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Study on Physical-mechanical Parameters of Ring-, Rotor- and Air-jet-spun Modal and Micro Modal Yarns
Študij fizikalno-mehanskih lastnosti modalnih in mikromodalnih prej, izdelanih po prstanskem in rotorskem postopku ter po postopku z zračnim curkom

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Abstract
The main physical-mechanical parameters of modal yarns (unevenness, faults, hairiness and spectrograms) were compared with the parameters of micro modal yarns of the same fineness and end-use. The difference in tenacity and elongation at break of different types of modal and micro modal-spun yarns is determined by yarn structure. The highest tenacity was achieved in the oriented structure of ring-spun yarn, followed by air-jet-spun and rotor-spun yarn, in the case of both modal and micro modal fibres. All types of modal yarns differ in overall unevenness and in terms of micro modal fibres. The values of the overall unevenness of ring-, rotor- and air-jet-spun modal yarns are greater than or equal to the same values of micro modal yarns. The spinning technique, and thus the yarn structure, determine the level of overall yarn evenness. The number of faults at different levels of sensitivity measurement to detect the highest number of thin and thick places and neps (–30%, +35% and +140%) is greater in rotor- and air-jet-spun yarn than in ring-spun yarn for both levels of fibre fineness. Periodic faults of short wavelengths with significant amplitude increase the number of yarn faults to a certain extent. Rotor-spun micro modal yarn shows the highest deviation from ideal unevenness, while ring-spun modal yarn shows the lowest deviation. Yarn hairiness depends on the spinning technique. Finer fibres cause lower hairiness in all yarn types.
Keywords: modal fibre, micro modal fibre, man-made cellulosic fibre, properties

Izvleček
Glavne fizikalno-mehanske lastnosti modalnih prej (neenakomernost, napake, dlakavost in spektrogrami) so bile primerjane z lastnostmi mikromodalnih prej enake finoče in končnega namena uporabe. Razlike v trdnosti in pretržnem raztezku različnih vrst modalnih in mikromodalnih prej določa njihova struktura. Najvišjo trdnost je dosegla prstanska preja z orientirano strukturo, tej sta sledili obe preji iz modalnih in mikromodalnih vlaken, izdelani po postopku z zračnim curkom (t. i. postopku air-jet) in rotorskem postopku. Modalne preje se med seboj razlikujejo v enakomernosti preje, prav tako tudi mikromodalne preje. Vrednosti enakomernosti prstanske, rotorske in z zračnim curkom (t. i. air-jet) spredene modalne preje so večje ali enake vrednostim mikromodalnih prej. Tehnika predenja in s tem struktura preje vplivata na njeno enakomernost. Število napak, merjeno pri različnih stopnjah občutljivosti, da bi zaznali najvišjo raven tankih in debelih mest ter nopkov (–30 %, +35 % in +140 %), je večje pri rotorski preji in preji z zračnim curkom (t. i. preji air-jet) kot pri prstanski preji pri obeh finočah vlaken. Na kratkih dolžinah ugotovljene periodične napake z veliko amplitudo povečajo število napak preje v določenem obsegu. Rotorska mikromodalna preja ima največje, prstanska modalna preja pa najmanjše odstopanje od idealne enakomernosti. Kosmatost preje je odvisna od postopka predenja. Finejša vlakna povzročajo manjšo kosmatost prej kot bolj groba vlakna.
Ključne besede: kemična celulozna vlakna, predivna preja, mikrovlakna, periodične napake

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1 Introduction

Today, there is a broad range of applications for modal fibres in the clothing industry for making lighter-weight knitted garments and articles worn next to the skin. Knitted fabric characteristics are largely dependent on the raw material composition of yarn and the yarn type from which a knitted fabric is made. Parameters of mass irregularity, which include overall unevenness, yarn faults defined as thin places, thick places, neps and hairiness, affect the appearance and other characteristics of a fabric. In general, specific samples must be made to reduce the number of input parameters, in order to find a more precise relationship between the effect of fibre type, fibre properties and the spinning process (including the type of spinning machine) on the basic physical-mechanical properties of yarn (and thus on the appearance and properties of a knitted fabric).

A number of researchers have dealt with the properties of ring-spun yarn [1], the dynamic properties of air-jet-spun yarn and rotor-spun yarn [2], the geometric analysis of spun yarns with the aim of assessing the tensile properties of air-jet-spun yarn [3], the assessment of the tensile properties of air-jet-spun yarn [4], and the tensile properties of rotor-spun yarn [5]. Yarn unevenness and hairiness has also been studied by a number of researches [6–9]. The effect of periodic faults on overall unevenness and/or on the number of faults in yarn has only been studied to a small extent [10, 11]. However, it is not evident from literature that a more significant study of the effect of fibre fineness on the basic physical and mechanical properties of different yarn types has been undertaken.

In order to reduce the number of different input parameters and to find a clearer connection between parameters, yarn with one type of different fibre parameters should be spun using the same technological process, the same twist coefficient and the same fineness. Thus, the effect of the spinning technique (rotor and ring) used for micro modal fibres on unevenness [12] and the unevenness of air-jet-spun yarn relative to rotor- and ring-spun micro modal yarn has already been studied [13]. The latter studies still continue, so that modal yarns are also included. Thus, the aim of this paper is to present a comparison of the basic physical-mechanical properties of ring-, rotor- and air-jet spun yarn made from modal fibres, and to extend that comparison to the same types of micro modal yarns.

2 Experimental part

For the purposes of this study, ring-, rotor- and air-jet-spun yarns were spun with a nominal count of 20 tex (Nm 50) from 1.3 dtex fibres with a length of 38 mm. The basic properties of these yarns were compared with the properties of yarns having the same end-use (knitting) from 1 dtex micro modal fibres with a length of 39 mm. Modal yarns were spun under the same technological conditions as micro modal yarns [12, 13]:

a) Ring-spun modal yarn was produced using the carding manufacturing process, comprising fibre preparation phases (opening, blending and carding), spinning preparation (drawing, pre-spinning and ring spinning), winding and cleaning. A Zinser 351 ring spinning machine connected to an Autoconer X5 winding machine was used for the ring spinning process.
b) Rotor-spun modal yarn was produced using the carding manufacturing process, comprising fibre preparation phases (opening, blending and carding), spinning preparation (drawing) and rotor spinning. A Schlafhorst A8 rotor spinning machine was used for spinning.
c) Air-jet modal yarn was produced using the carding manufacturing process, comprising fibre preparation phases (opening, blending and carding), spinning preparation (three drawing passages) and air-jet spinning. A Rieter J 20 machine was used for spinning.
d) Yarn unevenness was determined in accordance with standard ASTM D1425/D1425M-14 Standard Test Method for Evenness of Textile Strands Using Capacitance Testing Equipment [16]. Unevenness, the number of yarn faults and hairiness were determined on an Uster Tester 4-S with a yarn throughput speed of 400 m/minute through the measuring field with a test time of 2.5 minutes. One measurement of each cross-wound package of each yarn type was performed.
e) The tensile properties of yarn were determined in accordance with standard ISO 2062:2009 Textiles – Yarns from packages – Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester [17]. Measurements were performed on an Uster Tensorapid 4 instrument. A total of 100 measurements per package of each yarn type were performed.

The number of fibres in the cross-section (n_f) was determined from the ratio between yarn fineness (T_{ty}) and fibre fineness (T_{tf}) using the following equation:

$$n_f = \frac{T_{ty}}{Tt_f} \tag{1}$$

The limiting irregularity CV_{lim} was calculated for man-made fibres and cotton using the following equation [18]:

$$CV_{lim} = \frac{100}{\sqrt{n_f}} \tag{2}$$

The index of irregularity I was determined from the ratio between the coefficient of variation of unevenness (obtained by measuring CV_m) and limiting irregularity (CV_{lim}) using the following equation:

$$I = \frac{CV_m}{CV_{lim}} \tag{3}$$

The index of irregularity is a measure of the unevenness deviation of a certain fibre type that will be spun in an ideal situation where I = 1. It also shows how well the machines used in certain technological phases run and whether any deviations in their operation occur. Fibre distribution in yarn is not completely controlled. In practice, the orientation of fibres in yarn is regarded as a random occurrence. The goal to be achieved in production is to maintain a constant number of fibres in any yarn cross section.

Non-periodic faults can be thin places, thick places and neps. The level of measurement sensitivity is typically as follows: –30%, –40%, –50% and –60% for thin places; +35%, +50%, +70%, +100% for thick places; and +140%, +200%, +280% and +400% for neps. Periodic faults or system faults occur due to the periodic irregular motions of individual machine elements and/or due to damage to those elements (e.g. rollers, gears, belts, vibrations, etc.). Periodic faults are shown using a spectrogram. If unevenness reaches the ideal value (I = 1), the spectrogram has an ideal curve. The spectrogram function takes the following mathematical form [18]:

$$S = f(\lambda) = \frac{1}{\sqrt{\pi nf}} \frac{\sin \frac{l_o}{\lambda}}{\sqrt{\frac{\pi l_o}{\lambda}}} \tag{4}$$

where: S = spectrogram, n_f = number of fibres in the yarn cross-section, l_o = fibre length and λ = wavelength. The real spectrogram curve deviates from the ideal curve.

3 Results and discussion

The fineness of all modal yarn types is very consistent and ranges from 20.13 to 20.22 tex, and from 20.04 to 20.15 tex in the case of micro modal yarns. The coefficient of variation of fineness among cross-wound packages is very low, generally below 1% (Table 1). This indicates the very high consistency of high-quality production. The number of fibres in the yarn cross section is calculated using equation 1, from which it is apparent that fibre fineness determines the number of fibres in the yarn cross-section of the same yarn fineness. The number of modal fibres in the yarn cross-section ranges from 155 to 156, while the number of micro modal fibres in the yarn cross-section ranges from 200 to 202. The number of twists in all yarn types is uniform and is determined according to the end-use of yarn (knitting). The twist coefficient ranged from 3,280 to 3,350 m^{-1} $tex^{0.5}$.

3.1 Tensile properties

The values of basic physical-mechanical parameters and the breaking elongation properties of yarns with a nominal count of 20 tex used to make knit garments are given in Table 1 and shown in Figure 1. Ring-spun modal yarn has the highest tenacity (23.81 cN/tex), followed by aerodynamic (20.77 cN/tex) and rotors with the lowest tenacity (15.39 cN/tex). Yarn elongation at break follows yarn tenacity. The highest elongation at break among modal yarns was found in ring-spun yarn (10.83%), followed by air-jet-spun yarn (9.25%), while the lowest elongation at break was found in rotor-spun yarn (8.17%). The difference in tenacity and elongation at break of different types of spun modal yarns (as well as micro modal yarns) is caused by yarn structure, as the result of the spinning technique. In principle, a greater number of fibres increases the contact surface among fibres, and thus causes a greater overall friction force for a particular yarn type. With the same number of twists, ring and or spun modal yarn has a lower tenacity (23.81 and 15.38 cN/tex respectively) than ring- and rotor-spun micro modal yarn (24.09 cN/tex and 15.86 cN/tex respectively). However, yarns from finer micro modal fibres did not impart significantly greater tenacity than yarns from coarser modal fibres in all yarn types. The highest performed work of rupture of modal yarn is observed in ring-spun yarn due to its oriented structure (14.84 N cm), followed by air-jet-spun yarn (11.22 N cm), while the lowest value of the performed work of yarn rupture is observed in rotor-spun yarn (7.66 N cm). The same sequence is also observed in micro modal yarns. By comparing modal and micro modal yarns, ring- and air-jet-spun yarn from finer micro modal fibres perform less work of yarn rupture (14.26 N cm, 10.78 N cm) than the same types of modal yarns (14.84 N cm, 11.22 N cm). In rotor-spun yarn, the higher fineness of micro modal fibres had practically no effect on the work of yarn rupture (7.70 N cm, 7.66 N cm).

3.2 Unevenness

The values of the unevenness parameters of all types of modal and micro modal yarns are given in Table 2 and shown in Figures 2–8. All types of modal yarns differ in overall unevenness and in micro modal fibres. Rotor-spun yarn has the greatest overall unevenness in the case of modal fibres (13.95 %), while ring-spun yarn has the lowest unevenness

Table 1: Main yarn parameters and tensile properties of ring-, rotor- and air-jet-spun modal and micro modal yarn

Type of material	Linear density		N[a]	Twist		Tenacity		Elongation		Work
	$\bar{x}$ [tex]	CV_b [%]	$\bar{x}$	$\bar{x}$ [m^{-1}]	CV_b [%]	$\bar{x}$ [cN/tex]	CV_b [%]	$\bar{x}$ [%]	CV [%]	[N cm]
Ring modal	20.13	0.82	154.8	745.3	2.91	23.81	6.89	10.83	5.46	14.84
Ring micro modal	20.04	1.02	200.4	734	2.3	24.09	6.43	10.3	5.27	14.26
Rotor modal	20.22	0.78	155.5	750	–	15.39	9.29	8.17	8.81	7.66
Rotor micro modal	20.12	0.84	201.2	750	–	15.86	8.55	8	7.92	7.7
Air-jet modal	20.14	0.28	154.9	[b]	[c]	20.77	8.36	9.25	7.35	11.22
Air-jet micro modal	20.15	0.46	201.5	[b]	[c]	20.55	7.37	9.01	7.02	10.78

[a] Number of fibres in cross section, [b] Air pressure, [c] 0.6 MPa

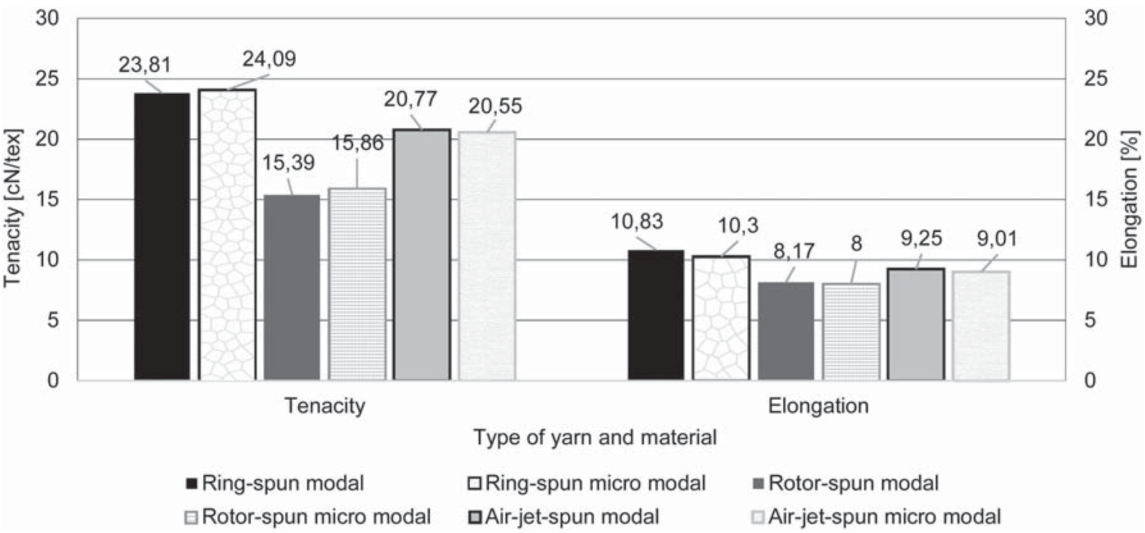

Figure 1: Tenacity and elongation of modal and micro modal ring-, rotor- and air-jet spun yarn

(10.21%). Furthermore, the values of the overall unevenness of ring-, rotor- and air-jet-spun modal yarn (10.21%, 10.95% and 12.33%) are higher than the same values of the micro modal yarns (9.67%, 12.69% and 12.12%). Thus, the spinning technique and consequently the yarn structure determine the level of overall yarn evenness. The coefficient of variation of the overall unevenness obtained as the mean value of 10 packages CV_b is highest in air-jet-spun modal yarn (2.44%) and air-jet-spun micro modal yarn (4.69%). The cause of the latter is the appearance of periodic faults with significant amplitudes in three packages of air-jet-spun modal yarn (1, 2 and 3) and in two packages of air-jet-spun micro modal yarn (3 and 4) at different wavelengths (Figures 7 and 8). Most yarns do not contain periodic faults with significant amplitudes. This is the reason CV_b values are low (Figures 3–6).

Overall yarn unevenness CV_m represents the effective (actual) value of yarn mass irregularity obtained through measurement. The limit value irregularity of yarn CV_{lim} is determined using equation 2, while the unevenness index of irregularity (I) is determined using equation 3. The value I of all modal yarn types ranges from 1.27 to 1.74. Because I is the value of the deviation of the achieved unevenness in production of one yarn type and one number of yarn twists in relation to ideal unevenness, the nearest value to the ideal value is obtained in ring-spun yarn (1.27), while the lowest value is obtained in the rotor-spun yarn

Table 2: Unevenness of ring-, rotor- and air-jet yarn spun from modal and micro modal fibres at different cut lengths

Type of material	Cut length															
	8 mm				1 m				3 m				10 m			
	CV_m [%]	CV_b [%]	CV_{lim} [%]	I	CV_m [%]	CV_b [%]	CV_{lim} [%]	I	CV_m [%]	CV_b [%]	CV_{lim} [%]	I	CV_m [%]	CV_b [%]	CV_{lim} [%]	I
Ring modal	10.21	0.98	8.04	1.27	3.49	4.51	–	–	2.74	7.4	–	–	2.25	10.98	–	–
Ring micro modal	9.67	1.96	7.06	1.37	3.25	3.89	–	–	2.28	5.66	–	–	1.61	8.72	–	–
Rotor modal	13.95	0.87	8.02	1.74	4.63	5.87	–	–	3.67	7.3	–	–	2.44	6.58	–	–
Rotor micro modal	12.69	0.67	7.05	1.80	4.41	4.51	–	–	3.56	5.41	–	–	2.56	4.59	–	–
Air-jet modal	12.33	2.44	8.03	1.54	3.74	6.68	–	–	2.32	7.07	–	–	1.23	8.37	–	–
Air-jet micro modal	12.12	4.69	7.04	1.72	2.91	3.47	–	–	2.11	5.59	–	–	1.21	8.52	–	–

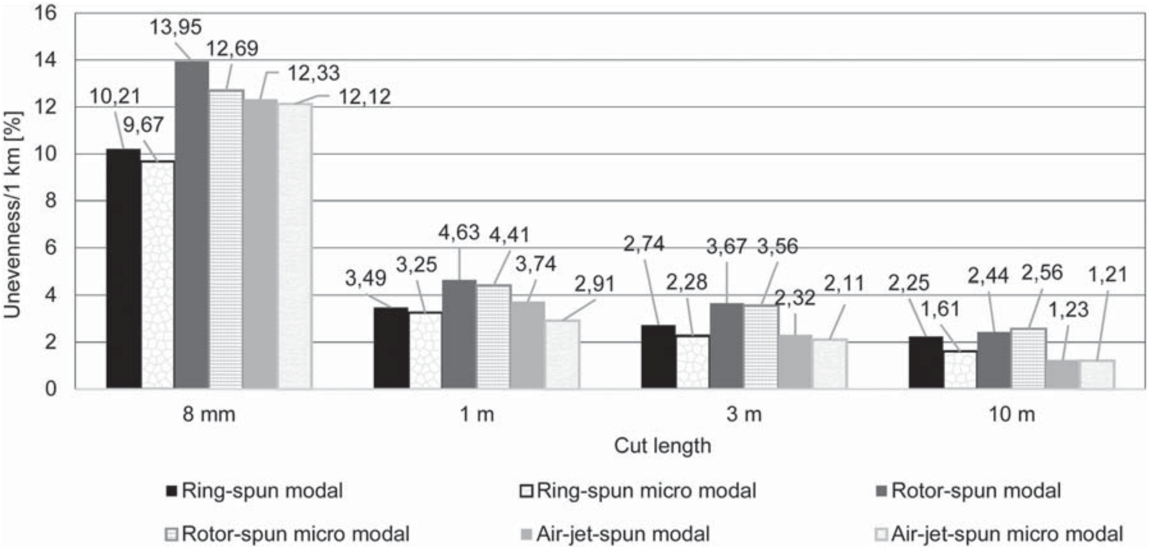

Figure 2: Unevenness of ring-, rotor- and air-jet-spun modal and micro modal yarns at different cut lengths

(1.74) in modal yarns. In micro modal yarns, I values range from 1.37 to 1.80. It can be concluded that the spinning technique also affects the irregularity index. In other words, coarser modal fibres cause a smaller deviation of yarn unevenness from ideal irregularity in the same fineness and end-use in all yarn types.

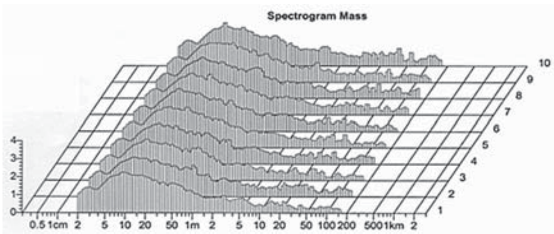

Figure 3: Mass spectrogram of modal ring-spun yarn

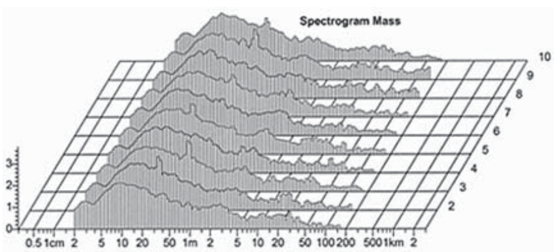

Figure 4: Mass spectrogram of micro modal ring-spun yarn

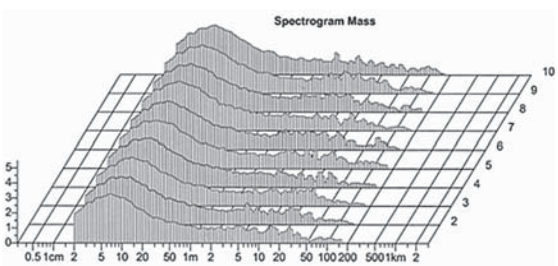

Figure 5: Mass spectrogram of modal rotor-spun yarn

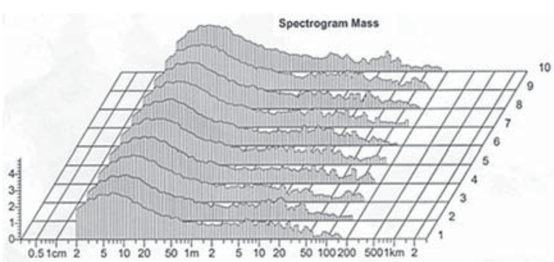

Figure 6: Mass spectrogram of micro modal rotor-spun yarn

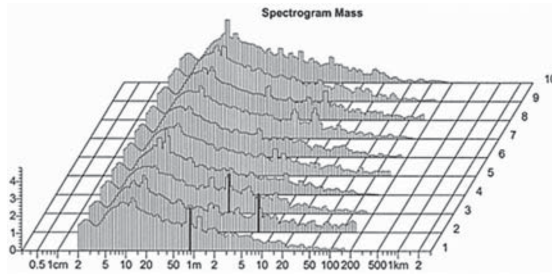

Figure 7: Mass spectrogram of modal air-jet spun yarn

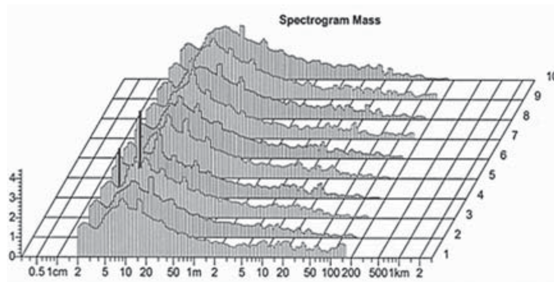

Figure 8: Mass spectrogram of micro modal air-jet spun yarn

3.3 Thin places

The number of thin places at different levels of sensitivity for all types of modal and micro modal yarns are given in Table 3 and shown in Figure 10. Rotor- (2316.8) and air-jet-spun yarn (1187.2) have a significantly higher number of thin places in modal yarn at a level of measurement sensitivity of –30% than ring-spun yarn (198.8). Comparing the same types of yarns spun from different fibres, it is evident that ring- and rotor-spun modal yarn have a greater number of thin places (198.8, 2316.8) than micro modal yarn (130.2, 1250.4). However, air-jet-spun modal yarn has a slightly smaller number of thin places (1187.29) than micro modal yarn (1197.4). The difference is 0.8% and can be ignored. At first glance, these results indicate that the greater fineness of micro modal fibres has no effect on the appearance of thin places in air-jet-spun yarn. However, because two periodic faults occurred with short wavelengths and significant amplitude in two out of 10 packages (Figure 8), the same faults increased the number of thin places. Accordingly, coarse modal fibres in ring and rotor spinning, particularly the spinning techniques (ring and rotor), create a greater number of thin places at a level of measurement sensitivity of –30% (greater weight reduction than the reference/

average weight of 100%) than finer micro modal fibres. To determine the effect of periodic faults on the number of thin places, more in-depth studies are necessary, with the specific preparation of yarn samples.

At the usual sensitivity level of –50%, which is typically used in spinning mills, rotor-spun yarn has a markedly greater number of thin places (8.1) than air-jet-spun (2) and ring-spun yarn (0.9) in the case of modal yarns. By comparing all types of modal yarns with micro modal yarns, yarns made from coarser modal fibres have a greater or a nearly equal number of thin places. Periodic faults of short wavelengths affect the number of thin places, as well as the coefficient of variation of unevenness of 10 packages CV_b. Figure 8 shows the systemic periodic fault of short wavelengths in air-jet-spun yarn, which increases the number of thin places and the value of CV_b.

3.4 Thick places

The number of thick places and the coefficient of variation of thick places of 10 packages are given in Table 4 and shown in Figure 11.

The number of thick places in all types of modal yarns at a level of measurement sensitivity of +35% is greatest in rotor-spun yarn (446), followed by air-jet-spun yarn (101.1), while the lowest number is seen in ring-spun yarn (29.7). In other words, the number of thick places in rotor-spun modal yarn is 15 times

Table 3: Thin places of ring-, rotor- and air-jet spun yarn from modal and micro modal fibres at different levels of sensitivity

Type of material	Level of sensitivity							
	–30%		–40%		–50%		–60%	
	Thin [km^{-1}]	CV_b [%]	Thin [km^{-1}]	CV_b [%]	Thin [km^{-1}]	CV_b [%]	Thin [km^{-1}]	CV_b [%]
Ring modal	198.8	13.78	5.2	28.46	0.1	316	0	0
Ring micro modal	130.2	26.8	1.4	90	0	0	0	0
Rotor modal	2316.8	3.72	235.8	9.62	8.1	44.07	0.1	316
Rotor micro modal	1250.4	2.96	61.1	9.31	0.9	122.2	0	0
Air-jet modal	1187.2	14.63	82	29.55	2	85	0	0
Air-jet micro modal	1197.4	32.7	79.7	60	1.8	190.5	0	0

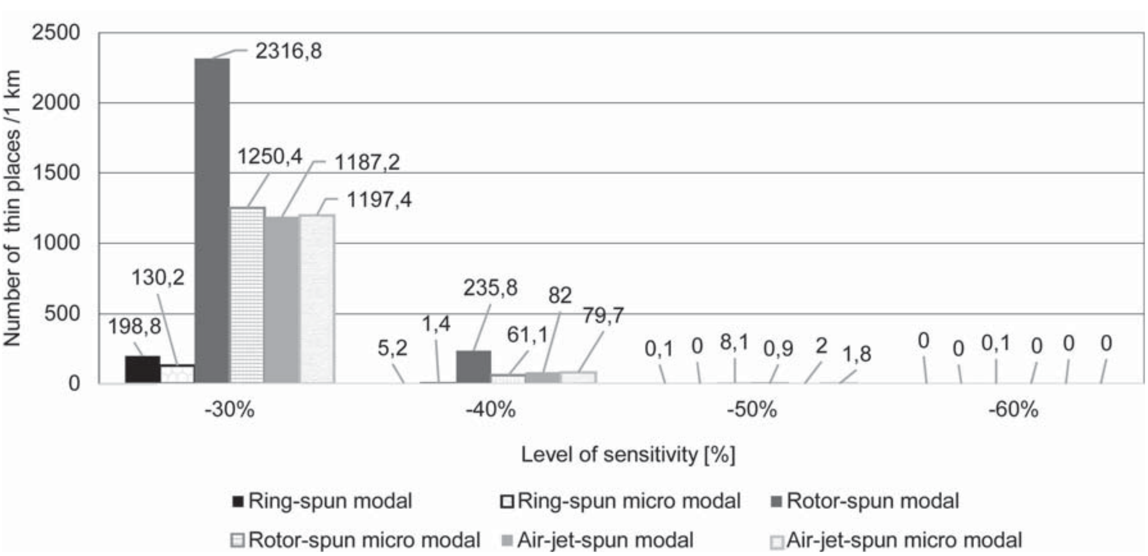

Figure 9: Number of thin places of modal and micro modal ring-, rotor- and air-jet-spun yarns for different levels of sensitivity

greater than in the ring-spun modal yarn, while the number of thick places in air-jet-spun modal yarn is 3.4 times greater than in ring-spun modal yarn.

At levels of measurement sensitivity of +50%, +70% and +100%, the sequence of thick places in modal yarns was the same as it was at a sensitivity level of +35%. The latter is analogous to micro modal yarns. By comparing the number of thick places at a level of measurement sensitivity of +35%, ring-spun yarns made from coarser modal and finer micro modal fibres have nearly the same number of thick places (29.7 and 30.4). Thus, the effect of fibre fineness on the number of thick places in ring-spun yarn at a sensitivity level of +35% is minimal. However, at a level of measurement sensitivity of +35%, a higher scattering of the number of thick places CV_b in ring-spun micro modal yarn (26.38%) is visible in relation to modal yarn (17.54%). The effect of the fineness of modal fibres on the number of thick places at a level of measurement sensitivity of +35% is significant in rotor-spun yarn. Thus, rotor-spun yarn from coarser modal fibres has a greater number of thick places at all levels of measurement sensitivity (446, 32.4 and 0.70) than rotor-spun yarn from finer micro modal fibres (245.8, 12.9, 0.1 and 0).

In air-jet-spun micro modal yarn, the number of thick places at a level of measurement sensitivity of + 35% does not decrease, but increases relative to or

Table 4: Thick places of ring-, rotor- and air-jet spun yarn from modal and micro modal fibres at different levels of sensitivity

Type of material	Level of sensitivity							
	+35%		+50%		+70%		+100%	
	Thick [km^{-1}]	CV_b [%]	Thick [km^{-1}]	CV_b [%]	Thick [km^{-1}]	CV_b [%]	Thick [km^{-1}]	CV_b [%]
Ring modal	29.7	17.54	1.8	57.22	0.3	225	0.1	316
Ring micro modal	30.4	26.38	5.8	76.21	2	115.5	0.3	160
Rotor modal	446	7.31	32.4	18.52	0.7	95.71	0	0
Rotor micro modal	245.8	7.19	12.9	28.91	0.1	320	0	0
Air-jet modal	101.1	16.09	3.4	60.76	0.4	174.7	0.1	316
Air-jet micro modal	132	46.25	5.4	56.7	0.4	130	0	0

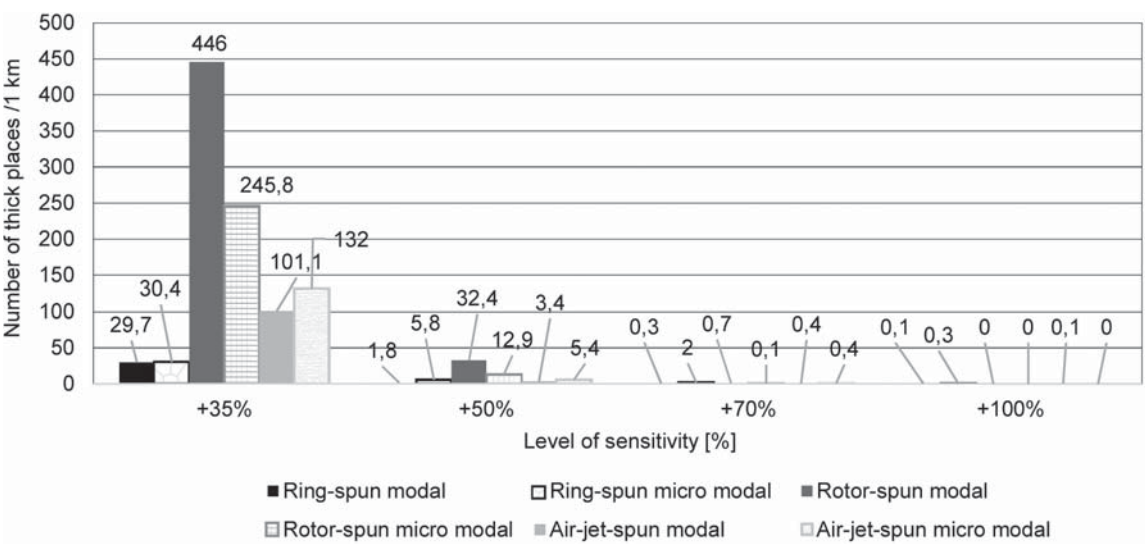

Figure 10: Number of thick places of modal and micro modal ring-, rotor- and air-jet yarns for different levels of sensitivity

is equal to (132, 5.4, 0.4 and 0) air-jet-spun modal yarn (101.1, 3.4, 0.4 and 0), which is analogous to the number of thin places in the same yarn. Here, too, the effect of the structure of air-jet-spun yarn and periodic faults in two out of 10 packages resulted in an increase in the number of thick places.

In spinning mills, the number of thick places is usually considered at a level of measurement sensitivity of +50%. The effect of finer micro modal fibres on the number of thick places is different and depends on the spinning technique. The use of micro modal fibres resulted in a 222.2% increase in the number of thick places at a level of measurement sensitivity of +50% in ring-spun yarn and a 28.8% increase in air-jet-spun yarn (including the effect of periodic faults), while a 60.2% reduction in the number of thick places was seen in rotor-spun yarn.

3.5 Neps

Since neps are actually thick places shorter than 4 mm, the number of neps in modal fibres follows the number of thick places (Table 5, Figure 12). Thus, the greatest number of neps in modal yarns at a sensitivity level of +140% is the smallest in the ring-spun yarn (72.7) followed by the air-jet-spun yarn (80.5) and the greatest in the rotor-spun yarn (1273.5). By comparing modal and micro modal yarns, it is evident that the ring- and air-jet-spun micro modal yarn has a greater number of neps (98.9, 280.6) than the modal yarn of the same type (72.7, 80.5). Only in

Table 5: Neps of ring-, rotor- and air-jet spun yarn from modal and micro modal fibres at different level of sensitivity

Type of material	Level of sensitivity							
	+140%		+200%		+280%		+400%	
	Neps [km^{-1}]	CV_b [%]	Neps [km^{-1}]	CV_b [%]	Neps [km^{-1}]	CV_b [%]	Neps [km^{-1}]	CV_b [%]
Ring modal	72.7	15.26	11	24.24	2.5	33.99	0.8	52.75
Ring micro modal	98.9	19.2	28.5	32.1	7.8	61	1.9	109.5
Rotor modal	1273.5	9.63	68.5	13.8	1.4	69.29	0.2	210
Rotor micro modal	778.8	5.96	31.2	20.1	1.3	81.5	0.1	100
Air-jet modal	80.5	33.42	5.3	35.66	0.6	86.67	0.1	316
Air-jet micro modal	280.6	63.4	14.1	65	1.6	89.4	0.2	210

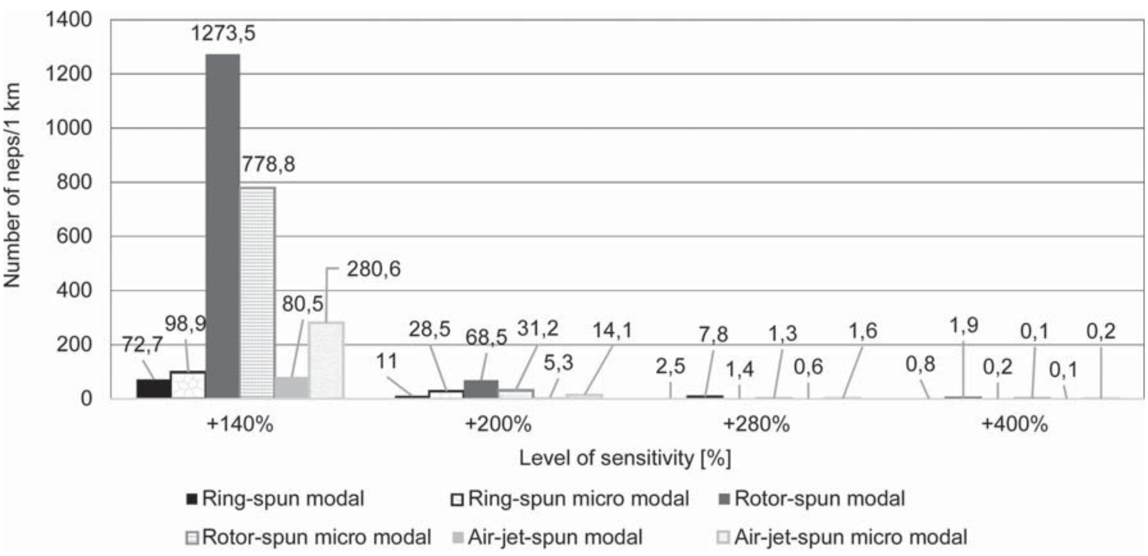

Figure 11: Number of neps of modal and micro modal ring-, rotor- and air-jet-spun yarns for different levels of sensitivity

the rotor-spun yarn from finer micro fibres the number of neps is smaller (778.8) in relation to the rotor-spun yarn from coarser modal fibres (1273.5). In other words, at a level of measurement sensitivity of +140% finer micro modal fibres increase the number of neps in the ring- and air-jet spinning, while their number decreases in the rotor spinning. In the air-jet-spun yarn the influence of periodic faults of short wavelengths with significant amplitude is, as with thin and thick places, probably significant.

At a level of measurement sensitivity of +200% the sequence of the number of neps is different. In modal yarns the smallest number of neps is found in the air-jet-spun yarn (5.3), followed by the ring-spun yarn (11) and finally the rotor-spun yarn (68.5). By comparing modal and micro modal yarns, it is apparent that the sequence of the number of neps is retained as well as at a level of measurement sensitivity of + 280% and +400%. Thus, finer micro modal fibres increase the number of neps in the ring- and air-jet-spun yarn at a level of measurement sensitivity of +200% but also at a level of measurement sensitivity of +280. Thus, by using micro modal fibres at a level of measurement sensitivity of +200% the number of neps increased in the ring- and air-jet-spun yarn by 159.1% and 166.0% respectively, and the number of neps in the rotor-spun yarn was reduced by 54.5%.

3.6 Hairiness

The values of hairiness of ring-, rotor- and air-jet-spun modal and micro modal yarns are given in Table 6 and shown in Figure 12. Yarn hairiness does not follow the number of faults, but is most dependent on the spinning machine type, i.e. the yarn formation technique and fibre fineness for the same end-use. In the case of modal yarns, the yarn with the lowest hairiness is the yarn produced using an air-jet spinning technique (3.71), followed by the yarn spun using a rotor spinning machine (4.34), while the yarn spun using traditional ring spinning (6.09) shows the highest hairiness. The effect of fibre fineness on the hairiness of yarns made using different spinning techniques is equally expressed. Namely, all yarns from finer micro modal fibres show lower hairiness than yarns from coarser modal fibres. The reduction of hairiness through the use of micro modal fibres is greatest in ring-spun yarn (13.3%), followed by rotor-spun yarn (5.99%), and lowest in relative terms in air-jet-spun yarn (4.04%). Air-jet-spun yarn (6.88%) has the highest scattering of hairiness among yarn packages.

Table 6: Hairiness (H) of the ring-, rotor- and air-jet-spun modal and micro modal fibres yarn from modal and micro modal fibres

Type of yarn and material	Hairiness [H]	CV_b [%]
Ring modal	6.09	2.8
Ring micro modal	5.28	4.05
Rotor odal	4.34	1.8
Rotor micro modal	4.08	1.67
Air-jet modal	3.71	4.6
Air-jet micro modal	3.56	6.88

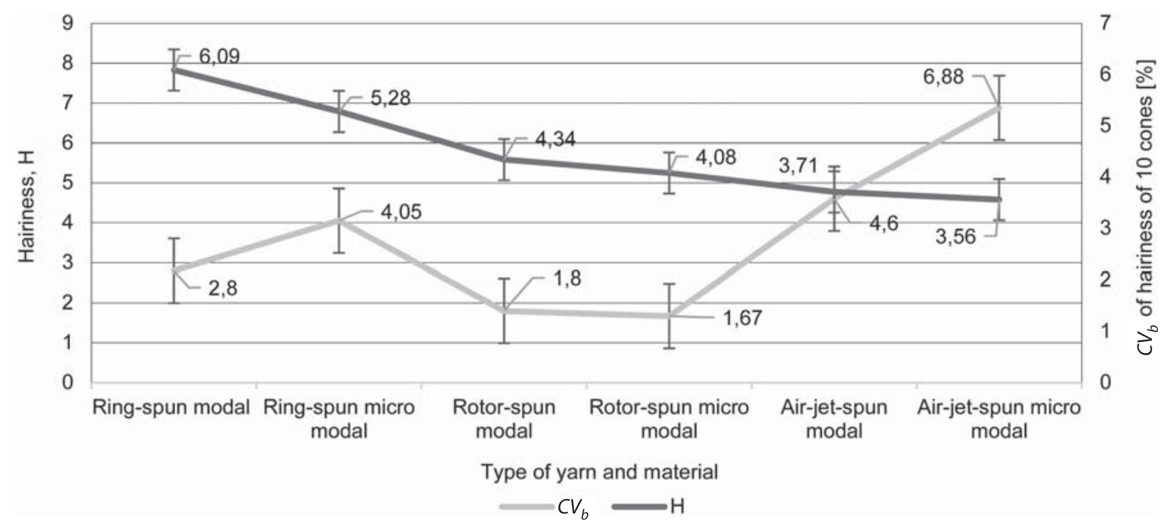

Figure 12: Hairiness H and CV of 10 cones of modal and micro modal ring-, rotor- and air-jet-spun yarns

4 Conclusion

Based on the obtained measurement results of the main physical-mechanical parameters of different types of modal and micro modal yarns, the following conclusions can be drawn:

- Ring-spun modal yarn has the highest tenacity (23.81 cN/tex), followed by air-jet-spun yarn (20.77 cN/tex), while rotor-spun yarn has the lowest tenacity (15.39 cN/tex).
- The elongation at break of modal yarns follows yarn tenacity: the highest elongation at break of modal yarn is found in ring-spun yarn (10.83%), followed by air-jet-spun yarn (9.25%), while the lowest elongation at break is found in rotor-spun yarn (8.17%).
- The difference in tenacity and elongation at break of different types of modal yarns (as well as micro modal yarns) is caused by the yarn structure, as the result of the spinning technique.
- The highest performed work of rupture of modal yarn is observed in ring-spun yarn due to its oriented structure, followed by air-jet-spun yarn, while the lowest value of the performed work of rupture is observed in rotor-spun yarn.
- The higher fineness of micro modal fibres in rotor-spun yarn had practically no effect on the performed work of rupture (7.70 N cm and 7.66 N cm).
- The spinning technique and consequently the yarn structure determine the level of overall yarn evenness.
- All types of modal yarns differ in overall unevenness and in micro modal fibres.
- The values of the overall unevenness of ring-, rotor- and air-jet-spun modal yarn (10.21%, 10.95% and 12.33%) are higher than the same values of micro modal yarns (9.67%, 12.69% and 12.12%).
- Most yarns do not contain periodic faults with significant amplitudes. This is the reason CV_b values are low.
- The coefficient of variation of the overall unevenness obtained as the mean value of 10 packages CV_b is the highest in air-jet-spun modal yarn (2.44%) and air-jet-spun micro modal yarn (4.69%). The cause of the latter is the appearance of periodic faults with significant amplitudes in three packages of air-jet-spun modal yarn and in two packages of air-jet-spun micro modal yarn at different wavelengths.
- Rotor-spun modal and micro modal yarn shows the highest deviation from ideal unevenness, followed by air-jet-spun yarn, while ring-spun modal yarn shows the lowest deviation.
- The number of faults at different levels of measurement sensitivity to detect the highest number of thin and thick places and neps (–30%, +35% and +140%) is greater in rotor- and air-jet-spun yarn than in ring-spun yarn for both fiber fineness.
- The effect of fiber fineness on the hairiness of yarns made using different spinning techniques is significant: in the case of modal yarns, the yarn with the lowest hairiness is the yarn produced using an air-jet spinning technique (3.71), followed by the yarn spun using a rotor spinning machine (4.34), while the yarn spun using traditional ring spinning (6.09) shows the highest hairiness.
- All yarns from finer micro modal fibres show lower hairiness than yarns from coarser modal fibres.

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