67
4	71.6	1.3	1.85
5	60.3	10.0	14.22
6	73.6	3.3	4.69
Average value	70.3	5.8	8.30

Summarizing the results of theoretical and experimental studies, it can be concluded that the presence of cutins on the fibers of technical hemp determines their high degree of hydrophobicity. Even after carrying out the technological operation of steaming hemp cotinine, as a result of which the content of fatty waxes in it decreased by almost three times, the wettability index did not increase much. It is on average 10.3 g, that is, it is half the wettability of flax fiber, which is equal to 127 g, and cotton – 140 g. This confirms the possibility of using hemp cotinine fibers without treatment as the main component of raw yarn. The use of fabric from such yarn in shoe production will allow manufacturers to save on expensive hydrophobic treatment of shoes and produce more environmentally friendly products.

4 Conclusion

As a result of research into the anatomical structure of technical hemp fibers, it was established that after mechanical processing of the fibers using the combing process, the husk is completely freed from the woody part: phloem, xylem, parenchyma, and a cuticle remains on the outside of the fibers, which gives them hydrophobic properties. These properties of hemp fiber were also confirmed by wettability studies. The results of this study proved that even after carrying out the technological operation of steaming hemp cotinine, as a result of which the content of fatty waxes in it decreased by almost three times, the wettability index did not increase much. It averages 10.3 g, that is, twice as much as the wettability of flax fiber, which is 127 g, and cotton - 140 g. This indicator confirms the possibility of using hemp cotinine fibers without treatment with water-repellent drugs.

The use of this fiber for the production of raw fabric without processing makes it possible to create textile shoes with water-repellent properties. Further research in this field should be aimed at obtaining mixed yarn based on technical hemp fibers, fabric using it, and the final stage is obtaining shoes with upper fabric based on this fiber.

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