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INFLUENCE OF PRODUCTION TECHNOLOGY ON THE COTTON YARN PROPERTIES

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Abstract

The main aim of this work is description of yarn production technology influence on the cotton yarn internal structure and selected properties. Three types of yarn production technology are selected. The internal structure is characterized from yarn cross-sections and longitudinal views. The hairiness is evaluated by the new method based on the image analysis. The influence of yarn internal structure on the ultimate tensile mechanical characteristics is discussed.

Introduction

The main aim of this work is investigation of yarn production technology influence on the cotton yarn properties. The yarn analysis is focused to the internal structure and corresponding geometrical and physical-mechanical properties. The yarns from the same material were spun under comparable technological conditions. Three technologies namely **ring, rotor,** and a **new pilot plant** one having improved hairiness (denoted as experimental yarn) were selected. The yarn fineness was 10, 20 and 29.5 tex. There were problems with spinning ability of 10-tex rotor yarn. For this fineness were therefore fabricated the ring and experimental yarns only.

The yarn structure was evaluated from cross sections and longitudinal views. The special software for data evaluation has been created. From the cross sections the structural characteristics in radial direction were evaluated. The packing density and fiber diameter were evaluated. The main shortcoming of this analysis is deformation of yarn subsurface layers caused by penetration of glues used for cross section creation.

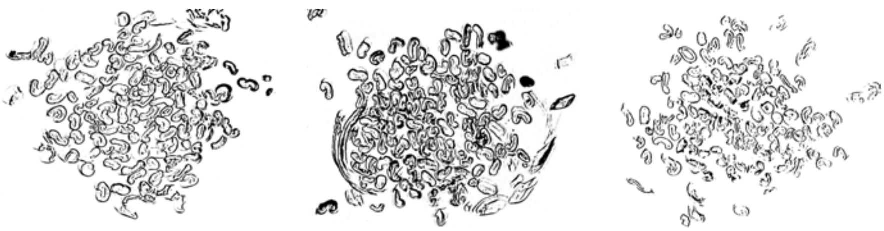
Longitudinal views were attractive for investigation of surface features. It is simple to identify of the type of yarn production technology (see. Figure 3b, c, d) and hairiness. This technique of hairiness evaluation is compared with hairiness measured on the Uster apparatus. The structural parameters are measured according to internal standards of Textile Research Center (Kremenakova 2003). The yarn unevenness and ultimate mechanical properties were measured according to ISO standards. For characterization of raw materials the fiber cross sectional areas and fineness were evaluated (Kremenakova 2003). The fibers length and strength were measured by standard procedures. Results are summarized in the tab.1. For 10-tex yarns the combed technology (finer, longer and stronger fibers) was used. The 20 and 29.5-tex yarns were prepared by carded technology.

Analysis of Yarn Cross-Sections

Typical cross sections are shown on the Figure 1. Due to the high variability between cross sections there are no visible differences between individual yarn types. For the rotor yarns (Figure 1b) the cross-directed fibers in subsurface layers (tips) are appeared. The radial analysis of cross sections was made by the Secant method (Kremenakova 2003; Neckar 1990; Kremenakova and Rubnerova 2001). The following mean characteristics from 40 cross sections were evaluated:

- Number of fibers
- Radial packing density trace
- Effective packing density
- Effective yarn diameter

Results are summarized in the table 1. The yarn twist was selected in accordance with requirement of the same twist coefficient for the same fineness. In practice is common to use higher twist coefficient for rotor yarns (leading to the higher strength).



a) Ring yarn no.3 b) Rotor yarn no.4 c) Experimental yarn no.5

Figure 1: Cross-sections of yarn 20 tex.

Fiber Number in Yarn Cross-Section

Common practice is to estimate number of fibers in yarn cross section as yarn fineness *T* divided by fiber fineness *t*. This relation is valid for the parallel fiber bundle only. Due to fiber inclination and curling are the real numbers of fibers in yarn cross section smaller. The quantity *T/t* is therefore multiplied by factor *kn* ($k_n < 1$), which is dependent on the technology of yarn production (Neckar 1990). Experimentally evaluated numbers of fibers in yarn cross section are given in the table 1. These values are linear function of yarn fineness and are not dependent on yarn production technology.

Yarn Diameter and Packing Density

Radial packing density trace characterizes packing density as function of distance from yarn center. This characteristic is generally function of yarn fineness, twist and diameter. Experimental evaluation of radial packing density trace is based on the division of yarn cross section to the radial system of annual rings and computation of relative portion of fiber areas to the ring area (Kremenakova 2003). Radial packing density traces are given in Figure 2. The differences between yarn production technologies are statistically insignificant. Higher values in the fiber axis vicinity for ring yarn fineness 10 tex are due to higher twist. This observation is in accordance with practical experiences.

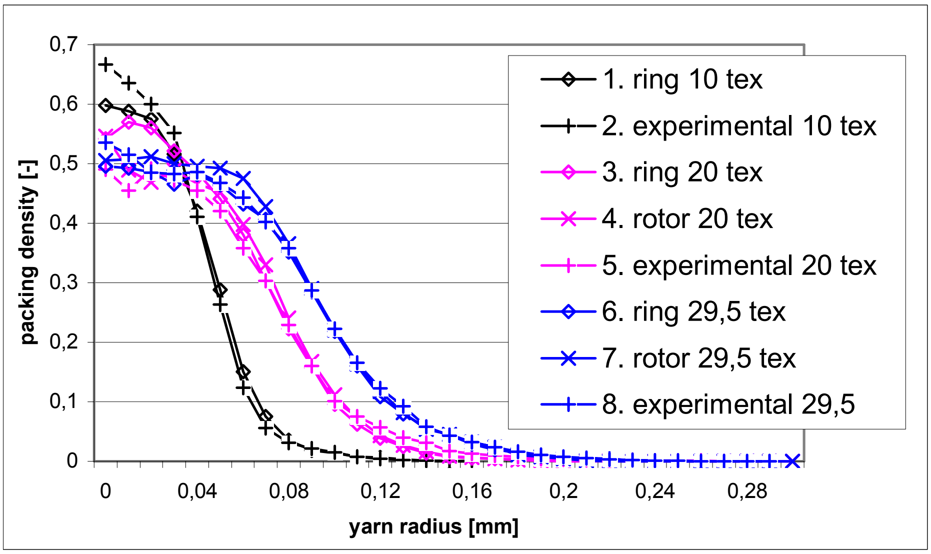


Figure 2: Radial packing density.

The yarn diameter is usually replaced by the diameter of equivalent cylinder containing majority of fibers. Effective yarn diameter is evaluated as value corresponding to the mean radial packing density 0.15. Alternatively it is possible to define yarn diameter as value corresponding to 50 % of hairiness function (Kremenakova 2003) (see next chapter). Instead of radial packing density trace the mean packing density is often used. The mean packing density μ is simply the ratio of fiber areas in circle having effective diameter to area of this circle. The effective yarn diameter *d* is defined by the relation: $d = \sqrt{4T/\pi\mu\rho}$, where *T* is yarn fineness and ρ is fiber density. It can be seen (Table 1) that the finest yarn 10 tex with maximal twist have maximal packing density and minimal diameter. Influence of yarn production technology is negligible.

Yarn Diameter and Hairiness

The characteristic structure of rotor yarn is given in Figures 3b, 3c, and 3d. The ring and experimental yarns have very similar helical appearance.

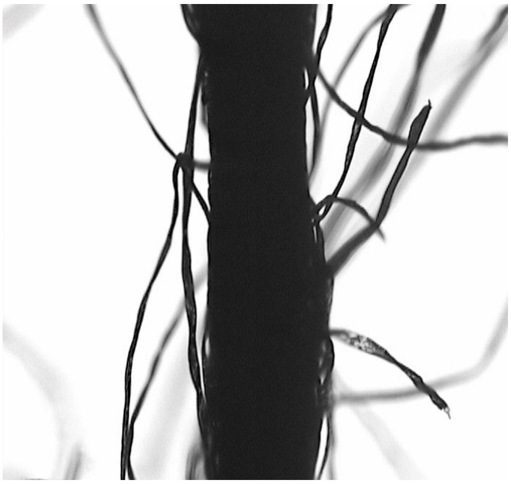


Figure 3a: Image for measurement of yarn hairiness.

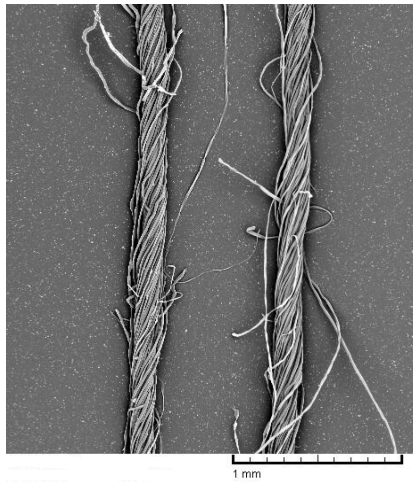


Figure 3b: Yarns 10 tex, left ring, right experimental.

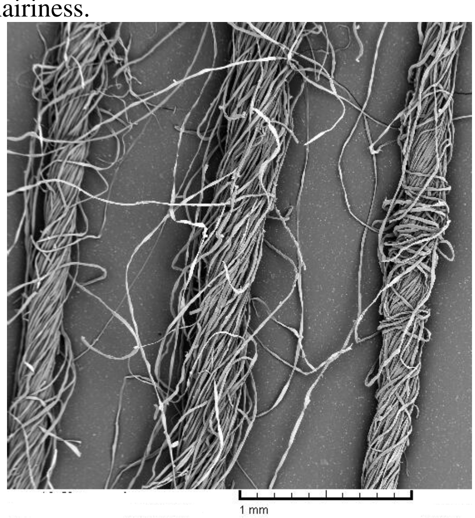


Figure 3c: Yarns 20 tex, left ring, in the middle experimental, right rotor.

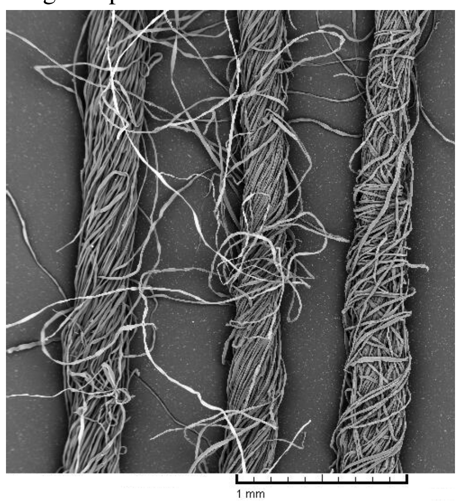


Figure 3d: Yarns 29,5 tex, left ring, in the middle experimental, right rotor.

Figure 3: Yarn longitudinal views.

Hairiness is a very important yarn characteristic influences fabric production processes and fabric properties. Hairiness characterizes the amount of free fibers protrudes from the compact yarn body towards the outer yarn surface. Mainly two optical principles are applied for measuring yarn hairiness. First one is based on counting fibers at relatively longer distances (1 mm and more) for example Zweigle, the second principle is scanning of light intensity of illuminated fibers in hairiness region, realized by Uster Tester. First method is unable to evaluate the fibers near to the yarn surface, while the second one gives only single cumulative scalar value characterizing yarn hairiness. The principle of measuring the yarn hairiness (Neckar and Voborova 2003) from longitudinal views is based on passing a light beam across the yarn image. Introducing an imaginary cut corresponding to one row of pixels processes the image. Black and white pixels are obtained after binary segmentation (dark gray to black and light to white). The mid point of longest section of black pixels defines the yarn axis. The distance of black pixels from yarn axes are determined. The relative frequency of the black pixels on each distance x is found experimentally from many images (usually 800 images) defines so called the blackness or hairiness function. Evaluation of hairiness requires determination of borders between yarn body and hairiness region, i.e. the value of effective yarn diameter, which corresponds to 50% of blackness function. The value of hairiness can be expressed numerically by estimation the area under the curve in the interval <d/2;3d>. There are close connection between this hairiness and hairiness evaluated from Uster Tester 4. Hairiness functions for all yarns are given on the Figure 4. There are visible differences between yarns having different fineness. For the same fineness are clear differences between yarn production technologies. Lowest hairiness and highest diameter have rotor yarns. Ring yarns have lowest diameter and moderate hairiness. Experimental yarns have moderate diameter and highest hairiness.

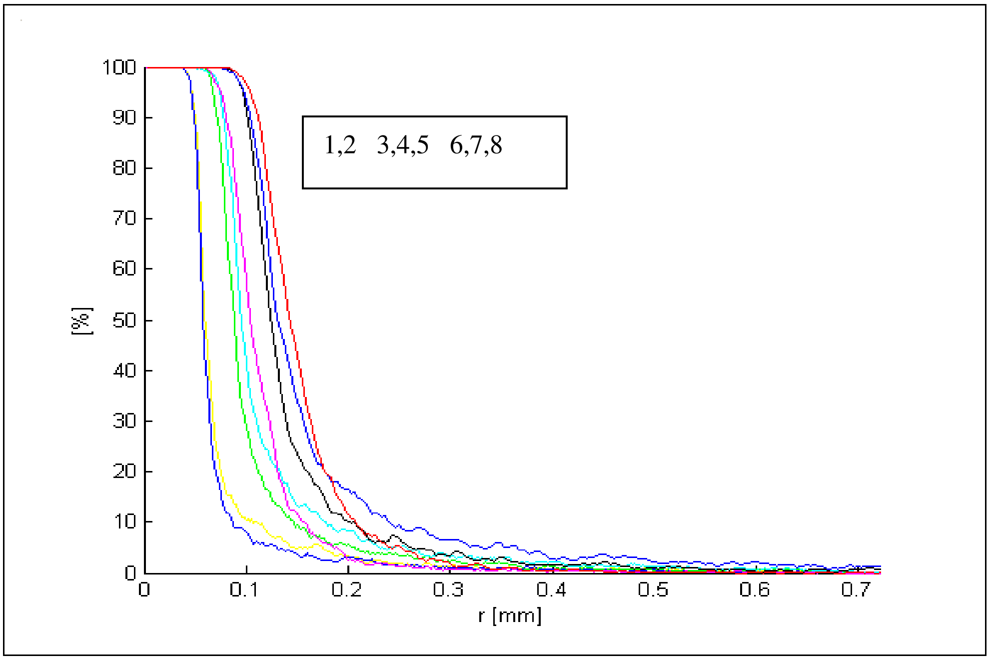


Figure 4: Hairiness functions.

Yarn diameters computed from hairiness curves are given in table 1 and on the Figure 5. There are some differences between both yarn diameters caused by distortion of glued cross sections. The linear dependence of yarn diameter on the yarn fineness is given on the Figure 5. The computed hairiness is given on the Figure 6. The hairiness is markedly increasing linear function of yarn fineness and the technology of yarn production is important as well. The hairiness is lowest for rotor, moderate for ring, and maximal for experimental yarns.

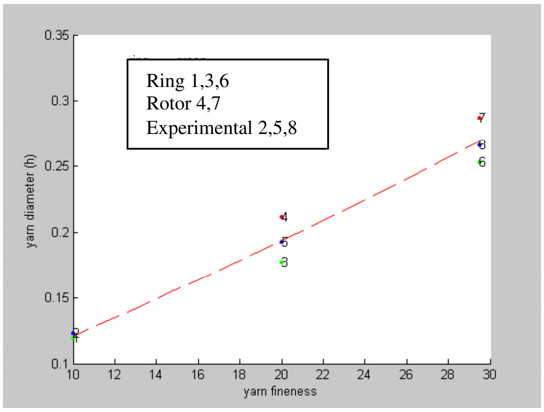


Figure 5: Yarn diameter [mm].

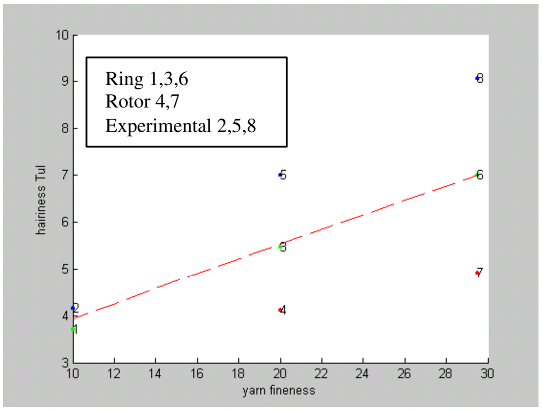


Figure 6: Yarn hairiness [-].

Yarn Unevenness

The yarn unevenness CV_{Uster}, thick/thin places and neps were measured on the Uster Tester 4 apparatus. Results are given in the table 2. The irregularity index I is ratio of CV_{Uster} and limit unevenness CV_{lim}

$$I = CV_{Uster} / CV_{\lim} \tag{1}$$

Limit unevenness is computed from Martindale relation [2]

$$CV_{\lim} = 100 / \sqrt{n_e} \tag{2}$$

where n_e is experimentally evaluated number of fibers in yarn cross section. The index of unevenness is clearly increasing function of yarn fineness. The influence of technology is statistically insignificant.

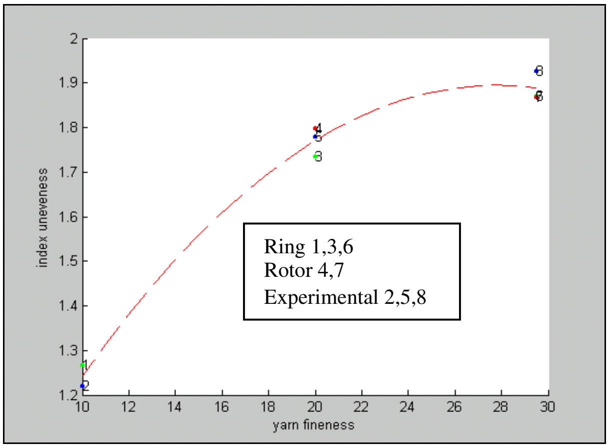


Figure 7: Unevenness index [-].

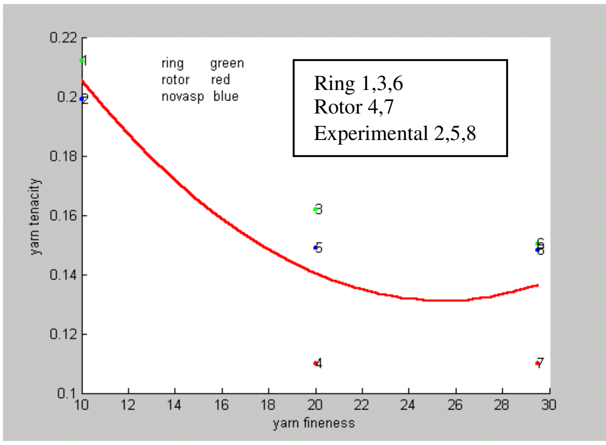


Figure 8: Yarn tenacity [N/tex].

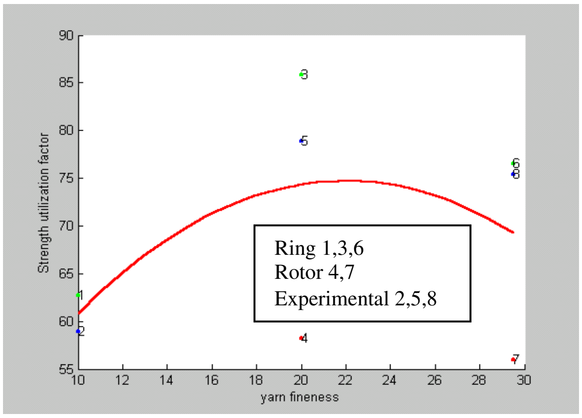


Figure 9: Fiber utilization factor [-].

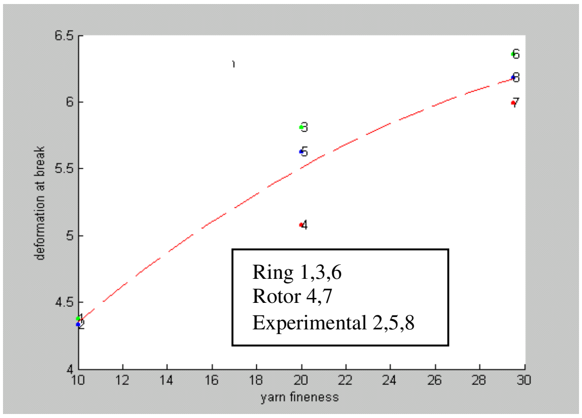


Figure 10: Yarn elongation [%].

Yarn Tenacity and Elongation

Single end strength was evaluated on the Instron strength tester 4411. Yarn tenacity and elongation values with fiber utilization factors in yarn are given in table 2 and dependences on yarn fineness are given on Figure 8, 9, 10. Yarn strength is a result of many variables, fiber parameters; including strength and surface characteristics, yarn specifications, resulting in yarn packing density, and the technology applied and machine setting. There is visible the known fact that increasing yarn count leads to decreasing of tenacity and increasing of break elongation. For the same yarn fineness is visible smallest tenacity and elongation at break for rotor yarn in comparison with ring and experimental ones. This result is due to disordered structure of rotor yarn. The structure of ring and experimental yarns are similar but experimental yarns have loosed subsurface layers and therefore the strength is slightly smaller. The fiber utilization factor in yarn shows the same tendency.

Discussion

The technology of yarn production leads to the following differences in yarn structure and properties:

- Rotor yarn has characteristic closed structure with tips. This yarn has smallest hairiness. Disordered internal structure leads to the smallest strength.
- The ring yarn has more arranged structure with higher hairiness and maximal strength.
- The experimental yarns have similar internal structure as ring one. The main differences are in hairiness and looser arrangements in subsurface layers. Result is slightly lower strength.
- Increasing of yarn titre leads to increasing number of fibers in yarn cross-section, increasing yarn diameter, hairiness and unevenness. The strength is a decreasing function of yarn titre.

Yarns from the same material produced by different technologies have comparable geometrical characteristics. The main differences are in hairiness strength and elongation at break.

Table 1.

	Yarn fineness 10 tex 100% cotton MII combed		Yarn fineness 20 tex 100% cotton AI carded			Yarn fineness 29,5 tex 100% cotton AI carded		
	Ring yarn No.1	**Exper. yarn No.2**	**Ring yarn No.3**	**Rotor yarn No.4**	**Exper. yarn No.5**	**Ring yarn No.6**	**Rotor yarn No.7**	**Exper. yarn No.8**
Fiber fineness [tex]	0,148 (0,143;0,153)*		0,196 (0,190;0,202)			0,183 (0,177;0,189)		
Fiber length [mm]	29,9 (28,9;30,8)		24,96 (24,0;26,0)			25,1 (24,1;26,1)		
Fiber tenacity. [cN/tex]	33,78 (27,70;40,54)		18,88 (15,31;22,45)			19,67 (16,39;22,95)		
Yarn fineness [tex]	9,88	9,43	19,42	19,82	20,1	28,46	29,48	29,42
Yarn twist [m^{-1}]/Twist coefficient [$m^{-1}ktex^{2/3}$]	1189 / 60 (1176;1202)	1232 / 60 (1222;1241)	889 / 65 (881;896)	888 / 65	802 / 65 (796;808)	658 / 65 (653;663)	681 / 65	652 / 65 (648;657)
Fiber number in yarn cross-sect. [-]	82 (79;85)	74 (71;77)	134 (128;140)	134 (126;142)	138 (133;143)	183 (174;192)	186 (178;194)	207 (197;218)
Packing density [-]	0,483 (0,464;0,502)	0,509 (0,492;0,527)	0,434 (0,411;0,457)	0,428 (0,406;0,450)	0,406 (0,388;0,424)	0,409 (0,393;0,424)	0,402 (0,385;0,419)	0,411 (0,392;0,431)
Yarn diameter from cross-s. [mm]	0,121 (0,117;0,126)	0,117 (0,113;0,121)	0,176 (0,162;0,190)	0,179 (0,163;0,194)	0,178 (0,167;0,189)	0,216 (0,199;0,234)	0,227 (0,216;0,238)	0,218 (0,201;0,235)
Yarn diameter from longit. views [mm]	0,119	0,123	0,177	0,212	0,192	0,253	0,287	0,267
Hairiness - image analysis [-]	0,015	0,018	0,023	0,018	0,031	0,028	0,021	0,042
Hairiness Uster [-]	3,7	4,16	5,47	4,12	7,01	7,00	4,91	9,07

* 95 % confidence intervals

Table 2.

	Yarn fineness 10 tex 100% cotton MII combed		Yarn fineness 20 tex 100% cotton AI carded			Yarn fineness 29,5 tex 100% cotton AI carded		
	Ring yarn No.1	**Exper. yarn No.2**	**Ring yarn No.3**	**Rotor yarn No.4**	**Exper. yarn No.5**	**Ring yarn No.6**	**Rotor yarn No.7**	**Exper. yarn No.8**
CV Uster [%]	13,99	14,19	14,98	15,53	15,15	13,83	13,70	13,39
Unevenness index [-]	1,27	1,22	1,73	1,80	1,78	1,87	1,87	1,93
Thin places [km^{-1}]	7/14	5/5	2/8	52/59	4/9	0/4	6/6	0
Thick places [km^{-1}]	60/70	54/66	357/242	116/140	204/204	152/96	44/46	105/91
Neps [km^{-1}]	160/195	166/219	692/484	646/711	483/525	318/212	168;20/195;18	200
Tenacity [$Ntex^{-1}$]	0,212 (0,206;0,218)	0,199 (0,194;0,205)	0,162 (0,159;0,166)	0,110 (0,107;0113)	0,149 (0,145;0,153)	0,151 (0,146;0,155)	0,110 (0,107;0,113)	0,148 (0,146;0,151)
Elongation [%]	4,38 (4,26;4,51)	4,33 (4,23;4,44)	5,81 (4,66;5,96)	5,08 (4,94;5,22)	5,63 (5,50;5,76)	6,36 (6,25;6,47)	5,99 (5,87;6,11)	6,18 (6,08;6,29)

* 95 % confidence intervals

Conclusion

The technology of yarn formation has great influence on the internal structure and mechanical properties. Especially the hairiness and ultimate mechanical tensile characteristics are changed due to structural differences. It is therefore possible to select right technology from point of view of desired properties and production economy. In the subsequent research are these yarns used for creation of fabrics and transport properties of fabrics are correlated with yarn characteristics.

Acknowledgment

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