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Effect of Fibre Fineness and Spinning Speed on Polyester Vortex Spun Yarn Properties

Abstract

The properties of vortex yarn made from 100% polyester fibre with different fibre finenesses and spinning speeds were studied. Four different fibre finenesses (0.9, 1.1, 1.3 and 1.5 dtex) were used to produce yarns of 20 tex polyester vortex yarn with five different delivery speeds (320, 340, 360, 380 and 400 m/min), and these yarns were then tested for their unevenness, tensile and hairiness related properties. Linear multiple regression methods were used for the estimation of the yarn quality characteristics. It is found that fibre fineness and spinning speed did not influence the tenacity of the vortex yarn. The yarn unevenness was found to be maximum for coarser (1.5 dtex) fibre and minimum for finer (0.9 dtex) fibre. Minimum thin places were noticed for 0.9 dtex fibre. The hairiness index (H) found decreases when the fibre becomes finer up to 1.1 dtex and then increases when the fibre becomes finer than 1.1 dtex. However, Zweigle hairiness (1 mm) decreases as the fibre becomes finer. The vortex spinning speed does not influence any of the yarn properties except the hairiness values.

Key words: *linear density, hairiness, Murata Vortex Spinning, polyester yarn, tenacity, vortex, Zweigle hairiness tester.*

Introduction

In the recent past, the textile industry has been focusing its attention on higher machine productivity, lower power consumption and less labour requirement. Vortex spinning provides the potential to create a "ring like" yarn structure with the combination of core and wrapper fibres [1]. The mechanical characteristics of the staple yarns are influenced by the yarn structure, characterised by an arrangement of individual fibres in the yarn cross section. Many characteristics such as tenacity, elongation at break, hairiness and uniformity of the spun yarn depend on the fibre distribution along the yarn cross section [2 - 4]. The arrangement of individual fibres and fibre distribution is highly influenced by the number of fibres in the cross section, decided by the selection of the fibre fineness. There are occasional references to the fibre arrangement in vortex yarn [5 - 10], but none has so far addressed the question of the spinning of polyester fibre in vortex spinning and the extent to which the fibre fineness has an influence on the structure and quality characteristics of polyester vortex yarn. Information regarding fibre fineness and length as well as the vortex spinning speed and yarn properties demands systematic investigation. This paper reports the results of experiments undertaken to establish a more in-depth understanding of the influence of polyester fibre fineness on the properties of vortex yarn. Moreover the effect of the vortex spinning speed on the properties of vortex yarn was studied with different fineness values.

Materials and methods

Preparation of vortex yarn samples

The yarns used in this study were made using a vortex spinning machine. Four different fineness polyester fibres were used (0.9, 1.1, 1.3 and 1.5 dtex). The fibre length was fixed at 38 mm for all the four types of fibres. Specifications of the polyester fibres are given in ***Table 1***. The conversion to drawn sliver was carried out using a Rieter drawframe D40 at a 500 m/min delivery speed. Three drawing passages were given to carding sliver, with the linear density of the finisher drawing sliver being adjusted to 4.22 ktex. The drawn slivers were spun into 20 tex polyester yarn on a Murata Vortex Spinning machine (MVS 861). Five different speeds, each with a 20 m/min difference, from 320 m/min to 400 m/min were used for all four fibre samples. The machine parameters used to produce these vortex yarns are given in ***Table 2***.

Table 1. *Specification of polyester fibres.*

Fibre	Fibre profile	Length, mm	Linear density, dtex	Tenacity, cN/tex	Extension at break, %
Polyester	Circular semi dull	38	0.9	6.0 ± 0.4	18 ± 5
			1.1		20 ± 5
			1.3	5.9 ± 0.4	22 ± 5
			1.5		24 ± 5

Table 2. *Vortex machine parameters.*

Delivery speed, m/min	320 ~ 400
Total draft	214
Main draft	30
Break draft	3
Feed ratio	0.96
Take up ratio	1.03
Condenser, mm	4.0
Gauge, mm	41 - 45
Nozzle	5 holes
Nozzle distance, mm	20.0
Spindle, mm	1.1
Apron spacer, mm	2.4
Nozzle pressure, MPa	0.50

Test methods

All yarn samples were tested for their unevenness, imperfections and hairiness index H on an Uster Tester UT5. The tenacity and elongation% were measured by an Uster Tensorapid UTR4. The hairiness was measured by counting the number of protruding fibres using a Zweigle Hairiness Tester (Model G567).

For each sample six cones were selected. Unevenness properties were evaluated using an Uster Tester UT5 at a speed of 400 m/min for 2.5 minutes. Tensile properties of the yarns were measured using an Uster Tensorapid at 5000 mm/min. Twenty observations were made for each yarn sample and then averages were calculated. The hairiness of the vortex yarn was measured by both the Uster Tester 5 and Zweigle hairiness tester Zweigle G567. The protruding hairs were determined by the Zweigle G567 for a 100 meter length for each sample at a speed of 50 m/min.

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Table 3. Effect of fibre fineness on vortex yarn properties at 5 different spinning speeds from 320 m/min to 400 m/min; ***Count****: 20 tex polyester vortex yarn.*

Property	Spinning speed, m/min																			
	320				340				360				380				400			
Fibre fineness, dtex	0.9	1.1	1.3	1.5	0.9	1.1	1.3	1.5	0.9	1.1	1.3	1.5	0.9	1.1	1.3	1.5	0.9	1.1	1.3	1.5
Yarn count, tex	19.67	19.70	19.71	19.72	19.67	19.77	19.76	19.67	19.69	19.75	19.79	19.69	19.66	19.72	19.66	19.63	19.68	19.72	19.68	19.63
Count CV%	0.61	0.43	0.42	0.47	0.37	0.41	0.38	0.49	0.47	0.58	0.46	0.50	0.40	0.54	0.50	0.41	0.66	0.38	0.46	0.24
Tenacity, cN/tex	27.47	27.74	27.88	27.72	27.42	28.15	28.27	27.67	27.64	27.92	27.91	27.76	27.80	28.06	28.17	27.89	27.69	27.74	27.58	27.18
Elongation at break, %	8.40	8.94	9.08	9.39	8.36	9.05	9.13	9.18	8.35	8.96	9.01	9.15	8.39	8.86	9.01	9.11	8.39	8.74	8.86	8.94
Unevenness, U%	8.57	8.84	9.16	9.86	8.48	8.76	9.09	9.89	8.56	8.84	9.11	9.89	8.54	8.80	9.10	9.81	8.56	8.87	9.05	9.79
CVm (1m)%	3.22	2.82	2.97	3.20	3.26	2.75	2.92	3.23	3.29	2.80	2.92	3.45	3.28	2.84	2.97	3.36	3.23	2.88	2.88	3.31
Thin (-30%)	483	588	767	1170	421	529	747	1186	425	573	740	1187	444	533	728	1192	435	543	703	1125
Thick (+35%)	28	47	60	119	35	50	62	112	38	57	57	105	44	60	54	94	57	66	60	87
Neps (+140%)	24	11	12	12	19	9	12	12	17	8	10	10	15	7	8	8	12	7	7	5
Hairiness, H	3.49	3.18	3.33	3.41	3.62	3.32	3.45	3.57	3.73	3.45	3.62	3.74	3.88	3.59	3.77	3.91	4.02	3.74	3.97	4.10
sh	0.69	0.59	0.60	0.60	0.72	0.61	0.63	0.64	0.72	0.63	0.65	0.67	0.76	0.66	0.69	0.70	0.78	0.69	0.73	0.74
Zweigle 1 mm hairs	466	828	1052	1719	538	985	1130	1835	652	1086	1166	2013	729	1231	1190	2010	903	1383	1295	2239
Zweigle 2 mm hairs	9	19	30	71	10	27	35	72	17	38	41	81	18	42	44	91	24	51	53	111
Zweigle 3 mm hairs	0.3	1.7	1.2	5.2	0	2	3	6	0	3	3	4	1	4	4	8	2	4	5	9
Zweigle S3 value	1.7	1.7	1.5	6.0	0.3	2.2	3	7.8	0	3.3	4.2	5.3	1	4.2	4.5	9.0	2.2	4.7	5.2	10.8

Statistical methods

Regression analysis is the most common statistical method used for estimation of the relationship between a dependent variable and one or more independent variables. The quantitative relationship between the properties of a textile material can be described by this regression analysis. The multiple regression analysis method was selected for establishing the relationship between the fibre fineness, spinning speed (independent variables) and yarn properties (dependent variable). Statistical analysis indicated that there was a nearly linear relationship between the fibre fineness and some of the yarn properties.

Statistical analyses were performed using MATLAB software version 7.0

Results and discussion

Mass irregularity and imperfections

The results of yarn unevenness and extra sensitive imperfections with five different speeds are shown in ***Table 3***. It is

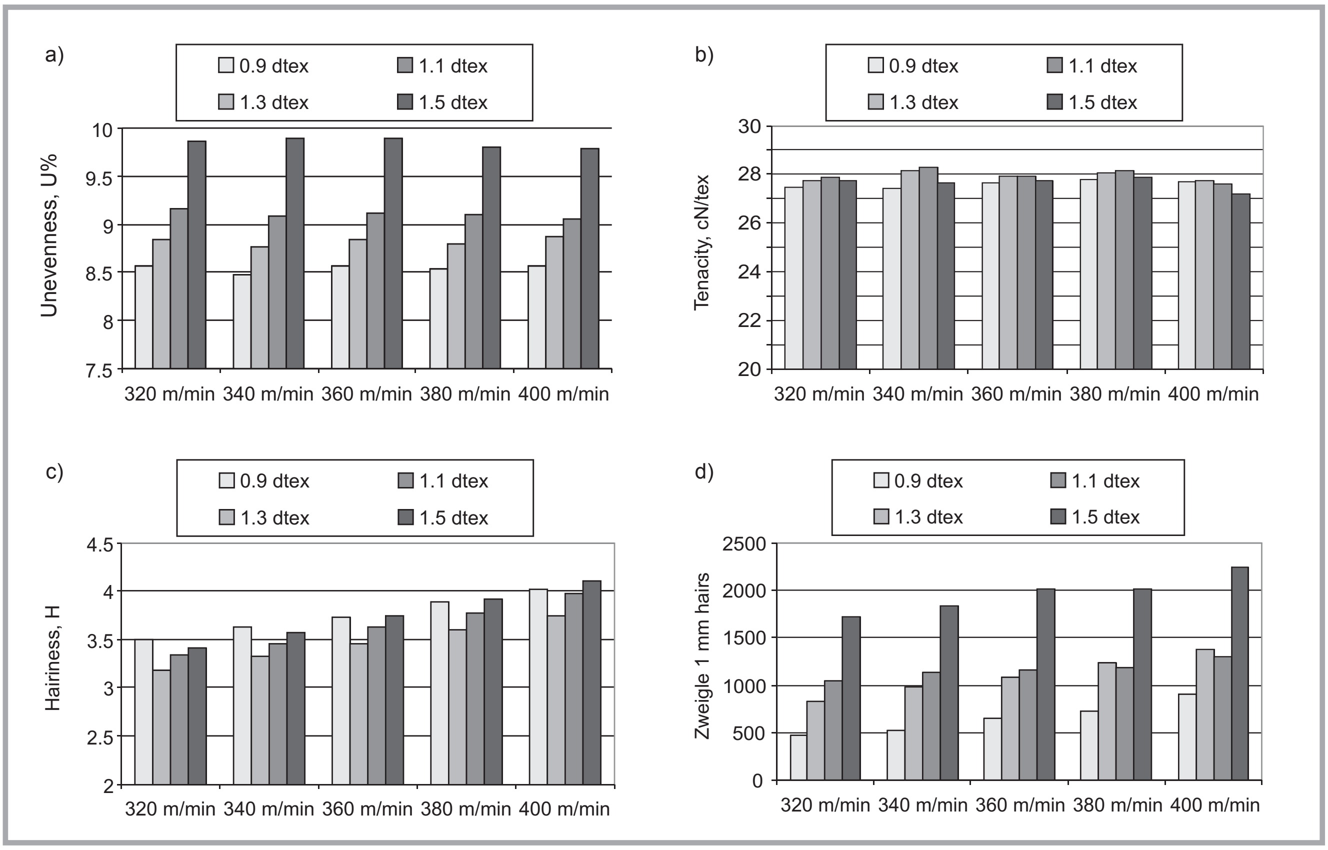

Figure 1. *Effect of fibre fineness on: a) polyester, b) tenacity of polyester, c) hairiness index - H, and d) Zweigle 1 mm hairs of polyester vortex yarn at different spinning speeds.*

observed that the vortex yarn made from finer polyester fibre shows lower unevenness and coarser fibre shows maximum unevenness. ***Figure 1.a*** shows that when the fineness of polyester fibre becomes coarser, the unevenness of polyester yarn made from vortex spinning becomes higher. Interestingly increasing the spinning speed from 320 m/min to 400 m/min did not have any influence on the unevenness of the vortex yarn.

The CVm(1m)% of vortex yarns made from all four different fineness polyester fibres shows that the yarn made from 1.1 dtex polyester fibre has a substantially lower CVm(1m)% than other coarser and finer polyester fibres. The higher CVm (1m) % of yarn made from 0.9 dtex fibre may be due to disturbance in yarn formation at the spindle tip caused by the higher number of fibres in the cross section.

Extra sensitive frequently occurring yarn faults are hardly recognisable on fabrics made from ring spun yarn, whereas in the case of vortex yarn, due to its lower hairiness and more clear nature of the fabrics, the influence of extra sensitive frequently occurring yarn faults is very important. Extra sensitive thin places (-30%) of vortex yarn made from 0.9 dtex polyester fibre are 60% less than for yarn made from 1.5 dtex polyester fibre. The result shows that the finer the fibre fineness, the fewer the thin places. The spinning speed does not have any significant influence on the thin places in all cases. Also extra sensitive thick places (+35%) are influenced by the fibre fineness. Coarser fibres have higher thick places due to the lower number of fibres in the cross section. The spinning speed has an influence on the thick places to a certain extent, which depends on the fibre fineness. Coarser fibre has a better tendency of yarn formation at higher speeds and causes fewer thick places at higher speeds than at lower speeds. Due to these reasons, thick places decrease linearly with an increase in speed for yarn made from coarser (1.5 dtex) polyester fibre. However, finer fibre shows contrary results. Fibres of 0.9 and 1.1 dtex show an increase in thick places with an increase in speed, which may be due to the greater number of fibres in the cross section, which causes a disturbance in fibre rotation in the nozzle zone during higher speeds. Vortex yarns made from 1.3 dtex fibre have a consistent level of thick places with different spinning speeds.

Table 4. *Regression equations for fibre fineness, spinning speed and yarn properties.*

Property	Regression equation	R^2
Tenacity, cN/tex	y = 0.0803 (f) - 0.0011(s) + 28.0658	0.019
Elongation at break, %	y = 1.1640(f) - 0.0026(s) + 8.4194	0.738
Unevenness, U%	y = 2.0940(f) - 0.0004(s) + 6.6928	0.927
CVm (1m)%	y = 0.1332(f) + 0.0006(s) + 2.7026	0.013
Thin (-30%)	y = [1.1882(f) - 0.0005(s) - 0.5237] × 10^3	0.906
Thick (+35%)	y = 90.8(f) + 0.0235(s) - 50.6517	0.707
Neps (+140%)	y = - 9.3(f) - 0.0044(s) + 24.0517	0.344
Hairiness, H	y = 0.0807(f) + 0.0075(s) + 0.8316	0.709
sh	y = - 0.0823(f) + 0.0014(s) + 0.2693	0.608
Zweigle 1 mm hairs	y = [2.0237(f) + 0.0055(s) – 3.1768] × 10^3	0.892
Zweigle 2 mm hairs	y = 106.9667(f) + 0.3415(s) – 207.1517	0.873
Zweigle 3 mm hairs	y = 8.6333(f) + 0.0350(s) – 19.6767	0.866
Zweigle S3 value	y = 10.2333(f) + 0.0352(s) – 21.1550	0.825

The nep level of vortex yarn made from fibre of different fineness shows that the fibre fineness has a certain level of influence on the nep level. The extra sensitive nep level (+140%) of finer polyester fibre (0.9 dtex) is higher than coarser linear density polyester fibres. Interestingly as the spinning speed of the vortex machine increases, the nep level starts to decrease in all four types of fibres used. In the vortex yarn formation, the fibre bundles came under the influence of the spiral vortex air stream and grouped together at the tip of the needle protruding from the central axis of the orifice. The reduction in the nep level may be due to the combination of higher speed and vortex air stream, causing the nep to be thrown out from the fast moving fibre bundles into the waste suction chamber.

Multiple regression equations that relate the fibre fineness, spinning speed and yarn properties are shown in ***Table 4***. The coefficient of determination, R^2, defines the fraction of variability in the dependent variable explained by the regression model. It is found that unevenness ($R^2 = 0.927$) and thin places ($R^2 = 0.906$) are highly influenced by the independent variables. On the other hand there is a moderate relationship between thick places of the vortex yarn ($R^2 = 0.707$), fibre fineness and the spinning speed. The CVm(1m)% ($R^2 = 0.013$) and neps ($R^2 = 0.344$) cannot be explained by these parameters. The regression equations revealed that the yarn unevenness and thin places are strongly dependent on the fibre fineness, followed by thick places (+35%). The spinning speed does not influence unevenness and extra sensitive thin places.

Figure 3 (see page 38) shows the scatter plot of predicted versus experimental values and the regression line of our model for unevenness and extra sensitive imperfections.

Tensile properties

The tensile properties of polyester vortex yarn made from fibre of different fineness are also shown in ***Table 3***. It is observed from ***Figure 1.b*** that the tenacity of vortex yarn is not influenced by the fibre fineness. Also the spinning speed has no affect on the vortex yarn tenacity, which proves the same finding of Bansal and Oxenhaum [4]. The results of the elongation % of vortex yarns shows that coarser fibre has greater elongation %. Also higher spinning speeds produce less extensible yarn, obviously due to less twist in the yarn structure during higher speeds. This trend was noted in 1.3 and 1.5 dtex fibres. Interestingly 0.9 and 1.1 dtex fibres do not show any difference in elongation % with an increase in the spinning speed, which may be due to the higher number of fibres in the cross section, which may help to form the amount of twist required, even at higher speeds, to withstand the elongation at break.

The statistical analysis shows that the tenacity ($R^2 = 0.019$) is not influenced by the fibre fineness nor the spinning speed; on the other hand these parameters have a moderate influence on the elongation in % ($R^2 = 0.738$). The regression equations show that the elongation in % is mainly dependent on fibre fineness. ***Figure 4*** (see page 39) shows the regression model of tenacity and elongation in %, where the values of tenacity are widely spread around the regression line.

Hairiness

In general, vortex spun yarn has consistently much lower hairiness than ring and compact spun yarns made from the same raw material. The variation in the hairiness index of 100% polyester vor-

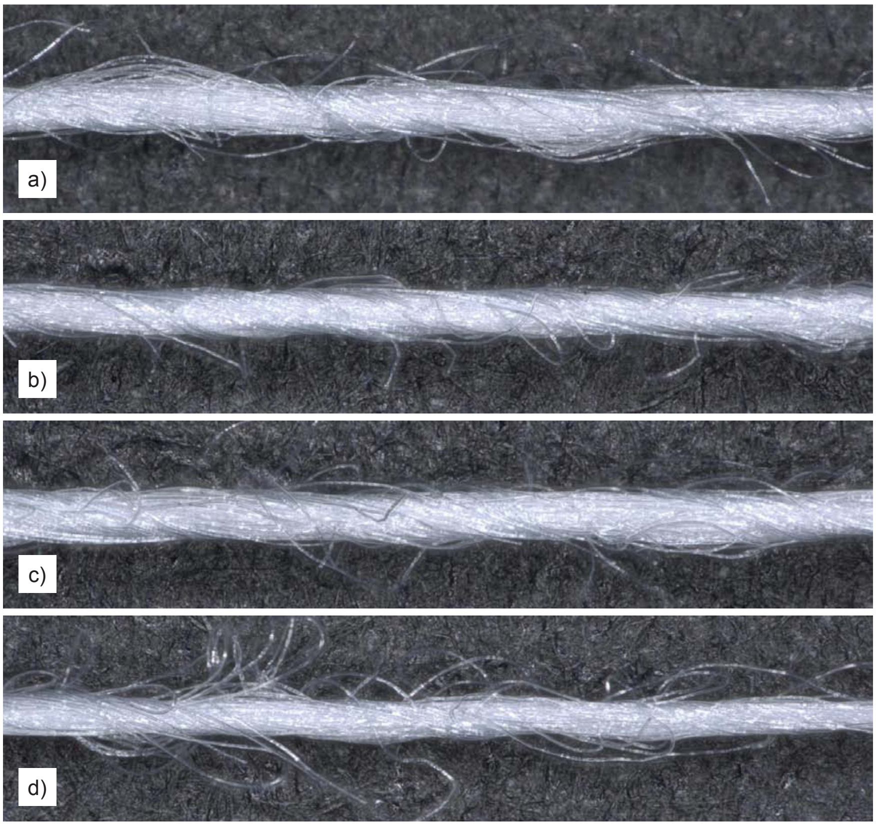

***Figure 2** Structure of polyester vortex yarn (20 tex) with fibres of different fineness; a) 0.9 dtex, b) 1.1 dtex, c) 1.3 dtex, and d) 1.5 dtex × 38 mm polyester fibre.*

tex yarn made with varying fibre fineness and spinning speeds is shown in ***Figure 1.c***. Generally the hairiness increases with an increase in the spinning speed. The results show that yarn made from 1.1 dtex fibre have the lowest hairiness index at any speed level compared with other fibres. The hairiness index - H, tends to increase, while the fibre fineness becomes coarser or finer than 1.1 dtex. The increase in the hairiness index - H, for finer fibre (0.9 dtex) may be due to the uneven wrapping of fibres in the main body of the yarn. The same was observed during microscopic evaluation of vortex yarn made from fibres of different fineness, shown in ***Figure 2***.

Protruding hairs of 1 mm length measured by the Zweigle hairiness tester (G567) are shown in ***Figure 1.d***. The results for the hairiness by length distribution in ***Table 3*** show that there are very few hairs 3 mm and above in all the vortex yarns, which can be termed as near zero hair yarn. There is a marked reduction in protruding hairs (1 mm) as the fibre fineness decreases. Vortex yarn made from coarser fibre (1.5 dtex) has 360% more protruding 1 mm hairs than that made from finer fibre (0.9 dtex). Irrespective fibre fineness, the spinning speed also has a direct influence on the protruding hairs. As the spinning speed increases, the reduction in twist level in the yarn structure causes an increase in the number of protruding hairs (1 mm).

Figure 5 shows the scatter plot of predicted versus experimental values and the regression line of our model for vortex yarn hairiness, H and Zweigle protruding hairs. The R^2 for the hairiness index - H, was found to be moderate ($R^2 = 0.709$), whereas Zweigle 1 mm hairs show a higher coefficient of determination ($R^2 = 0.892$). The regression equations revealed a strong relationship between fibre fineness and zweigle hairs, followed by spinning speed.

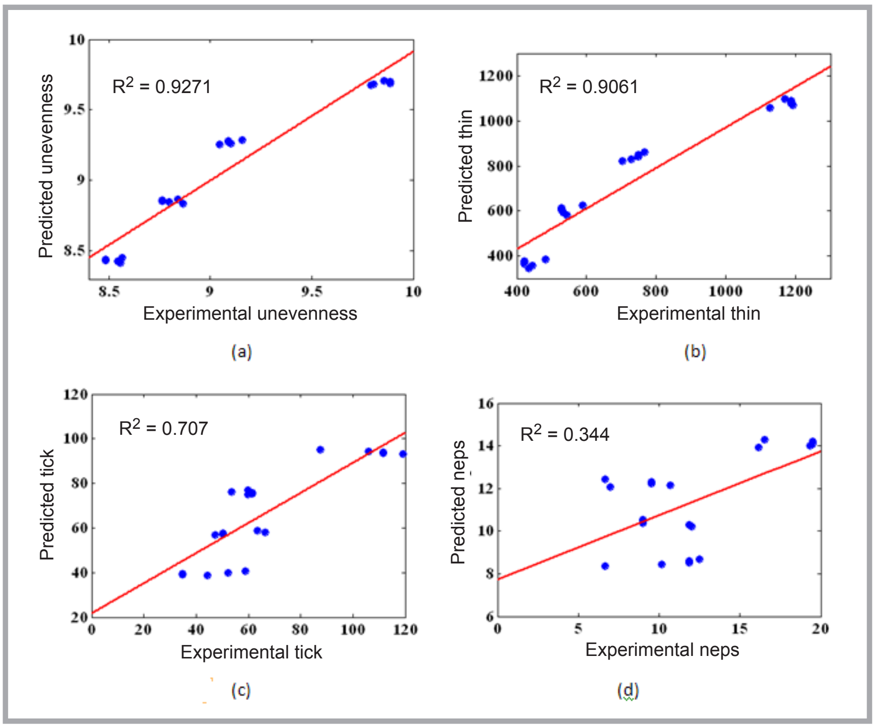

***Figure 3.** Coefficient of determination R^2: a) unevenness U%, b) thin (-30%), c) thick (+35%), d) neps (+140%).*

Conclusions

1. Regularity characteristics such as unevenness, and thin and thick places achieve much better values when spinning vortex yarn with finer polyester fibres, which shows that the number of fibres in the cross section has a greater influence on the evenness characteristics of polyester vortex yarn. Finer fibre makes better evenness than coarser fibre at all speed levels. The spinning speed does not influence the unevenness of vortex yarn for any fibre fineness. However, in yarn made from finer fibre, the higher number of fibres in the cross section causes a disturbance in continuous yarn formation in the nozzle zone and, therefore, gives a higher CVm (1m)%. The CVm(1m)% of polyester vortex yarn

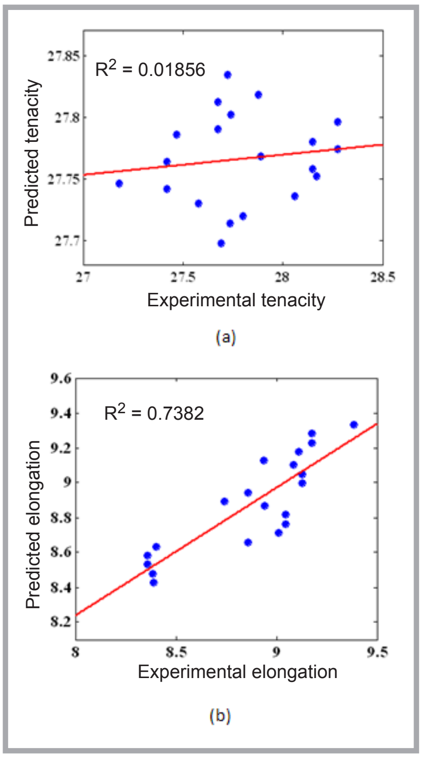

Figure 4. *Coefficient of determination R^2: a) tenacity in cN/tex, b) elongation in %.*

is less than for 1.1 dtex polyester fibre, and thereafter it increases as the fibre fineness becomes coarser. Finer fibres make fewer thin and thick places due to the higher number of fibres in the cross section. The nep level of polyester vortex yarn goes down slightly with an increase in the spinning speed due to neps being thrown out of the yarn body at higher speeds. Finer fibres cause greater neps due to disturbance in the formation of the yarn structure.

2. There is no specific relationship between fibre fineness and the vortex yarn tenacity. The tenacity of polyester vortex yarn is influenced neither by fibre fineness nor by the spinning speed of the vortex spinning machine. The same has been proved by earlier researchers. Vortex yarn made from coarser fibres has a higher elongation % than finer fibres. The elongation % of vortex yarn made from finer fibres (0.9 and 1.1 dtex) is not influenced by the spinning speed, whereas the spinning speed reduces the elongation properties of vortex yarn made from coarser fibres of 1.3 and 1.5 dtex. The performance of vortex yarn at the post spinning stage needs to be studied further to understand the real effect of tensile properties of vortex yarn.
3. Vortex yarn made from 1.1 dtex fibre shows a lower hairiness index, H, whereas finer fibre of 0.9 dtex has a higher hairiness index, H, due to the uneven yarn structure. Yarn made from fibres coarser than 1.1 dtex also shows an increase in the hairiness index, H. The Zweigle tester results show that finer fibre causes more wrapping of fibres over the yarn structure compared to coarser fibre and, due to vortex yarn being made from finer fibres, there are far fewer protruding hairs. The spinning speed of the vortex machine has a linear relationship with protruding hairs of polyester vortex yarn. The hairiness level increases with an increase in the spinning speed and a reduction in fibre fineness.

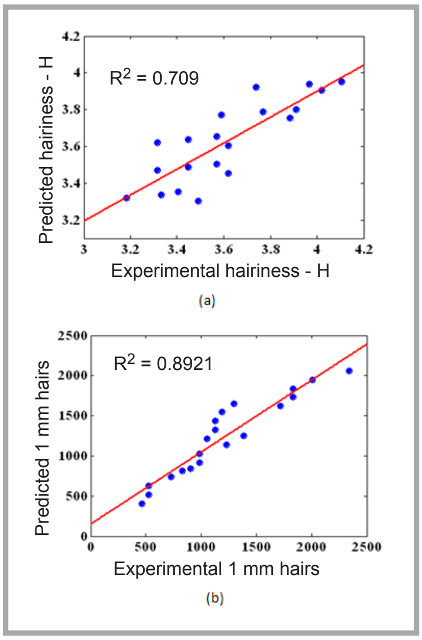

Figure 5. *Coefficient of determination R^2; a) hairiness - H, b) Zweigle 1 mm hairs.*

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