THE RELATION BETWEEN VISCOSE FIBERS' CHARACTERISTICS AND THEIR YARN PROPERTIES

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Abstract: *While cellulosic fibers have the third largest fiber's market-share, the production of viscose (as regenerated cellulosic fibers) was growing globally during the first decade of the 21st century with an average annual rate of 7%. Most of these fibers are used for apparel industry and it is necessary to study the performance of these materials in textile yarns. This study reports the results for characterizing two sets of viscose yarns with the same linear density (25 tex) that are produced at two different twist levels (409 and 877 twist/m). Viscose fibers characteristics including cross-section, fineness, orientation, and tenacity were evaluated and correlated to the produced yarns' physical and mechanical properties. Yarn evenness, mass distribution, thin and thick places, yarn hairiness, as well as the tenacity were improved by increasing the twist multiplier. On the other hand, the productivity (kg/h) of these yarns was decreased for that increase in the twist multiplier. These results show the relation between the yarn quality and productivity, where improving the product's qualities might be associated with a decrease in industrial process productivity. Therefore, it is important to carry out similar studies to optimize the processing parameters according to the end use of the produced yarns and their required performance.*

Keywords: *Viscose fibers characteristics, yarn properties, tenacity, haireness, USTER.*

1 INTRODUCTION

Man-made regenerated fibers are defined as fibers created via a chemical change of the natural material [1]. Viscose is a man-made regenerated fiber that is produced from cellulose dissolved pulps and its raw materials such as, wood, cotton or bamboo. Hardwood forests are the main sources nowadays of cellulose used for producing the viscose fibers. Hardwood cellulose is transformed into dissolving wood pulp that is processed into either viscose filament yarns or staple fibers. Wood-based regenerated cellulose fibers are used as alternatives to cotton fibers. The production of viscose (as regenerated cellulosic fibers) was growing globally, as shown in Figure 1, during the first decade of the 21st century with an average annual rate of 7.7% [2, 3].

Considering the relationship between viscose fibers parameters and yarn properties, there were multiple efforts to develop theoretical models to predict the mechanical behavior of twisted short fiber structures. For example, Pan [4] introduces a relationship between the mean fiber volume fraction and the twist level of the yarn and pointed out that the tensile and shear moduli are proportional to the fiber tensile modulus. Fiber volume fraction, fiber length and fiber orientation distribution in the yarn have significant effects on the yarn moduli through these factors [4].

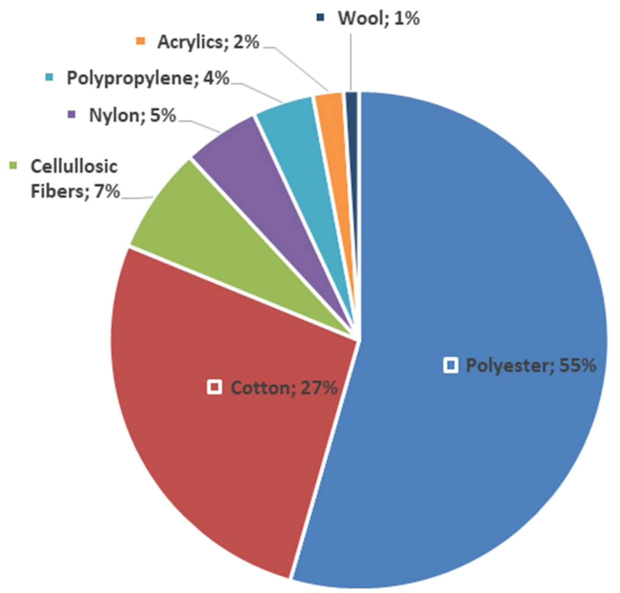

Figure 1 Global consumption of fibers at mills in 2015 [2]

Abbasi and others [5] produced three counts of cotton/polyester blends at different twist factors to study the effect of the twist level on the mechanical and physical characteristics of the low twisted yarns. They found that the yarn manufactured with the higher twist level (230 turns/m) and higher yarn count (50 tex) showed better yarn strength compared to the other twist factors and yarn counts. By increasing the twist level, the coefficient of variation decreased in all yarn counts; this may be due to higher amount of fibers present in yarn cross-section. The irregularity index and yarn hairiness of low twist yarn decreased with the increases of yarn count, moreover it decreased with the increase of twist per meter for the same count [5].

In another study [6], yarn evenness, faults, hairiness and diameter properties were tested using an USTER® Tester 5 for carded and combed yarns. In carded yarns, the increase of twist coefficient increased the evenness, tenacity and elongation values and decreased USTER hairiness and diameter values significantly. In combed yarns, increasing the twist coefficient improved tenacity and elongation and decreased number of thick places, neps, hairiness, and diameter values significantly [6].

The yarn hairiness is formed by protruding fiber portions from the relatively constricted basic body of the yarns. Different methods used for evaluating yarn hairiness were reviewed by Barella and Manich [7]. The hairiness of two-ply yarn decreases as the ply twist increases. The rate of reduction in hairiness with respect to twist is higher for the single-yarn twist than for the ply-yarn twist, particularly for the finer two-ply yarn. Variation in hairiness decreases as the ply twist increases [8].

For the staple yarns the ratio between the fiber tenacity and mean yarn tenacity is an important parameter that affects the yarn strength. The twist level, fiber properties, and fiber orientation are the main characteristics that influence the coefficient of fiber stress utilization. Zubair et al [9] presented a mathematical model, based on the assumptions of small deformation, constant packing density and contraction ratio. He used numerical integration considering real fiber stress-strain relationship and fiber orientation before the process of yarn breakage, when all fibers are mechanically stressed [9]. Neckář [10] also, validated the theoretical models compared with the experimental results. The main goal of this study is to study the relation between viscose fibers' characteristics and their yarn properties.

2 EXPERIMENTAL WORK

2.1 Materials

Two sets of viscose yarns have the same count (25 tex), produced at two different twist levels (409 and 877 twist/m) were used to investigate the relation between viscose fibers' parameters and their yarn physical and mechanical properties.

2.2 Methodology

Viscose fibers were tested for their count, strength (stress-strain curves), and have microscopic images for cross sectional and longitudinal views. Viscose yarns were tested for their count, twist coefficient, evenness using USTER tester, strength, as well as the microscopic images for the cross-sectional and longitudinal views. Yarns were also scanned through micro computed tomography (CT) scanner.

a) <u>Viscose yarn cross-section view</u>

The preparation of Viscose yarn cross-sectional views passed through the following steps:

1. The swelling solution was prepared (glue + special swelling agent) in small plate.
2. Thirty samples were taken of each yarn type and dipped one by one in the solution then arranged and fixed them until dried for 1st day.
3. Samples were treated in the same way during the 2nd day, but with the exception of dipping in glue only.
4. Samples were treated for their surface during the 3rd day using a small painting brush and glue only.
5. The wax solution was prepared during the 4th day and covered the yarns completely in the middle of metallic molds.
6. Samples were placed in freezer for one day, after that the samples were collected.
7. The slices of the yarn cross sections were prepared using microtome and the cross-sectional views were collected using optical microscope. Then, the sample images were analyzed using the NIS elements software.

b) <u>Yarn twist</u>

Twist per meter was measured on yarn twist tester according to standard procedure D1422–99 [9]. Thirty samples from each group of yarn were measured and the mean value of twist was calculated. The measured diameter and yarn twist were used to determine the twist angle (1) according to the following equation [11].

$$\tan \beta_D = \pi D Z \qquad (1)$$

where: D is yarn diameter, Z is twist/meter and β_D is maximum twist angle.

c) <u>Load-elongation curve of viscose yarns</u>

Load-elongation test of the yarns was performed according to the standard test methods ASTM D2256-02 [12]. Instron 4411 tensile testing machine was used to measure and draw the correlation between the yarn extension and applied load at a constant speed of 200 mm/min.

d) <u>Viscose yarns evenness</u>

Yarn evenness, mass distribution, and imperfections (neps, thin and thick places) were measured using USTER tester 4, at the Technical University of Liberec according to the ASTM D1425-96 at standard conditions (temperature: 20±2°C and relative humidity: 65±4%) [13]. The measured sample length was 1000 m, with an extra length of 5 m before each measurement. The machine speed was 400 m/min and five samples from each group were measured, as shown in Figure 2 [14].

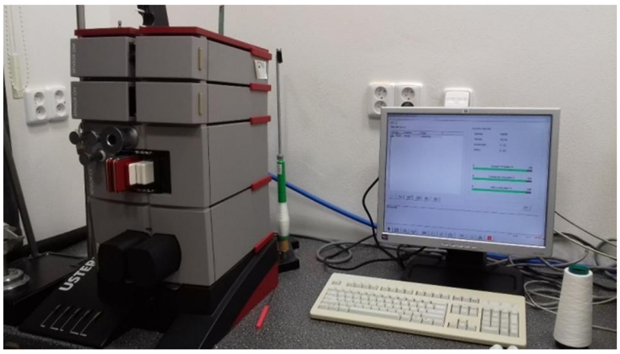

Figure 2 USTER tester 4 for yarn evenness

e) Viscose fibers fineness and strength

The viscose fibers fineness and strength were measured using VIBRODYN 400 according to the standard test method ISO 5079. For accurate calculations and analysis, one hundred fiber samples were measured as five groups, 20 samples for each. The first step of this test was to measure the fiber fineness (dtex) by hanging one end of the fiber to the optimum pretension Vibro-clips (100 mg for fiber counts ranging between 1.0 to 2.4 dtex), then clamping the other end to measure the fiber fineness. The second step was to measure the fiber strength, as illustrated in Figure 3. Finally, the fiber tenacity (cN/tex) was calculated for each sample.

Figure 3 Testing of fiber fineness and strength using VIBROSKOP and VIBRODYN 400

Table 1 Viscose fibers fineness and tenacity

No	Titer [dtex]	Force [cN]	Elongation [%]	Tenacity [cN/tex]
1	1.14	5.48	10.90	48.07
2	1.24	5.48	13.60	44.19
3	1.40	4.44	7.40	44.31
4	2.33	8.37	8.60	35.92
5	2.03	8.06	11.10	39.70
6	1.57	4.86	7.20	30.96
7	1.52	5.75	8.90	37.83
8	1.45	5.02	8.40	34.62
9	1.09	4.37	7.70	40.09
10	1.55	5.73	10.20	36.97
11	1.40	5.67	10.90	40.50
12	1.46	5.29	9.90	36.23
13	1.02	5.00	7.70	49.02
14	1.50	5.19	10.60	34.60
15	1.41	3.20	6.40	22.70
16	1.33	4.92	8.60	36.99
17	1.59	6.48	9.70	40.75
18	1.50	5.71	10.90	38.07
19	1.30	4.14	8.90	31.85
20	1.16	5.19	8.20	44.74
Average	**1.45**	**5.24**	**9.29**	**37.78**
Std. dev.	0.30	1.19	1.74	6.16

No	Ten/10% [cN/tex]	YM1% [cN/tex]	YM1% [cN/dtex]	YM1% [g/den]
1	46.64	1067.98	106.80	120.96
2	39.64	1104.84	110.48	125.14
3	0.00	825.00	82.50	93.44
4	0.00	1092.27	109.23	123.71
5	38.55	1064.04	106.40	120.52
6	0.00	1111.46	111.15	125.89
7	0.00	1228.62	122.86	139.16
8	0.00	931.03	93.10	105.45
9	0.00	1362.39	136.24	154.31
10	36.81	746.24	74.62	84.52
11	39.64	932.14	93.21	105.58
12	0.00	948.63	94.86	107.44
13	0.00	2121.57	212.16	240.30
14	33.85	673.33	67.33	76.26
15	0.00	854.61	85.46	96.80
16	0.00	966.17	96.62	109.43
17	0.00	1748.43	174.84	198.03
18	36.97	993.33	99.33	112.51
19	0.00	1184.62	118.46	134.17
20	0.00	1463.79	146.38	165.79
Average	**13.60**	**1121.02**	**112.10**	**126.97**
Std. dev.	19.15	342.95	34.30	38.84

3 RESULTS AND DISCUSSION

3.1 Viscose fibers fineness and tenacity

The average viscose fiber fineness was measured by VIBROSKOP 400 was 1.45 dtex at significantly high standard deviation 0.30 dtex. Moreover, the average fibers tenacity, tested on VIBRODYN 400, was 37.78 cN/tex with 6.16 cN/tex standard deviation and breaking elongation of 9.29% with 1.74% standard deviation, as listed in Table 1.

3.2 Viscose fibers cross-sectional view

The fibers cross-sectional views were prepared by taking the slices using the microtome, and then samples were imaged under the optical microscope. The obtained best images of the 25 tex yarns 409 and 877 twist/m were analyzed using NIS elements software, as shown in Figures 4 and 5 respectively. The average fibers' diameter for 409 Z/m is 12.79 µm, whereas for 877 Z/m is 12.30 µm. The slightly difference in fibers diameter may be due to the fibers wrapping and compactness obtained by higher twist level.

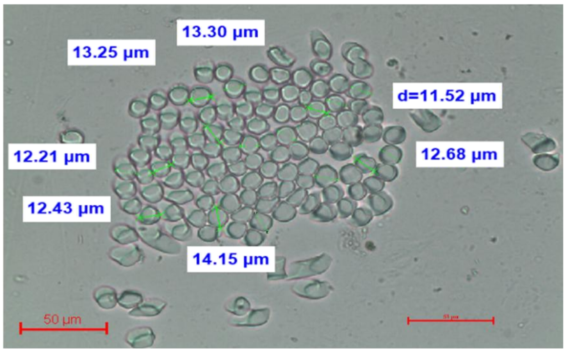

Figure 4 Viscose fibers cross-sectional view for yarn 25 tex, 409 twist/m

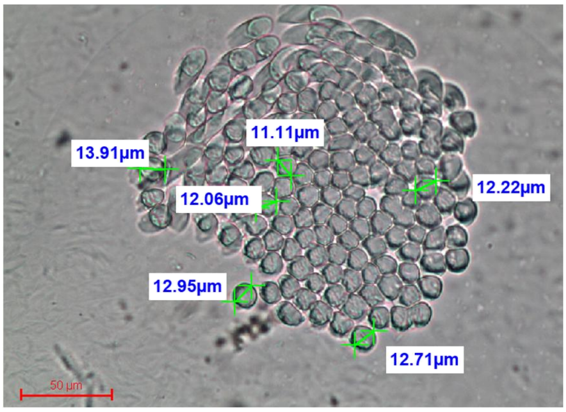

Figure 5 Viscose fibers cross-section for yarn 25 tex, 877 twist/m

3.3 Viscose yarns twist level

The average viscose yarns twist level for the two experimental groups was 409 and 877 twist/m with a standard deviation of 11 and 14 twist/m, respectively, as listed in Table 2.

Table 2 Viscose yarns twist per meter

Samples	Sample 1 (409 twist/m)	Sample 2 (877 twist/m)
1	398	862
2	395	883
3	421	879
4	396	887
5	431	855
6	423	850
7	398	879
8	404	864
9	399	852
10	422	898
11	405	891
12	411	873
13	397	885
14	421	879
15	409	886
16	412	883
17	407	864
18	403	885
19	412	889
20	419	897
Average	**409**	**877**
Std. dev.	**11**	**14**

3.4 Viscose yarns load-elongation curves

There is no significant difference between the average values of viscose yarns load and elongation for both 409 and 877 twist/m, as can be observed from the values in Table 3. The yarn tenacity was calculated as 26.02 and 25.18 cN/tex for the low and high twist, respectively. This slight reduction in the yarn tenacity may be due to exceeding the optimum (critical) twist level [15].

Table 3 Load-elongation data of viscose yarns 25 tex, 409 and 877 twist/m

Samples Code	Sample 1 (409 twist/m)		Sample 2 (877 twist/m)	
	Load [N]	Elongation [mm]	Load [N]	Elongation [mm]
1	5.87	35.41	6.46	41.63
2	5.93	38.56	5.17	33.15
3	6.54	36.06	5.97	38.96
4	6.96	39.03	6.94	44.78
5	6.52	39.4	6.79	41.48
6	6.6	39.81	5.99	37.7
7	7.03	38.96	6.67	40.21
8	6.58	38.13	6.65	42.31
9	6.65	37.7	6.9	42.3
10	6.36	36.05	5.41	35.61
Average	**6.50**	**37.911**	**6.295**	**39.813**
Std. dev.	0.38	1.56	0.63	3.51

3.5 Viscose yarns evenness

The USTER tester 4 statistics for viscose yarns 25 tex (409 and 877 twist/m) are summarized in Tables 4 and 5, respectively. Increasing the twist level improved the yarn regularity and decreased imperfections, hairiness, and yarn diameter. The number of thin places (-40%), thick places (+70%), and neps (+140%) decreased from 13, 23, and 41 to be 5, 1, and 4 /km, respectively. The yarn irregularity (U%, unevenness) decreased from 8.62 to 8.04%. Moreover, the average coefficient of mass variation (CV_m 1m) decreased from 4.87 to 3.74% [16]. These results are consistent with other previous studies [4-5].

Table 4 USTER 4 statistics for yarn 25 tex, 409 twist/m

Nr	1	Mean CV Q95	Max	Min
U% [%]	8.62	8.62	8.62	8.62
U inert [%]	1.73	1.73	1.73	1.73
U hi [%]	2.54	2.54	2.54	2.54
CVm [%]	11.37	11.37	11.37	11.37
CVm 1m [%]	4.87	4.87	4.87	4.87
CVm 3m [%]	3.97	3.97	3.97	3.97
CVm 10m [%]	2.78	2.78	2.78	2.78
CVm 50m [%]	1.72	1.72	1.72	1.72
CVm Inert [%]	2.16	2.16	2.16	2.16
CVm Hi [%]	3.17	3.17	3.17	3.17
Thin -30% /km	299.0	299.0	299.0	299.0
Thin -40% /km	13.0	13.0	13.0	13.0
Thin -50% /km	0.0	0.0	0.0	0.0
Thin -60% /km	0.0	0.0	0.0	0.0
Thick +35% /km	53.0	53.0	53.0	53.0
Thick +50% /km	23.0	23.0	23.0	23.0
Thick +70% /km	14.0	14.0	14.0	14.0
Thick +100% /km	9.0	9.0	9.0	9.0
Neps +140% /km	41.0	41.0	41.0	41.0
Neps +200% /km	13.0	13.0	13.0	13.0
Neps +280% /km	7.0	7.0	7.0	7.0
Neps +400% /km	4.0	4.0	4.0	4.0
H	10.11	10.11	10.11	10.11
sh	1.92	1.92	1.92	1.92
2D∅	0.273	0.273	0.273	0.273
CV2D 8mm [%]	9.40	9.40	9.40	9.40
S2D 8mm [%]	0.030	0.030	0.030	0.030

Table 5 USTER statistics for yarn 25 tex, 877 twist/m

Nr	1	Mean CV Q95	Max	Min
U% [%]	8.04	8.04	8.04	8.04
U inert [%]	1.07	1.07	1.07	1.07
U hi [%]	1.94	1.94	1.94	1.94
CVm [%]	10.11	10.11	10.11	10.11
CVm 1m [%]	4.87	4.87	4.87	4.87
CVm 3m [%]	3.74	3.74	3.74	3.74
CVm 10m [%]	3.018	3.018	3.018	3.018
CVm 50m [%]	0.95	0.95	0.95	0.95
CVm Inert [%]	1.33	1.33	1.33	1.33
CVm Hi [%]	2.43	2.43	2.43	2.43
Thin -30% /km	174.0	174.0	174.0	174.0
Thin -40% /km	5.0	5.0	5.0	5.0
Thin -50% /km	0.0	0.0	0.0	0.0
Thick +35% /km	11.0	11.0	11.0	11.0
Thick +50% /km	2.0	2.0	2.0	2.0
Thick +70% /km	1.0	1.0	1.0	1.0
Thick +100% /km	0.0	0.0	0.0	0.0
Neps +140% /km	4.0	4.0	4.0	4.0
Neps +200% /km	0.0	0.0	0.0	0.0
H	5.54	5.54	5.54	5.54
sh	1.17	1.17	1.17	1.17
2D∅	0.205	0.205	0.205	0.205
CV2D 8mm [%]	7.09	7.09	7.09	7.09
S2D 8mm [%]	0.017	0.017	0.017	0.017

Table 6 Averages of overall yarn data

Twist level [T/m]	Fiber diameter [µm]	Yarn tenacity [cN/tex]	yarn Irregularity [%]	Thin places (-40%)	Thick places (+70%)	Neps (+140%)	Coef. of mass variation (CV_m 1m) [%]
409	12.8	26.0	8.62	13	23	41	4.87
877	12.3	25.2	8.04	5	1	4	3.74

4 CONCLUSION

The average viscose fiber fineness was 1.45 dtex, the fibers tenacity was 37.78 cN/tex and breaking elongation was 9.29%. The viscose yarn physical properties including fibers' cross-section, diameter and twist have been analyzed for two groups of twist levels. The higher twist multiplier improved the fibers orientation and cohesion forces, which decreased the yarn diameter from 12.79 to 12.30 µm. Moreover, the yarn unevenness, hairiness, thin-, thick-places, neps were decreased at the twist level of 877 twist/m. The coefficient of variation of mass distribution decreased from 4.87 to 3.74%, respectively. There are slightly differences between the tenacity and elongation results for both groups that might be due to exceeding the optimum twist level. These results show the trade-off between the yarn quality and productivity, where increasing the twist to certain levels might enhance the product qualities, this will also decrease the productivity of the industrial process. Therefore, it is necessary to optimize these parameters according to the required performance and the end use of the produced yarns.

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