T. Jackowski,
B. Chylewska, D. Cyniak

Technical University of Łódź

ul. Żeromskiego 116, 90-543 Łódź, Poland

Influence of the Spinning Process Parameters on Strength Characteristics of Cotton Yarns

Abstract

In this paper, the strength parameters of cotton yarns formed on the Rieter R1 spinning machine and on the Textima ring spinning machine were analysed. For the rotor spinning machine, the influence of linear density of the feeding sliver and of yarns on their specific strength, elongation and elasticity was evaluated. For the rotor spinning machine, the following parameters were used:

- *rotational speed of the rotor - 100,000 r/min (1666.7 r/s)*
- *rotational speed of the opening roller - 7,000 r/min (116.7 r/s)*
- *linear density of yarns: 18, 20, 25, 30 tex.*

The spinning machine was fed with slivers after the second passage of drawing with the linear densities: 3.5, 4.0, 4.5, 5.0 ktex. On the ring spinning machine, yarns of linear densities of 25 and 40 tex were formed from the roving 400 tex. Analysis of the results for rotor-spun and ring-spun yarns showed that rotor-spun yarns are characterised by higher elasticity, which makes them a very good material for knitting purposes.

Key words: *rotor spinning, rotor spun yarn, yarn quality parameters, tenacity elongation, elasticity.*

Introduction

Cotton yarn is one of the most popular linear textile products. The basic requirement for obtaining products of the desired quality is the raw material of proper quality. The cotton used in Polish spinning mills comes predominantly from Central Asia. It is processed into carded yarns which are produced on ring spinning machines and rotor open-end spinning machines, the rotor spinning frames being the most popular type of the latter. In comparison with classic yarns produced from raw materials of the same characteristic, rotor-spun yarns have a different geometrical construction with a smaller degree of fibre arrangement along the yarn axis. Hence we also have lower strength of the yarn and lower irregularity of linear density and strength. It must be noted that yarns produced on the most modern rotor spinning machines are similar to ring-spun yarns.

The parameters of the raw material significantly influence the basic quality parameters of the yarns. Numerous studies [1-5] have shown that the quality of ring-spun yarns is influenced primarily by length, strength and fineness of fibres, and that of rotor-spun yarns by strength, fineness of fibres, length of fibres and regularity of fibre length, as well as impurity content. Figure 1 shows the degree to which the individual characteristics of a given fibre influence the breaking force of ring-spun yarn (a) and rotor-spun yarn (b).

For the high-efficiency knitting and weaving machines currently used, yarn of better quality produced from high quality fibres, is required. The quality characteristics of such yarn include:

- linear density and deviation of the actual linear density from the nominal one,
- coefficient of variation of linear density,
- yarn twist (twist coefficient),
- strength characteristics of the yarn and its elongation at breakage,
- purity of the yarn,
- irregularity of yarn linear density (CV%) acc. to Uster apparatus,
- hairiness of the yarn.

Most yarn parameters are determined with the use of measuring apparatus. The values of individual characteristics are referred to world standards according to the Uster statistics, and in this way the quality of yarn is assessed. Uster statistics are the most commonly used quality assessment for yarn.

Strength Characteristics of Yarn

The tensile strength of yarn is an important criterion in assessing yarn

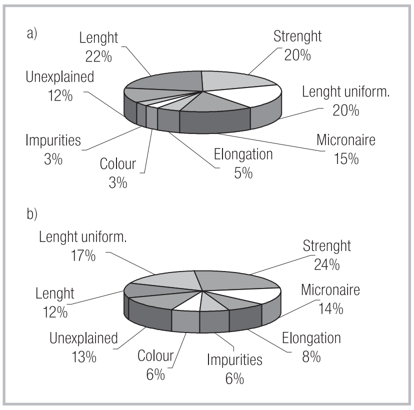


Figure 1. *Dependence of yarn breaking force on fibre characteristics [4], a) ring-spun yarn; b) rotor-spun yarn.*

quality. The number of yarn breakages in spinning, weaving and knitting processes largely depend on it. Apart from the specific strength, another important factor is the coefficient of yarn strength variation, which significantly influences the number of yarn breakages in further processes.

In knitting yarns, strength is not such an important parameter. In the knitting process, yarn is not subjected to very great loads. However, knitting yarn must have sufficient elongation and elasticity. In any chosen section of yarn, during the process of its drawing, we can isolate three fractions of fibres [6]: locked fibres - n_1, fibres not quite locked - n_2, and fibre ends decisive for the hairiness of the yarn - n_3. The sum of these gives the total number of fibres in the cross-section of yarn - n:

$$n_1 + n_2 + n_3 = n \qquad (1)$$

Tension is transferred only by the fibres of the first two fractions, and the fibres of the second are only partly engaged in tension transfer. Thus, yarn strength depends both on the strength of the fibres locked in the yarn and on the resisting forces of the unlocked fibres which can be relocated.

According to formula (2) [6], tension p in the fibre in the twisted yarn at the distance x from the end of the fibre is:

$$p=\frac{2\zeta}{\mu}(\mu\cdot\xi\cdot b+h)\cdot\left(\exp\frac{\mu\cdot x}{2\zeta}-1\right) \qquad (2)$$

where:
ζ - the radius of curvature of a given element of the fibre,
μ - the coefficient of friction between fibres,
b - the width of fibre,
h - the elementary adhesion force, and
ξ - the external pressure on the fibre.

According to formula (2), tension p is caused by friction resistance and by adhesion. Among strength parameters of the yarn, its elasticity is of special importance. In the course of winding, warping, weaving or knitting, the yarn is subjected to considerable tension which grows with the growing speed of machines. Changes of tension following the changes of speed are suppressed thanks to the elasticity of the yarn. Tensile forces cause strains which are the sum of three component strains [7]:

- immediate elastic strain,
- viscoelastic or high elastic strain,
- plastic strain.

Immediate elastic strains already occur at the smallest values of the tensile force and are independent of the time of stress operation. They appear at the moment of applying the force and disappear when the force is removed. According to Hook's law, the value of strain is directly proportional to the values of tensile stress and inversely proportional to elastic properties of the material, as expressed by Young's modulus:

$$\varepsilon_{sn}=\frac{\sigma}{E} \qquad (3)$$

where:
ε_{sn} - elastic strain,
σ - tensile stress,
E - Young's modulus for the fibrous material.

Viscoelastic strains (high elastic) ε_{so} occur after the tensile force exceeds the limit of the material's (yarn) elasticity. They appear second after elastic strain. The disappearance of viscoelastic strain depends on time, and occurs with a certain delay after the moment of removing the force. The occurrence and changes in viscoelastic strains of the fibre are described by Maxwell's equation:

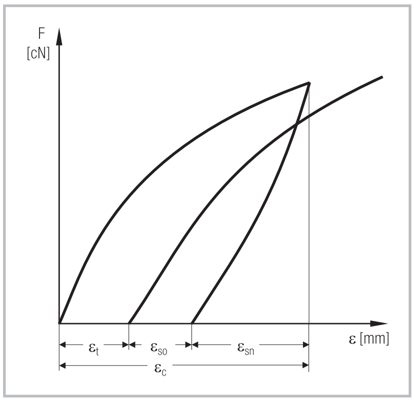


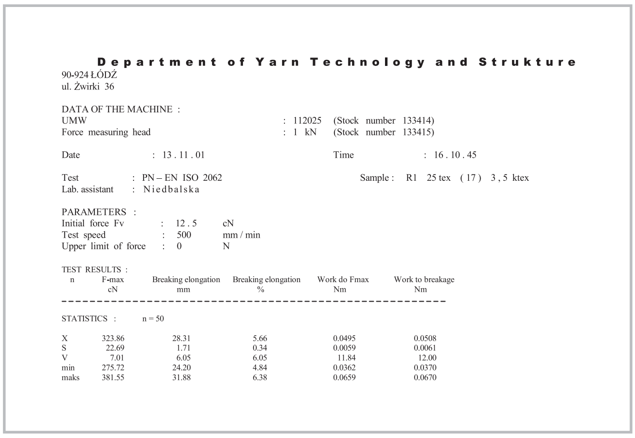
Figure 2. Yarn strains during its drawing.

$$\frac{d\varepsilon_{so}}{dt}=\frac{1}{E}\cdot\frac{d\sigma}{dt}+\frac{1}{\eta}\cdot\sigma \qquad (4)$$

where:
$\frac{d\varepsilon_{so}}{dt}$ - speed at which viscoelastic strain appears,
$\frac{d\sigma}{dt}$ - speed at which tensile stress grows,
η - the viscosity coefficient of fibre material (yarn).

From equation (4), it follows that the speed at which viscoelastic strain appears is directly proportional to the speed at which stress grows and also to the value of operating stress, and is inversely proportional to the elasticity and viscosity of the material.

Plastic strains occur after the tensile force exceeds the limit value of the so-called flow of material (yarn). They appear third after elastic and viscoelastic strains. Plastic strain is of an irreversible character. The speed at which plastic strain appears is directly proportional to the value of the operating tensile stress, and inversely proportional to viscosity of the material:



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Department of Yarn Technology and Strukture
90-924 ŁÓDŹ
ul. Żwirki 36

DATA OF THE MACHINE :
UMW                                   :  112025   (Stock  number  133414)
Force  measuring  head                :  1  kN    (Stock  number  133415)

Date               :  13 . 11 . 01                Time               :  16 . 10 . 45

Test            :  PN – EN  ISO  2062                  Sample :   R1   25 tex   ( 17 )   3 , 5  ktex
Lab. assistant  :  Niedbalska

PARAMETERS  :
Initial  force  Fv       :   12 . 5      cN
Test  speed              :   500         mm / min
Upper  limit  of  force  :   0           N

TEST  RESULTS  :
  n      F-max     Breaking elongation   Breaking elongation   Work do Fmax    Work to breakage
          cN              mm                    %                  Nm               Nm
-----------------------------------------------------------------------------------------------

STATISTICS  :      n = 50

X        323.86         28.31                 5.66               0.0495           0.0508
S         22.69          1.71                 0.34               0.0059           0.0061
V          7.01          6.05                 6.05                11.84            12.00
min      275.72         24.20                 4.84               0.0362           0.0370
maks     381.55         31.88                 6.38               0.0659           0.0670
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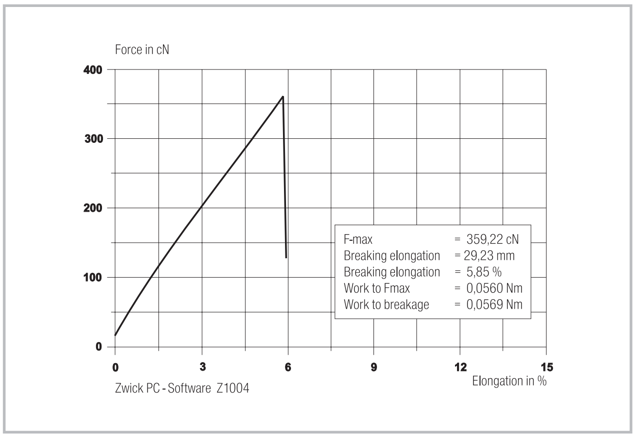
Figure 3. Print-out of strength parameters.



F-max = 359,22 cN
Breaking elongation = 29,23 mm
Breaking elongation = 5,85 %
Work to Fmax = 0,0560 Nm
Work to breakage = 0,0569 Nm

Figure 4. Diagram of yarn breaking.

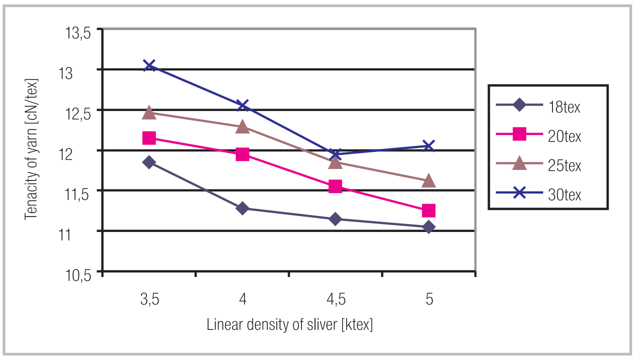


Figure 5. Tenacity of yarns in function of linear density of the sliver feeding the rotor spinning machine.

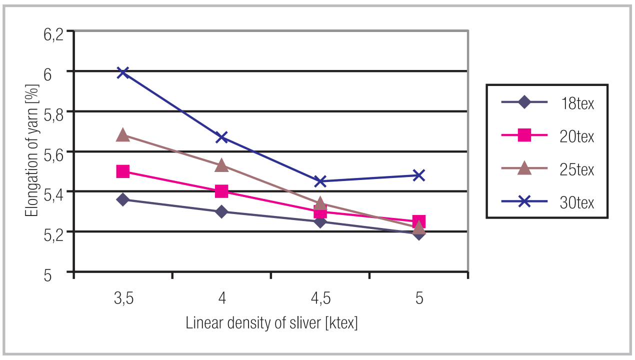


Figure 6. Elongation of yarns in function of linear density of the sliver feeding the spinning machine.

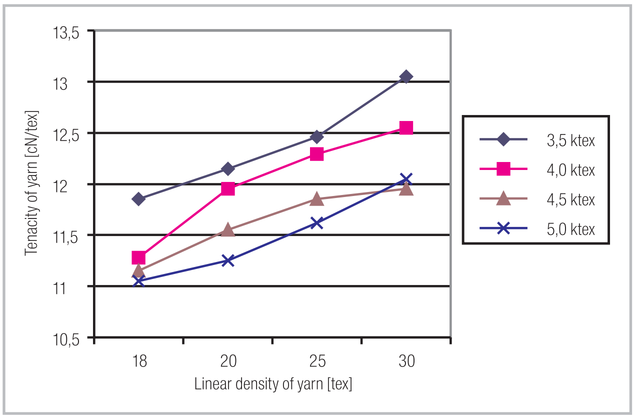


Figure 7. Tenacity of yarns in function of yarn linear density.

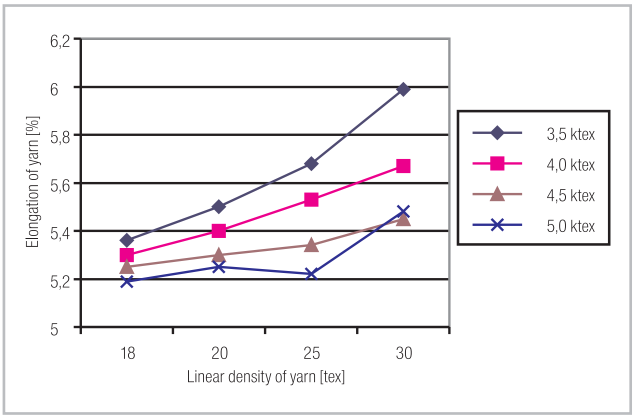


Figure 8. Elongation of yarns in function of yarn linear density.

$$\frac{d\varepsilon_t}{dt} = \frac{1}{\eta} \cdot \sigma \qquad (5)$$

where:

$d\varepsilon_t$ - speed at which plastic strain appears.

If the tensile stress does not change over time, the value of plastic strain is a function of time of its operation:

$$\varepsilon_t = \frac{1}{\eta} \cdot \sigma \cdot t \qquad (6)$$

The total strain ε_c is the sum of three strains: immediate elastic ε_{sn}, high elastic ε_{so}, and plastic ε_t:

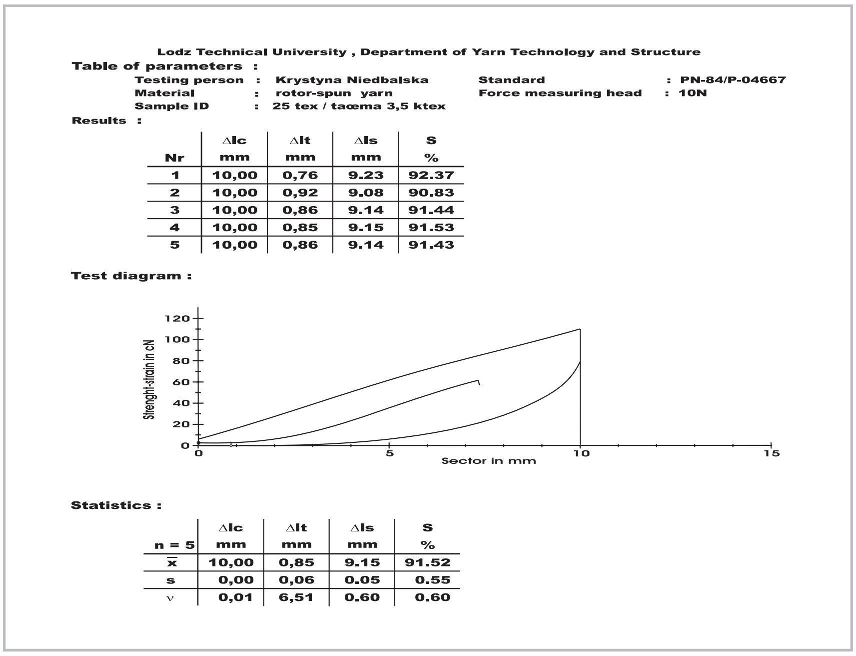
$$\varepsilon_c = \varepsilon_{sn} + \varepsilon_{so} + \varepsilon_t \qquad (7)$$

Component strains depend on the value of the total strain, the time of loading and the time of relaxation after the load is removed.

In practice, we usually take the component appearing at the moment the load is removed from the yarn as the value of the immediate elastic strain. The growing time of relaxation causes growth in the high elastic strain and a decrease in the plastic strain. Due to this fact, when determining both component strains, the relaxation time after removing the load is carefully defined.

Among the mechanical properties of yarns elasticity is very important. The yarn is subjected to considerable tension during the processes of winding and knitting. Tension is suppressed thanks to the yarn's elasticity. Elasticity is the feature of the material which characterises its ability to reproduce its initial shape and size, after external loads are removed [6].

Yarn elasticity is usually characterised by the degree of elasticity, determined according to the Polish Standard PN-



Lodz Technical University , Department of Yarn Technology and Structure

Table of parameters :

Testing person : Krystyna Niedbalska
Material : rotor-spun yarn
Sample ID : 25 tex / taœma 3,5 ktex
Standard : PN-84/P-04667
Force measuring head : 10N

Results :

Nr	∆lc mm	∆lt mm	∆ls mm	S %
1	10,00	0,76	9.23	92.37
2	10,00	0,92	9.08	90.83
3	10,00	0,86	9.14	91.44
4	10,00	0,85	9.15	91.53
5	10,00	0,86	9.14	91.43

Test diagram :

Statistics :

n = 5	∆lc mm	∆lt mm	∆ls mm	S %
$\overline{x}$	10,00	0,85	9.15	91.52
s	0,00	0,06	0.05	0.55
ν	0,01	6,51	0.60	0.60

Figure 9. Computer print-out of the degree of elasticity measurement.

84/P-04667. The degree of elasticity is expressed in per cent, as the ratio of elastic strains

$$\varepsilon_s=\varepsilon_{sn}+\varepsilon_{so}$$

to the total strain ε_c. The values of elastic and plastic strains can be determined from the diagram of the hysteresis of yarn drawing which is shown in Figure 2. The values of all component strains depend on the value of the load or the total strain of the material. Any increase in the load or strain results in decreasing the elastic components and increasing the plastic strain.

Subject of Studies and Results

The strength parameters of cotton yarns formed on a Rieter R1 spinning machine (a rotor spinning machine of the third generation) and a Textima 2111 ring spinning machine were analysed. Spinning on the R1 machine was carried out with the speed of the rotors at 100,000 r/min, and the speed of opening rollers at 7,000 r/min. 16 variants of yarn were prepared. For each of the four feeding slivers of linear density from 3.5 to 5 ktex, yarns of linear densities from 18 to 30 tex were manufactured.

Measurements of yarn strength were conducted on the automatic tension tester Zwick 1120. The computer printout contained a diagram of the drawing and the value of the breaking force

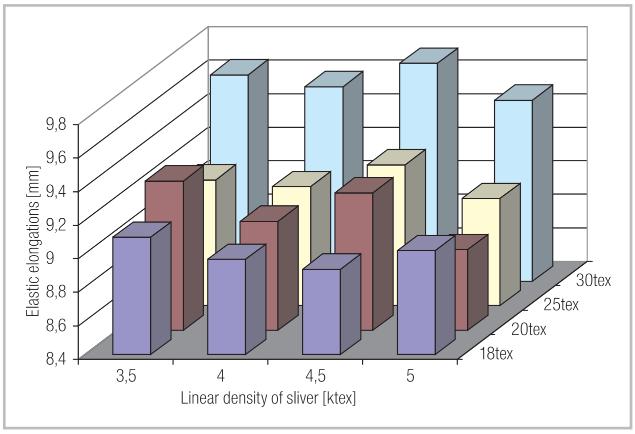


Figure 10. Absolute elastic elongations of yarns.

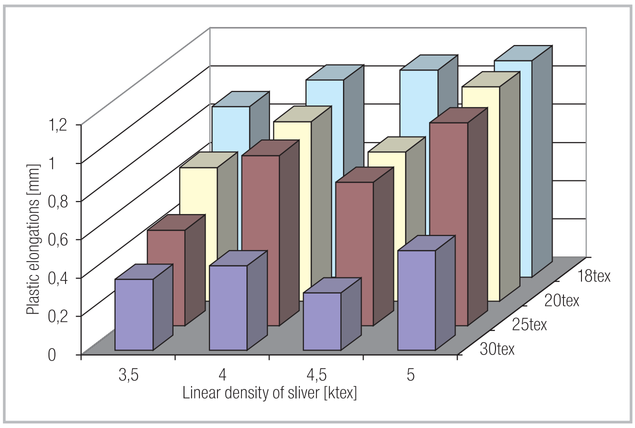


Figure 11. Absolute plastic elongations of yarns.

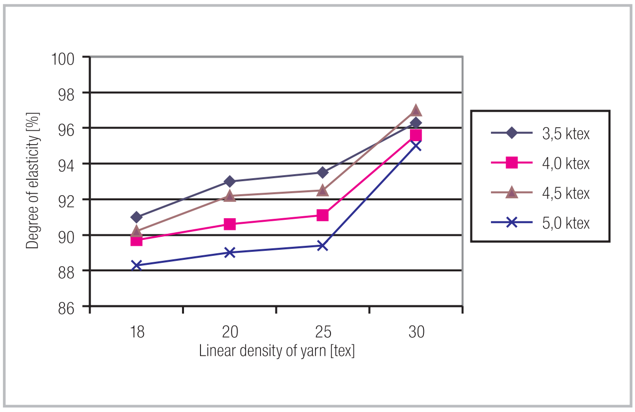


Figure 12. Degrees of elasticity of yarns.

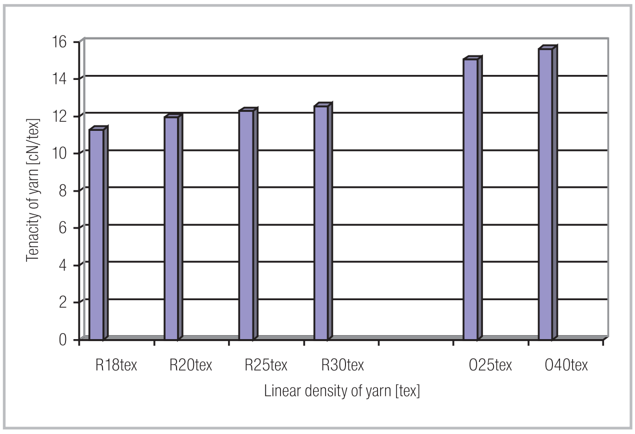


Figure 13. Tenacity of rotor-spun and ring-spun yarns.

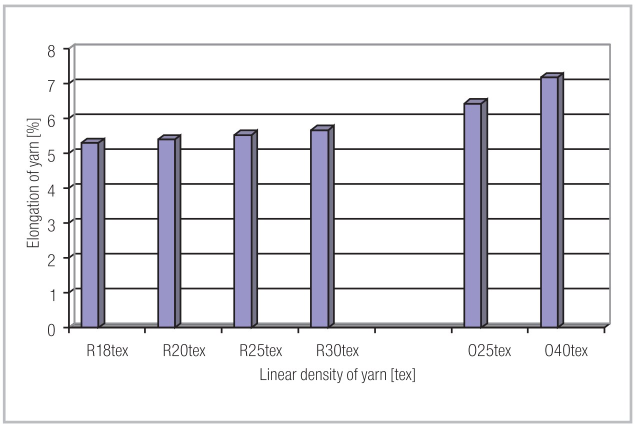


Figure 14. Elongation of rotor-spun and ring-spun yarns.

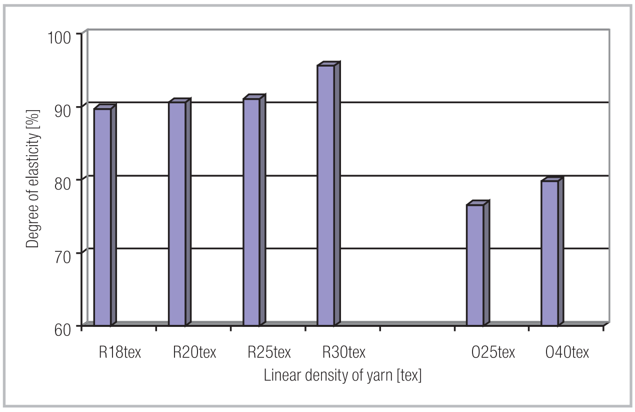


Figure 15. Degree of elasticity of rotor-spun and ring-spun yarns.

F_{max} [cN], breaking elongation [mm] and [%], work performed until the moment of reaching the maximum force [cN] and until breakage [cN], as well as indices of dispersion of the parameters measured. Examples of computer print-outs obtained from the automatic tension tester are presented in Figures 3 and 4.

Figures 5 and 6 present the course of changes of the specific strength and elongation in the function of changes to the linear density of the slivers feeding the rotor spinning machine. Yarns formed from the feeding sliver with a linear density of 3.5 ktex have the highest values of tenacity and elongation. With the growth in linear density of the sliver, a decrease in tenacity and elongation of yarns occurs.

Figures 7 and 8 present the tenacity and elongation of yarns in the function of linear densities of the yarns formed. With the growth in linear density of the yarns, the tenacity and elongation of the yarn also grow. This is caused by the growth of the number of fibres in the cross-section of yarns. Yarns 18 tex contained 106 fibres in the cross-section, and yarns 30 tex contained 176 fibres. These results confirm earlier studies [8].

The dependencies presented in Figure 7 and 8 confirm the good strength parameters of yarns obtained from the feeding sliver 3.5 ktex. With the growth in linear density of the used feeding slivers, the draft in the spinning machine increases as well. For yarns 18 tex, drafts for the feeding slivers are from 194 to 278, and for yarns 30 tex from 117 to 167. The lowest values of draft occur for the feeding sliver 3.5 ktex. With the growth in linear density of the yarns analysed (18, 20, 25 and 30 tex), the drafts used in the rotor spinning machine decrease, and measure 194, 175, 140, 117 respectively.

The degree of elasticity was determined for the formed yarns. Tests were conducted on the Zwick 1120 automatic tension tester with the initial stress of sample 0.2 cN/tex.

The spacing of grips in the tension tester was 500 mm, and the drawing speed was 50 mm/min. A sample computer print-out is shown in Figure 9. The print-out presented in Figure 9 contains the first loop of the drawing hysteresis and the results of the following parameters: Δlc - absolute total elongation, Δlt - absolute plastic elongation, Δls - absolute elastic elongation, S - degree of elasticity calculated from the relation:

$$S = \frac{\Delta ls}{\Delta lc} \cdot 100\%$$

s - standard deviation,
v - coefficient of variation.

Diagrams of the determined elastic and plastic elongation and the degree of elasticity are presented in Figures 10, 11 and 12. Yarns of linear density 30 tex are characterised by the highest absolute elastic elongation and the lowest absolute plastic elongation. When the linear densities of yarns decrease, elastic elongations also decrease whereas plastic elongations increase.

Analysing the results of yarn elasticity (Figure 12), we can see that the greatest degree of elasticity was obtained for the yarns of linear density 30 tex (number of fibres in the cross-section - 176), and the smallest for the yarn 18 tex (number of fibres in the cross-section - 106). With the decreasing linear density of yarn, the value of degree of elasticity in the yarn also decreases.

The statistical analysis conducted showed the existence of correlation between the linear density of feeding slivers and the degree of elasticity of yarns, which confirms the influence of the sliver linear density within the studied range 3.5-5.0 ktex on the degree of elasticity of yarns.

In order to compare the strength parameters of yarns from the R1 rotor spinning frame and the ring spinning frame, a roving of linear density 400 tex was formed from the sliver 4 ktex. It was fed into the Textima 2111B ring spinning frame, which produced yarns 25 and 40 tex. The yarn 25 tex was formed at the twist coefficient of 120, and the yarn 40 tex at the twist coefficient of 115. A comparison of the strength characteristics of rotor-spun yarns with linear densities from 18 to 30 tex, made from the sliver 4 ktex, and of ring-spun yarns is presented in Figures 13-15. In the figures rotor-spun yarns are marked with letter R and ring-spun yarns with letter 0.

Ring-spun yarns are characterised by higher tenacity and elongation and by lower elasticity. Similar to rotor-spun yarns, a ring-spun yarn of greater linear density is characterised by a higher degree of elasticity. The higher elasticity of rotor-spun yarns is one of the main reasons why they are used for knitting purposes. This feature makes up for the lower-tenacity strength of these yarns. Analysis of problems concerned with the irregularity of linear density and with twist of cotton yarns spun on ring and rotor spinning machines were independently presented also in [9,10].

Conclusions

- Ring-spun yarns are characterised by greater tenacity and elongation but smaller elasticity. Similar to rotor-spun yarns, ring-spun yarns with greater linear densities have a higher degree of elasticity.
- Strength parameters of yarns are especially important for rotor-spun yarns. Due to their different method of forming, these parameters are lower than for ring-spun yarns. Because of their higher elasticity, rotor-spun yarns are used mainly for knitting purposes. This feature makes up for the lower tenacity of these yarns.
- Producers of spinning machines find it very important for a rotor spinning machine to work with the draft of 400 and fed with a sliver of linear density 4.5-5 ktex. It helps to increase the efficiency of drawing frames considerably. However, the quality of the yarns obtained from slivers with lower linear density is better.

❑

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