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Characteristic and Application of Knop Fancy Yarns

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Abstract
Apart from the simplest division into continuous and point effects, the classification of fancy yarns does not exist. There is also no published complex guide concerning technological aspects of the production of fancy yarns. The elaboration of such guides could be time consuming and probably they would not fit exactly the requirements of rapidly changing industry and end-user demands. The geometry of the effects could be considered as a classifying factor. Other factors supporting classification are the tensions of component yarns occurring during the twisting process. Thus we can classify knop yarn as a point effect fancy yarn, and according to the tension changes we rank knop yarn as a subgroup of bunch yarns. In the knop yarn group, the component yarns change their functions during the twisting process – periodically one of them is the core yarn and next it changes the function to become an effect yarn. In this way one may obtain fancy colour effects. The properties of this type of yarn were investigated focussing on changing the twist and frequency of occurring effects using multiple regressions. The most useful seems to prediction of the impact of the knop yarn type of aesthetic of fabrics and their mechanical parameters.

Key words: *knop fancy yarn, mechanical properties, classification, geometric model, production method.*

Introduction

Fancy yarns are extremely useful and attractive textile products, but at the same time they are very difficult to characterise or group. A great number of attempts to do so have taken place, e.g. a demonstration of the richness of fancy yarn architecture and some chosen possibilities of their application into woven and knit structures. In addition their economic value and impact on other textile industries have been already demonstrated [1, 2]. This estimation, based on Asian producers of fancy yarns, suggests that this is one of the branches of the textile industry which absorbs changes in the market without difficult, it is easy to manipulate and, therefore, to introduce new products. Other study attempted to classify fancy yarns depending on their effects [3, 4] which is congruent with existing standards [5] concerning the nomenclature of fancy yarns. It seems that the most important technological factors influencing the structure of knop fancy yarns are the tensions of component yarns during the twisting process, which impact the geometry of the fancy yarn directly. The structure of the fancy yarn decides about its mechanical properties – bending, stiffness, elongation at break, and unevenness of tensions of yarns during post processing – weaving and knitting [5 - 9]. We assume that during bunch fancy yarn production, there is constant tension on the core yarn different than for the effect yarn [7]. In this way one of the component yarns is the core, the second creates the effects at all times [2]. When we change the tensions of all component yarns periodically, as a result we will obtain a knop yarn – where the component yarns change their functions periodically – the core and the effect. When we have different colours of component yarns we obtain two different colours along the length of fancy yarn knops. But if we have two quite different types of component yarns – different linear densities, different twist, different elasticity and finally quite different raw materials, as a result we obtain so-called fancy yarn [2, 10]. Sometimes it could give quite unforeseen structural and mechanical effects. The other problem is the unevenness of twist along the length of the fancy yarn [11 - 14], which should be stabilised during the re-twisting process; but achievement of complete stability is impossible. Snarls occur very often and cause post processing disturbances. Although knop yarn looks attractive, it is very difficult to weave (air jet looms) and knit (all types of machines). Spinning technologists try to establish knop yarn properties on the basis of a very expensive research method - trial and error. Knitters are rather unwilling to use this type of yarn, with very long knops, as the knops might be very stiff and may impact the needles . Weavers prefer to use the rapier looms to insert knop yarn as the weft. They do not use knop yarn as the warp at all, because it causes variations in warp tensions, like in the case of bunch yarns [7].

The aim of the paper was to see the relation between knop yarn's mechanical parameters and their impact on those of the final products, both yarns and fabrics, which will support the design process of fancy yarns and fabrics. Descriptions of the relation between selected parameters of yarns are presented in the form of functions joining these parameters.

Materials and methods

Production and geometrical model of knop yarn

There are two basic possibilities of knop fancy yarn production: The first utilises a ring twisting frame and the second – a hollow spindle. The first possesses very small efficiency, because of the necessity of the next step of the re-twisting process to stabilise the twist [7, 10, 11], whose efficiency is near 10m/min. In the hollow spindle twisting method one combines the processes of knop fancy yarn production and the re-twisting process, whose efficiency is near 70 m/min [14]. The rule of knop fancy yarn production is the same in these two methods. Moreover we ought to periodically change the tensions of component yarns. Hence the yarn that is delivered with higher tension creates the core. Next we reduce the tension of this yarn, while at the same time we increase the tension of the second component yarn, which in this moment comprises the effect. The nominal crimp is one of the fancy yarn twisting machine settings, which is the average value of the crimp between the knops and of the crimp in the knop. We can change the tensions of the component yarns in two manners: The first relates to the ring twisting machine settings. The tensions of component yarns are changed by the effect of specially putting two component yarns through the two arms of the rocker that are set at a constant angle (however we can change the value of this angle because it is one of the machine settings). The move of the rocker causes changes in the tensions of the component yarns supplied. These tensions are not equal nor constant during knop fancy yarn production. In this method the two component yarns are supplied under the same supplying roller in the ring-twisting frame. The rotation speed of the rocker is not constant – near the maximum points of rocker inclination, the rocker is slowed down and in the end it stops for a few seconds. In this moment the knop is created. The speed of the rocker is one of the machine settings.

The importance of component yarns is proved by few changes in the sequences of putting the component yarns through the specific guide that causes a variation in the dimensions of the knop. The higher the angle between component yarns in the guide, the longer the knops are. The geometry of knop fancy yarn (***Figure 1***) is composed of sequences of thick places separated by continuously twisting two component yarns.

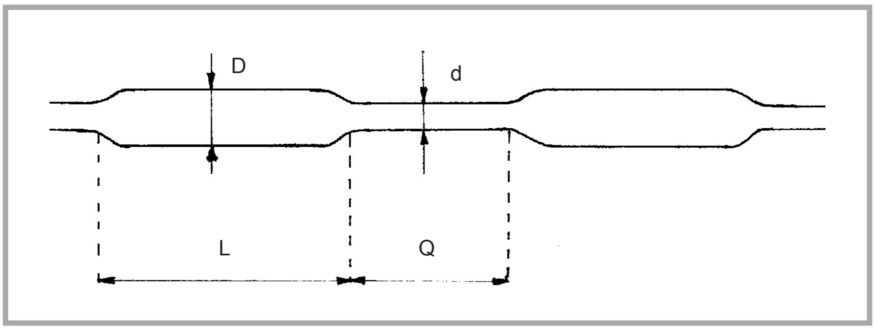

Figure 1. *Geometrical model of knop yarn.*

The thick places are created by winding effect yarn around the core yarn . We can distinguish the length of the knop L, its thickness D, the distance between them Q, and the nominal diameter of continuously twisted component yarns d. The sum of the distance between the knops and the length of a knop is the stitch of this kind of fancy yarn. The value of the second twist given to the yarn when binding is constant and should be lower than 150 t.p.m - near 100, because a higher value of twist may increase very intensively the bending stiffness of the final fancy yarn. Thus one cannot fully stabilise the twist. This type of yarn always has the tendency to produce local snarls. In order to investigate the structural and mechanical properties of knop yarn one assumes the following thesis: when one changes the main settings of the ring twisting machine (the nominal twist and the speed of the rocker) in this way one will alter the structural parameters and mechanical properties of the knop fancy yarn. On this study we investigated the mode of variation in the parameters mentioned above and also the properties of knop yarn in fabrics.

Experimental part

Twenty knop yarns were produced on a ring twisting machine PL-31C according to the plan of the experiment (***Table 1***). Initially one assumed the production of 24 samples based on the experimental plan, but due to extreme values provisioned by it, some of the samples could not be produced. Some of those of knop yarns, however, were produced according to the technological schema of knop yarn production with specific settings, which had no effects (***Figure 2.a***), and the others - very small effects (***Figure 2.b***). In some sectors of the experiment plan we had great problems with knop yarn production. As a conclusion we can state that these nominal machine settings are not proper for knop yarn production, which proves how specific production conditions for knop yarns are. The optimal variant of settings for knop yarn production is a twist of 300 t.p.m and rocker speed of 60 movements of rocker/min. The nominal twist was changed in the range of 100 – 600 t.p.m and the speed of the rocker was varied between 30 – 120 rocker movements/min. We utilised two acrylic component yarns (PAN; 32×2 tex) as the two component yarns. Next using the different types of knop yarns previously produced, we produced

Table 1. *Plan of experiment: yellow – yarns without distinct effects, red– yarns with small effects, blue– yarns with a very difficult process of twisting, pink– yarns that were not produced, white – yarns with distinct effects where the process of production was conducted without problems.*

Speed of rocker, movements/min \ Twist, r.p.m.	100	200	300	400	500	600
30	A1	A2	A3	A4	A5	A6
60	B1	B2	B3	B4	B5	B6
90	C1	C2	C3	C4	C5	C6
120	D1	D2	D3	D4	D5	D6

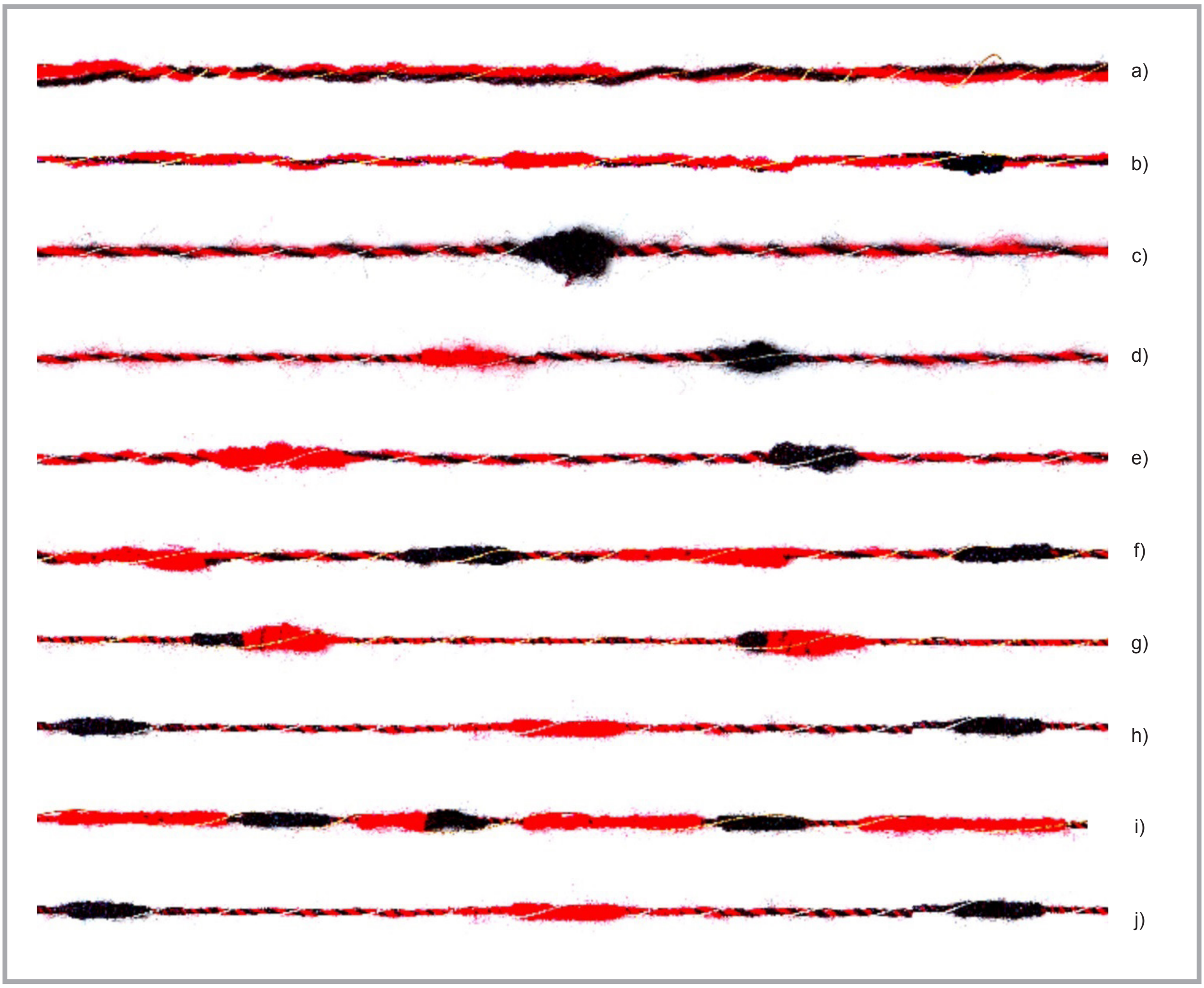

Figure 2. *View of the knop yarn: a) without distinct effects – sample B1 (twist – 100 t.p.m., rocker speed – 60 rocker movements/min.), b) without distinct effects – sample C2 (twist – 100 t.p.m., rocker speed – 90 rocker movements/min), c) with distinct knops – sample A2 (twist – 200 t.p.m., rocker speed - 30 rocker movements/min), d) with distinct knops – sample A3 (twist – 300 t.p.m., rocker speed - 30 rocker movements/min), e) with distinct knops – sample B3 (twist – 300 t.p.m., rocker speed - 60 rocker movements/min), f) with distinct knops – sample C4 (twist – 400 t.p.m., rocker speed - 90 rocker movements/min), g) sample A5 (twist – 500 tpm, rocker speed - 30 rocker movements/min), h) sample B5 (twist – 500 t.p.m., rocker speed - 60 rocker movements/min), i) sample C6 (twist – 600 t.p.m, rocker speed - 90 rocker movements/min). In the case of yarn D5 the knops are hard and not compressible, but evident, which is caused by the high twist, j) sample D5 (twist – 500 t.p.m, rocker speed - 90 rocker movements/min).*

15 samples of woven fabrics using different weaves: satin, plain and twill, and 16 samples of knitted fabrics using different stitches: rib, links – links and plain.

The rotation of spindles was constant and equal to 2,500 r.p.m. The angle between the arms of the rocker was constant and equal to 90 deg, and the binding twist was 100 t.p.m. The outputs of the model of experiment were as follows: the linear density of the final knop yarn, thickness of effects, length of effects, distances between effects, the elongation at break, and the tenacity of the knop yarn. We used computer image analysis to assess the structural parameters of the knop yarns. Pictures of the knop yarns were taken by an Agfa scanner 1212 (Germany) at a resolution of 600 dpi. Next we improved the brightness and resolution of these pictures using the Corel Programme. In the end we used a special computer programme which was prepared using the Visual Basic platform and specially designed to measure the yarns' structural parameters, having already been utilised successfully in previous investigations of fancy yarn properties [13, 15]. Investigations of the linear densities and breaking parameters were done according to [15, 16].

We analysed changes in the structure of knop yarns at different nominal twists and speeds of the rocker. The yarns with the smallest value of twist and speed of the rocker do not have distinct knops. This type of the yarn is fluffy and thick (***Figure 2.a***).

Also yarn C2 has small effects. Knops are flat, invisible, rarely and irregularly placed, which is partly due to the small twist. This yarn is less fluffy than yarn B1 because it has a bigger twist (***Figure 2.b***).

Yarn A2 is fluffy due to the small twist. Knops are not correct: they are less stable and the distances between them are large (***Figure 2.c***).

Yarn A3 has less fluffy knops than yarn A1, because yarn A3 has bigger twist. Knops are more compressible (***Figure 2.d***).

Table 2. Results of experiments carried out on the structure and selected mechanical properties of knop yarns.

Type of yarn	Yarn linear density, tex	Thickness of the first effect, mm	Thickness of the second effect, mm	Average value of the effect thickness, mm	Length of the first effect, mm	Length of the second effect, mm	Average value of the effect lengths, mm	Distance between effects, mm	Breaking force, cN	Elongation at break, mm	Tenacity, cN/tex
A1	144.6	-----	-----		---	---		----	1724	107.7	11.9
A2	174.6	3.9	4.0	3.9	10.3	9.2	9.7	118.9	1426	88.3	8.2
A3	209.7	2.6	3.0	2.8	11.3	8.8	10.0	47.4	1487	96.8	7.1
A4	204.9	2.2	2.2	2.2	7.2	6.6	6.9	53.9	1510	105.7	7.4
A5	397.3	2.1	2.0	2.0	8.5	5.6	7.0	43.1	1327	122.1	3.3
A6	338.4	1.6	1.7	1.7	10.7	9.0	9.9	34.0	1321	119.1	3.9
B1	144.3	------	----		----	---		---	1511	112.0	10.5
B2	158.0	1.9	1.7	1.8	5.9	4.4	5.1	31.9	1521	105.2	9.6
B3	208.0	2.1	2.2	2.1	14.4	10.6	12.5	42.2	1478	87.3	7.1
B4	278.8	1.7	1.8	1.8	12.6	8.6	10.6	11.3	1388	103.7	5.0
B5	281.0	1.8	1.8	1.8	15.2	9.6	12.4	34.3	1513	107.9	5.4
B6	338.0	1.6	1.6	1.6	9.3	7.5	8.4	11.2	1346	117.1	4.0
C2	151.0	1.7	1.7	1.7	8.3	5.5	6.8	33.6	1517	101.9	10.0
C3	210.3	1.9	1.8	1.8	12.6	10.0	11.3	26.9	1467	100.2	9.9
C4	263.5	1.7	1.7	1.7	15.6	10.6	13.1	19.2	1299	95.3	4.9
C5	337.2	1.7	1.7	1.7	16.7	12.3	14.5	8.7	1359	109.7	4.0
C6	374.1	1.8	1.6	1.7	14.9	9.6	12.2	17.8	1374	104.8	3.7
D4	257.1	1.8	1.7	1.8	17.3	10.6	14.0	8.1	1296	99.0	5.0
D5	315.7	2.1	1.9	2.0	15.0	9.8	12.4	8.8	1394	104.0	4.4
D6	395.4	1.5	1.5	1.5	14.2	8.6	11.4	6.7	1342	100.9	3.4

Production of yarn B3 went very well because the machine parameters (twists and speed of the rocker arms) had an optimal value. With these set parameters, the rocker worked regularly and did not cause interferences. Distances between the effects are the same. Knops are more compressible, longer and thinner than in the case of yarn A3, which is due to a higher relative rocker speed (***Figure 2.e***).

Yarn C4 is one of the optimal knop yarns. The consequence of this is the equal distance between the effects. Distances between the effects are smaller than for yarn C3 as when the twist increases the distance between the effects decreases (***Figure 2.f***).

Yarn A5 is one of those yarns whose twist did not proceed smoothly. Knops are hard and very packed because this yarn has a high twist (***Figure 2.g***).

In the case of yarn B5 the length of effects is greater than in the case of yarn A5 because the relative velocity of the rocker is larger. Knops are compressible (***Figure 2.h***).

Yarn C6 is very badly twisted. It is followed by frequent outbursts caused by knops overlapping, as a result of setting a high twist. The effects are longer than for yarn B5 because the relative velocity of the rocker is higher. Knops are hard and inflexible (***Figures 2.i*** and ***2.j***).

Results and discussion

Results of the experiments carried out on the yarns and their analysis

Due to the large discrepancy of the results of the experiments carried out on the knop yarn structure, an analysis was performed separately for each component yarn. Average values of the thicknesses and lengths of the effects were taken into account in the regression analysis. The unevenness of the effects of knop yarn is caused by the uneven work of the rocker synchronised with the twisting mechanism. This phenomenon is particularly evident in the case of very low and very high values of the twist and rocker speed. Due to the unique nature of the decorative yarn, in the mathematical analysis parameters characterising the above-mentioned yarns were also taken into account. Fancy yarns are characterised by inherently very large discrepancy of structural parameters (high CV values). Finding mathematical rules governing the production of fancy knop yarn facilitates the work of producers. Results of the experiments carried out are presented in ***Table 2***.

Analysis of the independent variables' impact on the linear density effects of knop yarn

A significant positive effect of the nominal yarn twist of the knop yarn on the resulting linear density of the yarn was detected:

1) linear density = 52.90 + 0.52 × twist ± standard error of assessment
   - Correlation coefficient R = 0.93,
   - Determination coefficient $R^2 = 0.865$,
   - Standard error of assessment (estimation) = 30.47,
   - Level of significance (twist):p = 0.0.

The determination coefficient indicates that 87% of linear density changes can be explained by the twist changes. The average linear density increases by 0.52 for every unit of twist.

The rocker speed has a negative impact on the thickness of the effects:

2) thickness of the effects = 0.124 + – 0.003 × speed of the rocker ± standard error of assessment
   - Correlation coefficient = 0.985,
   - Determination coefficient: $R^2 = 0.97$,
   - Standard error of assessment (estimation) = 0.101,
   - Level of significance (speed of the rocker): p = 0.13.

The slower the rocker is, the thicker the effects on the yarns are.

A positive influence of the rocker speed on the length of the effects was detected – the higher the speed of the rocker, the longer the effect is:

Table 3. Plan of woven sample preparation, including changes in weave (satin, twill, plain) and knop fancy yarn introduction (A1, A3, B3, C4, D5).

Type of weave / Type of knop yarn	satin	twill	plain
A1	T1	T2	T3
A3	T4	T5	T6
B3	T7	T8	T9
C4	T10	T11	T12
D5	T13	T14	T15

Table 4. Plan of experiment for the weaving process.

Fabrics with weft – knop yarn type		density, yarns/dm		crimp, %		fabric cover, %			filling, %		fabric thickness, mm	fabric surface density, g/m²
		weft	warp	weft	warp	weft	warp	weft and warp	weft	warp		
A1	T1	120	250	3.5	11.5	67	55	85	78	111	1.54	289.6
	T2	110	250	4.0	18.0	62	55	83	74	125	1.37	284
	T3	86	250	4.0	12.0	48	55	77	67	195	1.12	219.2
A3	T4	116	250	2.5	16.5	78	55	90	88	122	1.91	339.6
	T5	112	250	2.0	14.0	75	55	89	88	138	1.85	300.8
	T6	84	250	2.0	15.0	56	55	80	75	222	1.42	252.8
B3	T7	96	250	5.0	9.0	64	55	84	73	122	1.95	341.2
	T8	94	250	4.5	10.5	63	55	83	74	138	1.92	330.8
	T9	72	250	3.0	12.0	48	55	77	64	222	1.54	259.2
C4	T10	98	250	3.5	13.5	74	55	88	83	131	1.83	382.4
	T11	82	250	6.0	17.0	62	55	83	71	150	1.79	360.4
	T12	64	250	3.5	10.5	49	55	77	63	245	1.51	290.8
D5	T13	110	250	5.0	19.0	91	55	96	101	101	2.05	430
	T14	102	250	6.0	23.0	85	55	93	96	159	1.96	418
	T15	76	250	4.0	21.0	63	55	83	80	262	1.69	362

3) length of the effect =
= 0.91 + 0.013 ×rocker arm speed ± standard error of assessment
- Correlation coefficient: R = 0.936,
- Determination coefficient: $R^2 = 0.876$,
- Standard error of estimation = 0.79,
- Level of significance p (speed of the rocker): p = 0.1.

Study on the impact of the independent variables on the distance between the effects

The distance between the effects depends mainly on the thickness and length thereof:

4) distance between the effects = - 19.48 + + 37.68 × thickness of the effect + - 1.98 × length of the effect ± standard error of assessment
- Correlation coefficient: R = 0.93,
- Determination coefficient: $R^2 = 0.86$,
- Standard error of estimation: 10.44,
- Level of significance: (thickness of the effects): p = 0.000, (length of the effects): p = 0.01.

A single increment of the thickness of the effect increases the distance between the effects of 37.68. With an increase in the thickness of the effect, an increase in the distance between the effects occurs, and with an increase in the length of the effect, a decrease in the distance between the effects takes place. 86% of the variation in the distances between the effects may be explained by the thickness and length of the change in effects.

Study on the impact of the independent variables on the elongation at break of knop yarn

The correlation coefficient is high, thus the correlation of the relationship between the elongation at break and length of the effects and between their twist and thickness is strong:

5) elongation at break = 112.5 + + 0.46 × twist - 1.63 × length of effect - 4.06 × thickness of the effect ± standard error of assessment
- Correlation coefficient: R = 0.86,
- Determination coefficient: $R^2 = 0.74$,
- Standard error of estimation: 5.2,
- Level of significance: (twist) p = 0.0007, (length of the effect) p = 0.001, (thickness of the effect) p = 0.12.

The biggest influence on the elongation at break is shown by the twist and length of the effects because the level of significance of these variables did not exceed 0.05. The increase in the elongation at break is 0.46 per unit increase in the twist. 74% of changes in the elongation at break is explained by the twist, length and thickness of the effects. The standard error of estimation is relatively small, hence we can conclude that the fit of the regression function to the actual value is correct.

The impact of the independent variables on the tenacity of knop yarn

The greatest impact on the tenacity of knop yarn is possessed by the linear density of the yarn, length of the effect and breaking force of the component yarn because their significance levels did not exceed the level of 0.05:

6) tenacity = 5.9 - 0.014 × linear density - 0.16 × length of the effect + + 0.004 × breaking force – 0.003 × twist ± standard error of assessment
- Correlation coefficient: R = 0.98,
- Determination coefficient: $R^2 = 0.97$,
- Standard error of estimation: 0.4,
- Level of significance: (linear density) p = 0.001, (length of the effect) p = 0.006, (breaking force) p = 0.02, (twist) p = 0.08.

Twist given to the knop fancy yarn exerts a lower effect on the tenacity thereof. An increase in the tenacity of the knop yarn occurs when reducing the linear density and twist and increasing\the breaking force. 97% of the tenacity of the knop yarn change can be explained by variations in the linear density of the knop yarn, by the breaking load and the twist. The standard error is relatively low, hence the fit of the regression function to the actual values is believed to be correct.

Results of experiments carried out on fabrics

Fifteen fabrics with different weaves were produced on the basis of the following wefts (variants of knop yarns): A1, A3, B3, C4, D5. The warp – polyester (PE 15 × 2 tex).

The types of fabrics manufactured are presented in ***Tables 3*** and ***4***.

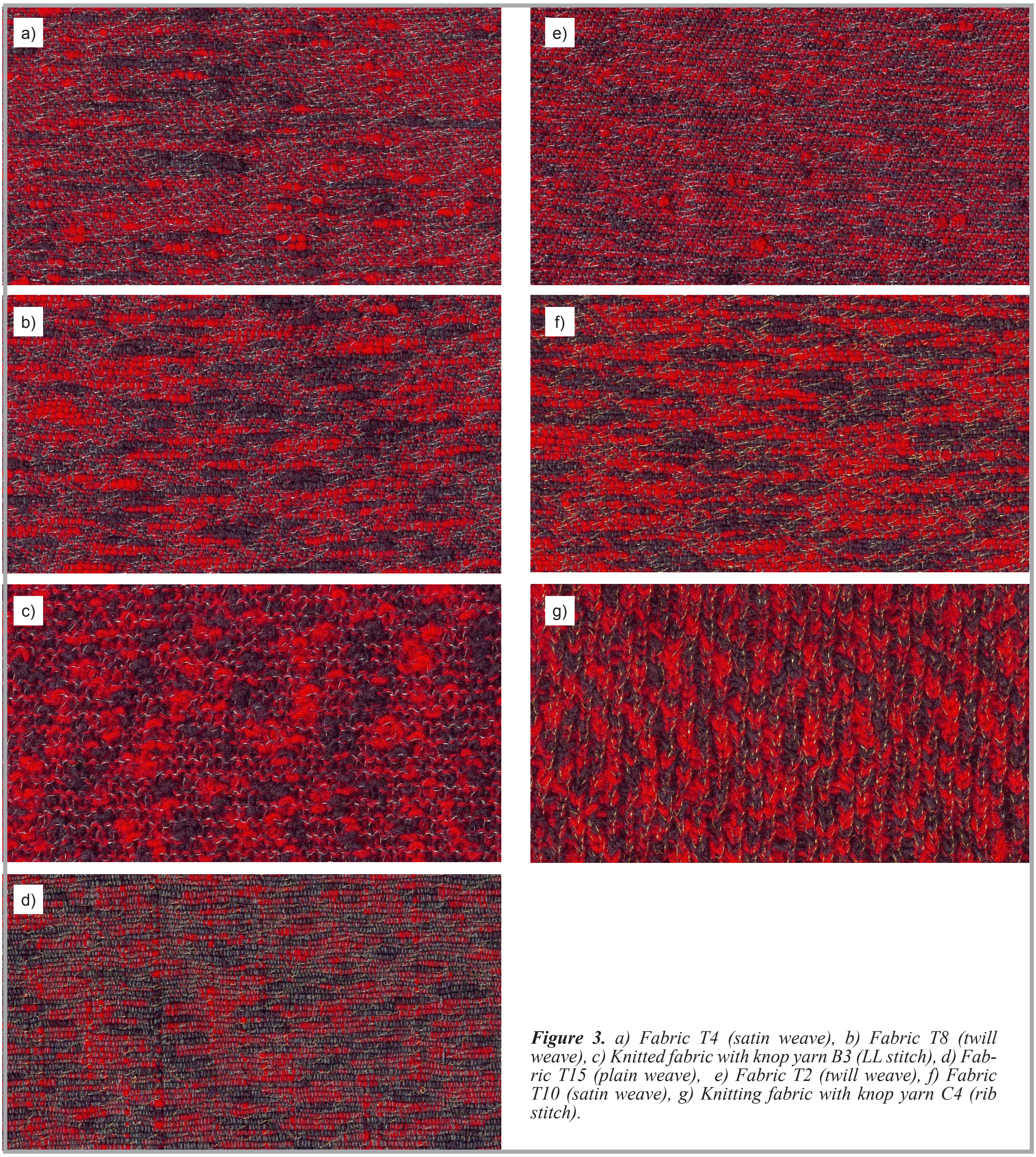

Figure 3. *a) Fabric T4 (satin weave), b) Fabric T8 (twill weave), c) Knitted fabric with knop yarn B3 (LL stitch), d) Fabric T15 (plain weave), e) Fabric T2 (twill weave), f) Fabric T10 (satin weave), g) Knitting fabric with knop yarn C4 (rib stitch).*

The density of the weft and warp in fabric is a parameter determining the concentration of weft or warp yarns therein related to its length and width.

The density of the warp is constant = = 250 yarns/dm.

The crimp of the weft or warp is the difference between the length of real yarn which composes the weft or warp and the straight length measured along the weft and warp related to the length of the fabric measured along the weft or warp.

The fabric cover measured along the weft or warp or weft and warp is calculated according to Ashenhurst formula:

$$z_{wa}/_{we} = g_{wa/we}\, d_{wa/we} \qquad (1)$$

$$z_{wa/we} = z_{wa} + z_{we} - 0.1\, z_{wa}\, z_{we} \qquad (2)$$

where,

$g_{wa/we}$ – density (the number of warp or weft yarns per dm)

$d_{wa/we}$ – diameter of warp or weft yarn.

The fabric filling takes into account the frequencies (the density), diameters of yarns and the number of bends of warp or weft yarns.

The fabric filling for a plain weave is calculated as follows:

$$E_{wa} = g_{wa} + D \qquad (3)$$

$$E_{we} = g_{we} + D \qquad (4)$$

$$D = d_{wa} + d_{we} \qquad (5)$$

Table 5. *Summary of the results of differences between: a) densities of yarns occurring in the groups of fabrics made with the following yarns b) crimps of knop yarns in groups of fabrics made with following yarns, c) fabric cover by weft yarns, d) fabric cover by the weft and warp (weft yarns, e) fabric filling with weft yarns, f) fabric thickness with different weft yarns, g) fabric's surface weight with different weft yarns: A1, A3, B3, C4, D5.*

a)

A1	---				
A3	0.5 1.3	----			
B3	0.027 18	0.02 16.6	----		
C4	0.006 24	0.025 22.6	0.2 6.0	----	
D5	0.005 9.3	0.02 8.0	0.09 8.6	0.03 14.6	----
	A1	A3	B3	C4	D5

b)

A1	----				
A3	0.03 1.6	----			
B3	0.6 0.3	0.6 2.0	----		
C4	0.5 0.5	0.1 2.1	0.86 0.16	----	
D5	0.2 1.16	0.04 2.8	0.19 0.8	0.26 0.6	----
	A1	A3	B3	C4	D5

c)

A1	---				
A3	0.01 10.6	----			
B3	0.6 0.6	0.02 11.3	----		
C4	0.34 2.6	0.09 8.0	0.42 3.3	----	
D5	0.01 20.6	0.02 10.0	0.02 21.3	0.02 18.0	----
	A1	A3	B3	C4	D5

d)

A1	---				
A3	0.03 4.66	----			
B3	0.42 0.33	0.03 5.00	----		
C4	0.42 1.00	0.09 3.66	0.42 1.3	----	
D5	0.02 9.00	0.03 4.3	0.33 9.3	0.02 8.0	----
	A1	A3	B3	C4	D5

e)

A1	---				
A3	0.02 10.6	----			
B3	0.2 2.6	0.008 13.3	----		
C4	0.8 0.6	0.08 11.3	0.66 2.0	----	
D5	0.02 19.3	0.06 8.6	0.02 22.0	0.01 20.0	----
	A1	A3	B3	C4	D5

f)

A1	---				
A3	0.01 0.38	----			
B3	0.009 0.46	0.08 0.07	----		
C4	0.011 0.36	0.7 0.016	0.09 0.09	----	
D5	0.001 0.55	0.07 0.17	0.09 0.09	0.006 0.19	----
	A1	A3	B3	C4	D5

g)

A1	---				
A3	0.07 33.4	----			
B3	0.005 46.0	0.2 12.6	----		
C4	0.006 80.0	0.01 46.8	0.01 34.2	----	
D5	0.0003 139.0	0.005 105.6	0.002 93.0	0.01 58.8	----
	A1	A3	B3	C4	D5

	- p level
	- the difference between values.
	- differences that are statistically significant because the p-value did not exceed 0.05.

where:

D – sum of diameters of weft and warp yarns.

The fabric filling for other weaves is calculated as the following:

$$E_{we} = (d_{we}\, R_{we} + d_{wa}\, p_{wa})/R_{we}\, A_{we} \quad (6)$$

$$E_{wa} = (d_{wa}\, R_{wa} + d_{we}\, p_{we})/R_{wa}\, A_{wa} \quad (7)$$

R_{we}, R_{wa} – weft and warp repeats,

p_{we}, p_{wa}, – number of bends of weft and warp yarns

A_{we}, A_{wa} – weft and warp yarn pitch (distance between the yarns):

$$A_{we} = 100/g_{we} \quad (8)$$

$$A_{wa} = 100/g_{wa} \quad (9)$$

Fabric sample presentations

Fabric T4 (***Figure 3.a***) was produced on the basis of knop yarn type A3 used as the weft. This fabric is characterised by sparsely distributed effects. Since this is a satin weave, the mass of the surface is higher than in the case of plain weave made from the same knop yarn (fabric T6), and in the case of twill fabric (fabric T5). The filling by the weft is relatively large and similar to that by the weft in the case of fabric T5 (the same knop yarn).

Fabric T8 (***Figure 3.b***) was produced on the basis of knop yarn type B3 used as the weft. In the case of fabric T8, the knops are clearly visible. The knops cumulate on the fabric and form patterns in the shape of waves and oblique lines. The density, thickness and area weight of the fabric is less than T7, and larger than in the case of fabric T9 (produced with the same knop yarn as the weft). Filling by the yarns is the same as for fabrics made of the same yarn and satin weave. The fabric is relatively soft and flexible.

On a flat knitting machine - APM ECO-2 knitted fabrics were produced using knop yarn type B3. The knitted fabric with an LL stitch is presented in ***Figure 3.c***. The knitwear is not curled. Knops form on the surface of the knitted fabric patterns in the shape of a zigzag.

Fabric T15 (***Figure 3.d***) was produced on the basis of knop yarn type D5 used as the weft. Since fabric T15 is made with a plain weave, the knops are covered by warp yarns. Fabric T15 is quite hard, stiff and rough, which is caused by the high twist of weft yarn used (D5). Filling by the weft is the highest in comparison with all the fabrics produced. The density, mass per unit area and thickness of the fabric are the smallest compared with those made from the same yarn.

Fabric T2 (***Figure 3.e***) was produced on the basis of knop yarn type A1 used as the weft. Fabric T2's surface effects are not visible because the fabric was made with yarn without effects (A1). Visible are incidental entanglement components only. The fabric is soft and flexible because it was made with yarn of low twist and low linear density. The density, filling, thickness and mass per unit area of the fabric are smaller than in the case of fabric with a satin weave and greater than in the case of plain weave fabric (the fabric made from the same yarn).

Fabric T10 (***Figure 3.f***) was produced on the basis of knop yarn type C4 used as the weft. On the surface of fabric T10 knops are visible for the most part. The fabric is quite rough, but not like T15 fabric. It is a fabric with a satin weave, thus the density, filling, thickness and mass per unit area is greater when compared with those made from the same yarn and of various weaves.

On the flat knitting machine APM ECO-2 knitted fabrics were produced using knop yarn type C4 (***Figure 3.g***). The knitwear is not curled, and it is very compressible. On its surface knops in the shape of zigzag patterns are visible.

Study of differences between the densities of knop yarns used as the weft in fabrics

Student's t-test at a significance level of p = 0.05 (***Table 5.a,*** see page 23) showed that there are significant differences in the densities of knop yarns used as the weft in fabrics made with the following knop yarns:

- A1 (small twist, low speed of the rocker) and B3 (medium twist, average speed of the rocker)
- A1 (small twist, low speed of the rocker) and C4 (middle twist, average speed of the rocker)
- A1 (small twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- A3 (medium twist, low speed of the rocker) and C4 (middle twist, average speed of the rocker),
- A1 (small twist, low speed of the rocker) and D5 (high twist, high speed of the rocker),
- A3 (medium twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- C4 (middle twist, average speed of the rocker) and D5 (high twist, high speed of the rocker).

Taking as a criterion that at least half of the cases analysed show important differences, it is clear that differences between the densities of knop yarns occurring in the fabrics that use different knop yarns as the weft influence the density of the wefts in the fabric made with the same weave.

Study of differences between the crimp of weft yarns in the fabrics

The Student t-test at a significance level of p = 0.05 (***Table 5.b***) showed that there are significant differences between the crimp yarns in fabrics made with the following yarns:

- A1 (small twist, low speed of the rocker) and D5 (big twist, high speed of the rocker)
- B3 (medium twist, average speed of the rocker) and D5 (high twist, high speed of the rocker).

The use of different knop yarns in the same weave does not cause major changes in the crimps of knop yarns in the fabrics.

Study of differences between the fabric cover by weft yarns in the fabrics

The Student t-test at a significance level of p = 0.05 (***Table 5.c***) showed that there are significant differences between the fabric cover by weft yarns in the group of fabrics made with the following yarns:

- A3 (medium twist, low speed of the rocker) and A1 (small twist, low speed of the rocker),
- A1 (small twist, low speed of the rocker) and D5 (high twist, high speed of the rocker),
- B3 (medium twist, average speed of the rocker) and A3 (medium twist, low speed of the rocker),
- D5 (high twist, high speed of the rocker) and A3 (medium twist, low speed of the rocker),
- C4 (middle twist, average speed of the rocker) and D5 (big twist, high speed of the rocker).

The use of different knop yarns as the weft in the same weave caused changes in the fabric cover by these yarns.

Study of differences between the cover by weft and warp yarns in the fabrics

The Student t-test at a significance level of p = 0.05 (***Table 5.d***) showed that there are significant differences between the cover by warp and weft yarns in fabric made with the following yarns:

- A1 (small twist, low speed of the rocker) and A3 (medium twist, low speed of the rocker)
- A1 (small twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- A3 (medium twist, low speed of the rocker) and B3 (medium twist, average speed of the rocker)
- A3 (medium twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- B3 (medium twist, average speed of the rocker) and D5 (high twist, high speed of the rocker)
- C4 (middle twist, average speed of the rocker) and D5 (high twist, high speed of the rocker).

Using a variety of knop yarns, changes in the cover by the weft and warp in the fabric occur in the case of the same fabric weave.

Study of differences between filling the fabrics with weft yarns

The Student t-test at a significance level of p = 0.05 (***Table 5.e***) showed that there are significant differences between filling with the following weft yarns in fabrics:

- A3 (medium twist, low speed of the rocker) and A1 (small twist, low speed of the rocker)
- B3 (medium twist, average speed of the rocker) and A3 (medium twist, low speed of the rocker)
- D5 (high twist, high speed of the rocker), and A1 (small twist, low speed of the rocker)
- D5 (high twist, high speed of the rocker) and B3 (medium twist, average speed of the rocker)
- D5 (high twist, high speed of the rocker) and C4 (middle twist, average speed of the rocker).

Use of different knop yarns as the weft does not significantly change the filling of fabrics by the weft in the case of the same fabric weave.

Study of differences between the thickness of fabrics made with different knop yarns used as wefts

The Student t-test at a significance level of p = 0.05 (***Table 5.f***) showed that there are significant differences between the thickness of fabrics made with the following knop yarns used as the weft:

- A3 (medium twist, low speed of the rocker) and A1 (small twist, low speed of the rocker)
- A1 (small twist, low speed of the rocker) and B3 (medium twist, average speed of the rocker)
- A1 (small twist, low speed of the rocker) and C4 (middle twist, average speed of the rocker)
- A1 (small twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- C4 (middle twist, average speed of the rocker) and D5 (high twist, high speed of the rocker).

The use of different knop yarns in fabrics with the same weave does not cause significant changes in the thickness of these fabrics.

Study of differences between the surface weight of fabrics made with different knop yarns used as wefts

The Student t-test at a significance of p = 0.05 (***Table 5.g***) showed differences between the surface weight of fabric made with the following knop yarns used as the weft:

- B3 (medium twist, average speed of the rocker) and A1 (small twist, low speed of the rocker)
- C4 (middle twist, average speed of the rocker) and A1 (small twist, low speed of the rocker)
- D5 (high twist, high speed of the rocker) and A1 (small twist, low speed of the rocker)
- A3 (medium twist, low speed of the rocker) and C4 (middle twist, average speed of the rocker)
- A3 (medium twist, low speed of the rocker) and D5 (high twist, high speed of the rocker)
- C4 (middle twist, average speed of the rocker) and B3 (medium twist, average speed of the rocker)
- D5 (high twist, high speed of the rocker) and B3 (medium twist, average speed of the rocker)
- C4 (middle twist, average speed of the rocker) and D5 (high twist, high speed of the rocker).

The use of different knop yarns as the weft caused changes in the surface mass of fabrics with the same fabric weave.

Conclusions

1. The linear density of knop yarns increases with an increase in the nominal yarn twist.
2. The slower the speed of the rocker, the thicker the knop effect on the yarn.
3. The higher the speed of the rocker, the greater the length of the knop yarn effects
4. The increase in the breaking force in the case of knop yarns is related to the nominal twist of the yarn, the linear density of the knop yarn and the length of the effects.
5. An increase in the nominal twist and a reduction in the length and thickness of the effects causes an increase in the elongation at break.
6. Experimental studies carried out on fabrics produced with the same weaves and made with different variants of knop yarns confirm the hypothesis that there are significant differences between the parameters of fabrics produced with different types of knop yarns, and changes in the parameters of knop yarns used to create fabrics cause a variation in the parameters of the fabrics.
7. On the basis of comparative analysis using the Student t-test at a p = 0.05 level of significance, it was found that there are major differences between the mean values of parameters characterising the fabrics:
   - fabric mass per unit area,
   - density of wefts.

   Minor, but still existing, are between:
   - fabric cover by the weft and warp,
   - thickness of the fabrics,
   - filling by the weft,
   - fabric cover by the weft.
   - crimp of wefts in the fabric.
8. Differences between the fabrics most often occurred in the case of knop yarn type D5 (high twist, high speed of the rocker). Fabrics with parameters differing quite often are those made of knop yarns A1 (small twist, low speed of the rocker), A3 (medium twist, low speed of the rocker) and B3 (medium twist, average speed of the arm rocker), while fabric made of C4 yarns (middle twist, average speed of the arm rocker) differ the least.

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