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Determining The Strength of The Loop Yarn Based on The Half-Cycle Stretching Deformation Considering The Unevenness

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Abstract
This study investigates the tensile strength of loop yarns under half-cycle stretching deformation while accounting for variations in thickness. Using the 'USTER TENSORAPID 4' device, key properties such as elongation at break, breaking strength, and Young's modulus were measured for yarns with a linear density of 37.03 tex. The findings highlight how changes in yarn thickness affect tensile performance, with thinner areas reducing strength significantly and thicker areas improving it. This research provides insights for optimizing textile materials by addressing variability in yarn properties to enhance overall durability and performance.

Keywords: loop yarn, tensile strength, young's modulus, elastic deformation, yarn thickness variation.

Introduction
In nature, any material, including products made of natural and synthetic fibers, is deformed under the influence of applied external forces, especially when the type of interlacement changes, that is, their shapes (sizes) or volumes change.

Such materials (products) that restore their initial dimensions after the end of external forces are called elastic, and the resulting deformations are called elastic. The force that tends to restore the original shape of the body is called an elastic force.

Elastic deformations occur when the force causing the deformation exceeds certain values specified for each material.

Young's modulus is a quantitative indicator of elastic strength, resulting from the electromagnetic interaction between a material's molecular particles.

A low value of Young's modulus indicates the elasticity of the given material, and a high value indicates the studied material's inelasticity, that is, stiffness.

Methods.

In the international system (SI), "Pascal (*Pa*)" is accepted as the main unit of measurement for this property of materials. It is quantitatively equal to the force applied to $1N$ (Newton) on $1m^2$ of surface, i.e., $1Pa=N/m^2$ [1].

Due to the wide range of Young's modulus values in different materials, the following additional units are adopted:

- *megapascal(MPa)=*10^6 *Pascal*

- *gigapascal (GPa)=10^9 Pascal*
- *terapascal (TPa)=10^{12} Pascal*

The following measurement units are accepted in the textile industry:

$1Pa=10^5$ kgf/mm^2 or $1Pa=10^8$ sN/mm^2

In practice, there are many elastic deformations, for example:

ductile - quick return deformation (stretching part);

elastic - slowly returning deformation;

plastic - irreversible deformation;

- unilateral and comprehensive stretching (compression);
- bend;
- displacement;
- torsion, etc.

The basic laws of elastic deformation were developed by the English physicist Robert Hooke in 1675 [2], and it is as follows:

1. For any small deformation, the elastic force is directly proportional to the deformation.
2. A small amount of deformation is directly proportional to the forces acting on the object.

Based on Hooke's law, we tried to determine the mathematical expression of the value of Young's modulus for a yarn made of 100% cotton fiber by studying uniaxial tensile deformation (see Figure 1).

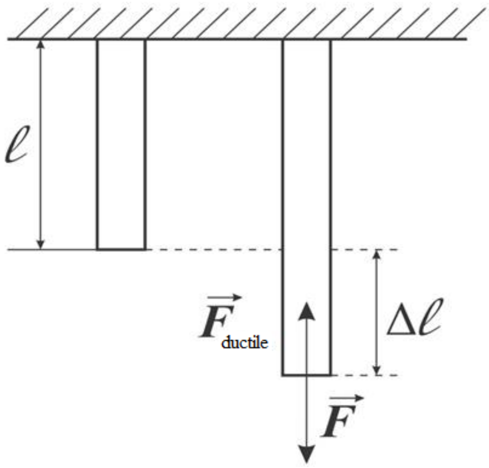

Figure 1. Uniaxial stretching deformation of the yarn.

Let a yarn of length (ℓ) rigidly fixed at one end be subjected to a tensile external compressive force of magnitude $\bar{F}$. As a result of deformation, the yarn acquires a slight absolute elongation ($\Delta\ell$).

Theoretical part.

Quantitative characteristic of deformation is relative elongation, i.e

$$\varepsilon = \frac{\Delta\ell}{\ell} \times 100\% \qquad (1)$$

In practice, this indicator is determined by the elongation at break (Elg-Elongation %) obtained as a result of yarn testing on half-cycle breaking machines of various designs.

As seen in Figure 1, according to R. Hooke's law, when a force of F is applied to an object of length l (in our example, a yarn), the length of the yarn increases by Δl. But in objects, together with the effect of gravity, a tensile (i.e. elastic) force is formed that brings the opposite elongated yarn to its position, and its amount is equal to the acting force F and its direction and it will be the opposite, that is:

$$F_{ductile} = -F \qquad (2)$$

In his experiments, R. Hooke found that with a small amount of deformation of objects, their absolute elongation (Δl) is directly proportional to the initial length of the object and the amount of the applied stretching force (F) and to the cross-sectional surface of the object (S) confirmed that it is inversely proportional, that is:

$$\Delta\ell = \alpha_{\text{ductile}} \frac{\ell \times F}{S} \qquad (3)$$

The proportionality coefficient α in this equation depends on the types of materials and is an indicator of their elastic properties. This coefficient can be determined theoretically for any material based on experiments or a molecular basis in some materials.

In the environment of scientific research based on the tension (deformation) of fabrics and various objects under the influence of external forces, the above proportionality coefficient α_{ductile} is taken as the inverse of Young's modulus, i.e.:

$$E = \frac{1}{\alpha_{\text{ductile}}} \qquad (4)$$

Using formulas (1) and (3), we find the value of relative elongation:

$$\frac{\Delta\ell}{\ell} = \alpha_{ductile} \frac{F}{S} = \varepsilon \qquad (5)$$

Where, we take the $\frac{F}{S}$ value as the elastic stress Ϭ.

The meaning of the expression of the formula (5) is that the relative elongation is directly proportional to the elastic stress, that is:

$$\varepsilon = \alpha_{\text{elastic}} \sigma \qquad (6)$$

Or, using formula (4), R. Hook's mathematical law can be expressed as follows:

$$\sigma = \frac{\varepsilon}{\alpha_{\text{elastic}}} = E \times \varepsilon \qquad (7)$$

that is, at small deformations, the tensile stress is directly proportional to the relative elongation.

Based on the received formula (7), the Young's modulus in stretching along the length of the material can be determined as follows [3]

$$E_{elongation} = \frac{\sigma}{\varepsilon} = \frac{\frac{G}{S}}{\frac{\Delta\ell}{\ell}} = \frac{F \times \ell}{S \times \Delta\ell} \qquad (8)$$

Where: $E_{\text{elongation}}$–Young's modulus of lengthwise stretching of objects, sN/mm^2; F – the force that pulls the object, sN; S – cross-sectional surface of the product, in mm^2; ℓ - initial length of the specimen, in mm; $\Delta\ell$ - absolute sample elongation, in mm.

In our research, we tried to determine the quantitative values of the elastic strength (Young's modulus) of the yarn under stretching conditions [4].

We tried to determine these data using the indicators obtained by the "USTER TENSORAPID 4" device (Swiss, "Uster" company) designed to determine the semi-cycle strength properties of the yarn according to the formula (8) [5].

Results and discussion.

The characteristics of the yarn with a linear density T=37.03 tex spun by the pneumomechanical method were measured on the above measuring device, and the following indicators were obtained:

- practical linear density– 37,09 tex;
- elongation at break-Eℓg=5,75%;
- the absolute breaking strength of the yarn -510,3 sN;
- relative tensile strength –Rkm=13,76sN/teks (510,3sN);
- Breaking force - 1305,3 sN sm.

Parameters of the measuring device:

- the length of the measured sample - ℓ=500mm.;
- sample test rate - 500 mm/min;
- tensile strength of samples –G - 100 N.

In the calculations, the cross-section of the yarn is conditionally assumed to be round, and its diameter is determined by the following formula.

$$d_{\text{yarn}} = \frac{1.25}{\sqrt{\text{N}_\text{M}}} = \frac{1.25}{\sqrt{26.96}} = \frac{1.25}{5.192} = 0.24\text{mm}$$

The cross-sectional surface of the yarn:

$$S = \frac{\pi \times d^2}{4} = 0.785 \times d^2 = 0.7854 \times 0.24^2 = 0.7854 \times 0.0576 = 0.0452\text{mm}^2$$

The value of absolute elongation $\Delta\ell$ with sample length $\ell=500mm$ and relative elongation at break $Elg=5.75\%$ is equal to

$$\Delta\ell = \ell \times \frac{E\text{lg}}{100} = 500\frac{5.75}{100} = 500 \times 0.0575 = 28.75\text{mm}$$

As the breaking force, we take the nominal breaking force of the yarn, equal to 510.9 sN.

Putting the obtained data into the formula (8), we get the value of the Young's modulus for the yarn sample.

$$E = \frac{510.9 \times 500}{0.0452 \times 28.75} = 196344\,\text{sN}/mm^2 = 0{,}0196\text{Pa}$$

It is known that natural cotton fibers, by their nature, have variable length, thickness, and strength indicators, and the yarns produced from them have different values in terms of the main indicators, and in the main indicators also have changes and they are evaluated by the value of the coefficient of variation (Cv) and their values are determined in various modern measuring instruments.

Quality control of the test sample of the yarn with linear density T=37.03 tex, which was tested on the "USTER TESTER-6" device of the "Uster AG" (Switzerland) company, installed in the testing laboratory of "FT Textile" LLC (in the city of Namangan) the results of the analysis of the indicators, the number of thin "thin" and thick "thick" areas compared to their nominal value, data in the form of percentages were obtained and they are presented in Table 1.

Table 1

The ratio of the number of thin and thick places of yarns to their nominal value, the table of percentage values

Indicator	number of thin places, pcs/km in yarn			number of thick places, pcs/km in yarn	
	-30%	-40%	-50%	+35%	+50%
Average value by 5 dimensions	1.0610	50,0	1.0	271,0	18.0
Maximum value	1.1050	93,0	3.0	298,0	20.0
Minimum value	1.0250	30.0	0	250,0	15.0

Using the data presented in Table 1, we tried to determine the values of the breaking strength of this yarn in the thin and thick places, using the values of Young's modulus for this sample yarn.

For this purpose, we tried to determine the value of the breaking force as a result of the change of the transverse surface of the yarn sample from the formula (8).

Formula (8) looks like this:

$$E = \frac{F \times l}{S \times \Delta l}$$

we change this formula

$F \cdot l = E \cdot S \cdot \Delta l$ from here we determine F.

$$F = \frac{E \cdot S \cdot \Delta l}{l} = E \cdot S \cdot \frac{\Delta l}{l} \qquad (9)$$

where $\frac{\Delta l}{l}$ - the relative elongation of the sample at break or "Uster Tensorapid - 4" can be taken in measuring devices, only they are given in percentage, but it must be converted to numerical values, that is:

For example: $E\text{lg} = 5{,}75\%$ $E\text{lg} = \frac{5{,}75}{100} = 0{,}0575$

and the resulting tensile strength of the yarn has the following expression:

$$\text{F} = \text{E} \cdot \text{S} \cdot \text{Elg} \qquad (10)$$

Using this formula, we determined the values of the breaking load G as a result of the change in yarn thickness, and they are summarized in Table 2, and the graphical representation is shown in Figure 2.

Table 2

Table of the result of the change of yarn thickness

Yarn diameters	"d" in mm value	Cross-sectional surface, mm^2	The value of Young's modulus, sN/mm^2	Breaking strength F, in sN
Calculated diameter 0,24	0,24	0,0452	196344.0	510.3
Deviation of thin places -30% (0,24x0,7)	0,168	0,0282	196344.0	249.5
Deviation of thin places -40% (0,24x0,6)	0,144	0,0157	196344.0	177.2
Deviation of thin places s-50% (0,24x0,5)	0,12	0,0113	196344.0	127.5

Deviation of thick places +35% (0,24x1,35)	0,324	0,1049	196344.0	929.14
Deviation of thick places s+50% (0,24x1,5)	0,36	0,1017	196344.0	1148.17

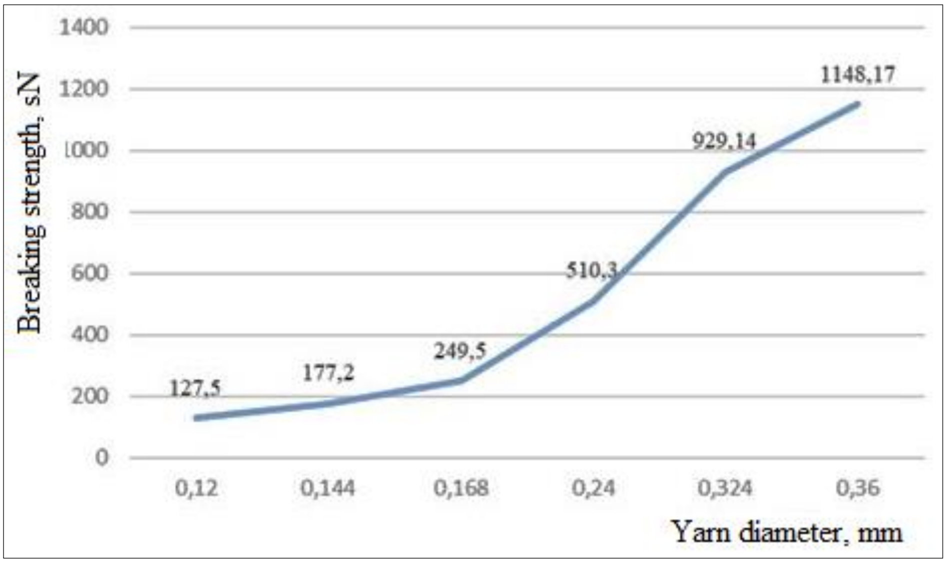

Figure 2. A graphical representation of the dependence of the breaking strength (F) on various changes in yarn thickness (d).

As can be seen from the graph, as the yarn diameter increases, its breaking strength increases. Also, with an increase in the percentage of thin places in the yarn, the breaking strength decreases, and with an increase in the percentage of thick places, the breaking strength increases.

The obtained values of breaking strength at different values of changes in yarn thickness correspond to the actual values [6].

Conclusions.

This article demonstrates that variations in yarn thickness substantially impact tensile strength. Thinner sections weaken the yarn, reducing breaking strength, while thicker regions enhance tensile properties. By quantifying these effects and utilizing theoretical models such as Hooke's law, the study underscores the importance of consistent yarn thickness for improved textile performance. These findings can guide the design and optimization of textile products, emphasizing the need for advanced quality control in yarn production.

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